MODIFICATION OF WEATHER DATASETS FOR EVALUATING THE ENERGY PERFORMANCE OF CLIMATE-ADAPTIVE BUILDING ENVELOPES

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ABSTRACT

This work presents a new methodology that uses modified weather data to evaluate the performance of climate-adaptive building envelopes. Current building energy simulation tools only support evaluations of the performance of 2D moveable shading, such as venetian blinds and screens. To address this limitation, we created modified weather data based on the amount of solar radiation that reaches a window's surface through its shading device. This modified weather data can be used to simulate the performance of the building without shading; the hypothesis is that the reduced solar radiation in modified weather data has a similar effect to the shading device. In this research, six fixed-shading cases were tested with six modified weather files to present the usefulness of the algorithm when evaluating the performance of a climate-adaptive building envelope. The results indicate that the pattern of indoor temperature profiles is fairly close in all cases, confirming the algorithm's plausibility.

KEYWORDS

Solar Radiation, Weather Data Creation, Climate Adaptive Building, Building Energy Simulation, EnergyPlus

INTRODUCTION

Performance-integrated fenestration design is a critical issue for energy savings and building aesthetics (Stevanović 2013). The integration of Climate Adaptive Building Envelopes (CABE) began with the development of building technology designed to respond to aesthetic demands and other various objectives (Linn 2014). CABE not only saves energy, but also provides occupants with thermal and visual comfort in

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indoor environments; its efficacy has been proven in several studies (Nielsen et al. 2011; Tzempelikos and Shen 2013; Yao 2014). However, most research has focused on 2D types of moveable shading (i.e., venetian blinds and screens), due to the limitations of current energy simulation tools. In other words, energy simulation tools are not currently capable of supporting 3D geometry with hourly time series geometric transformation (Kim et al. 2015).

Previous studies have presented methodologies for assessing the performance of 3D CABEs that select hourly results from multiple simulations based on shading scenarios (Kim et al. 2015; Vlachokostas and Madamopoulos 2016). However, in building energy simulation programs, a building energy load calculation at a specific time step is fed back into the calculation at the next time step (Crawley and Pederson 2001). This means that selecting results from multiple simulations with different conditions might cause inaccurate calculations of the CABE's performance. To address this limitation, this study introduces an algorithm using modified weather data that responds to shading scenarios.

BACKGROUND

The amount of incident solar radiation transmitted through building envelopes is directly related to the energy consumption of Heating, Ventilating, and Air Conditioning (HVAC) systems; shading devices serve as a means of providing an appropriate level of incoming radiation, considering both energy needs and daylighting performance (Maestre et al. 2015). Essentially, solar energy contains two types of radiation: beam (direct) and diffuse. Beam radiation is shortwave energy that travels in parallel lines directly from the sun. Diffuse radiation is energy that is scattered in random directions by air molecules and particles in the sky (Duffie and Beckman 2013). Thus, strategies for designing shading devices require the consideration of both beam and diffuse radiation, and should be based on building orientation, site location, outdoor weather conditions, and the specific characteristics of the project.

Building energy simulation tools require hourly annual meteorological input data such as solar radiation, temperature, and wind to predict energy consumption (Hong et al. 1999). Solar radiation is measured in different ways in weather stations around the world. Direct Normal Irradiance (DNI) is the amount of beam radiation that always reaches a surface perpendicular to the sun's rays, regardless of time. Diffuse Horizontal Irradiance (DIF) is the amount of diffuse radiation received on a horizontal plane. Finally, Global Horizontal Irradiance (GHI) is the sum of the direct and diffuse radiation that reaches a horizontal surface. To simulate and study building performance, EnergyPlus and DOE-2.1e, whole-building energy simulation tools, use DNI and DIF, and DNI and GHI, respectively (Loutzenhiser et al. 2007).

Several studies have elaborated upon the use of weather data with building simulation techniques operating along various scales. For example, predicted weather data were integrated into building simulations in order to study the influence of climate change on built environments (Guan 2009). In addition, the impact of solar radiation on building energy consumption was presented and associated with the use of modified

weather data (Vlachokostas and Madamopoulos 2016). To this extent, research into the creation of suitable weather data, in accordance with various objectives, has great potential to facilitate the study of built environments.

METHODOLOGY

This study used the modified weather data (i.e., solar radiation) that reached a window surface via the CABE scenario for its performance evaluations. The conceptual workflow of the process is described in Figure 1. The amount of transmitted solar radiation on the window surface after CABE's hourly transformation was simulated using energy simulation tools; the values were then converted to horizontal radiation values that comprised the source of the modified weather data. Eventually, the modified weather data represented CABE's influence on the solar radiation from a particular orientation. More precisely, the amount of hourly admitted beam and diffuse radiation on a vertical window associated with a CABE scenario was converted into hourly DNI and DIF in order to create modified weather data. Then, a base-case energy model without CABE input parameters used the modified weather data to produce an example CABE performance; this was not supported by traditional energy modeling methods (see Figure 2).

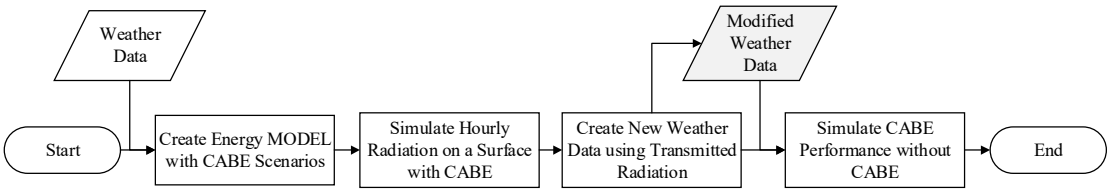

Figure 1. Conceptual workflow of CABE performance evaluation

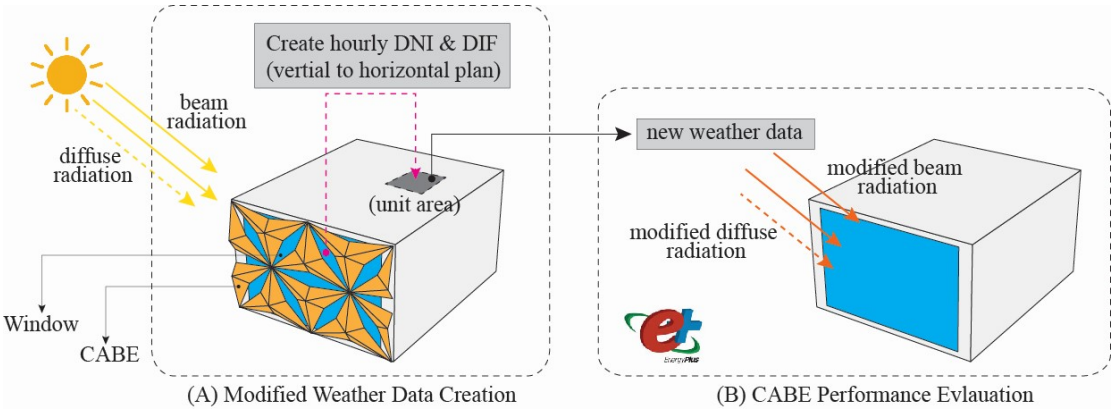

Figure 2. Example CABE performance evaluation process

This study's scope was as follows. First, as a preliminary test, we focused on the fixed shading devices on a skylight. Since the goal was to support the plausibility of the algorithm, the process of converting the vertical radiation to horizontal was omitted. Second, we assumed that the air temperature between the window and shading device was equal to the outdoor temperature recorded in the weather data; the impact of the material properties on the temperature was not considered.

To test the algorithm, we simulated six skylight shading cases, as described in Figure 3. The base-case building energy simulation model was a closed office space, specifically 7m × 6m × 3m (width × depth × height). For this study, it was assumed that the model was located in Houston, Texas. Shading cases 1 to 4 were tilted toward the west at 0, 15, 30, and 45 degree angles, respectively. Shading case 5 was vertical and faced the south, and shading case 6 was an example of shading via complex geometry. Additionally, to investigate the influence of radiation from the skylight, all walls and the floor of the energy model were identified as adiabatic; this excluded the roof and window. The internal loads (i.e., occupants, lighting, and equipment) in the model were all eliminated for the entire time, for the reasons mentioned above.

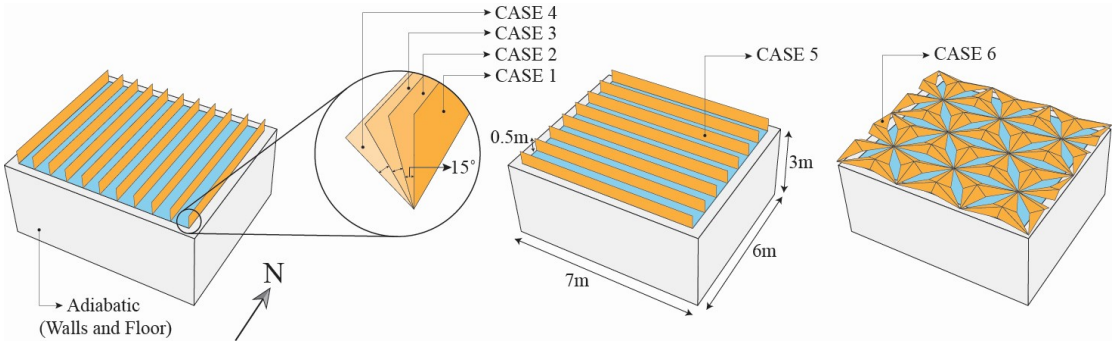

Figure 3. Building geometry with six shading cases

RESULTS

The installation of the shading device was expected to increase the comfortable hours up to 21 percent over one year in Houston, Texas, which implies that solar radiation is a critical weather element in this area (Liggett and Milne 2014). The impact of solar radiation and shading as recorded in this study is described in the following results.

First, Figure 4 depicts a comparison of the indoor temperature profiles for each test case during the summer and winter solstice days. During the summer solstice day, there were only slight differences among the indoor temperature profiles of the models with and without the shading device. There was approximately a 2.5°C persistent difference at all times among the indoor temperatures of all six profiles during the summer solstice day. In addition, the indoor temperatures of the simulation models paired with modified weather data were consistently lower than the models with original weather data. During the winter solstice day, there were only slight differences among the indoor temperature profiles of the models with and without the shading device. There was approximately a 2.0°C consistent and continuous difference among the indoor temperatures of all six profiles during the winter solstice day. In addition, the indoor temperatures of the simulation models paired with modified weather data were constantly lower than the models with the original weather file.

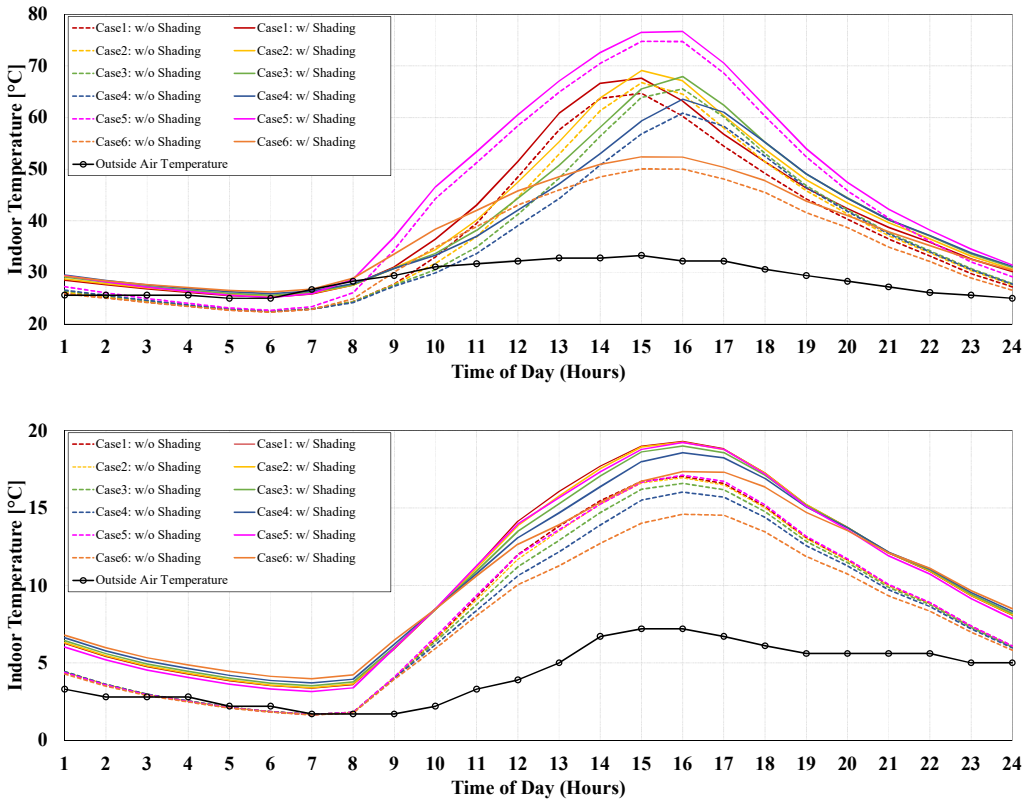

Figure 4. Indoor temperature profiles for summer (upper) and winter (bottom) solstices

Second, correlation trends were calculated to display how closely the hourly indoor temperatures of the models with the shading device agreed with the indoor temperatures of the models without the shading device. The coefficient of the determination, the R-squared value, was statistically calculated to understand whether there was a linear relationship among the samples of paired data. Figure 5 shows the scatter plot for the summer and winter solstice days; the scatter plot indicates that the indoor temperatures of the models with the shading device compared fairly well with the indoor temperatures of the models without the shading device, with an $R^2 = 0.999$ for both solstice days.

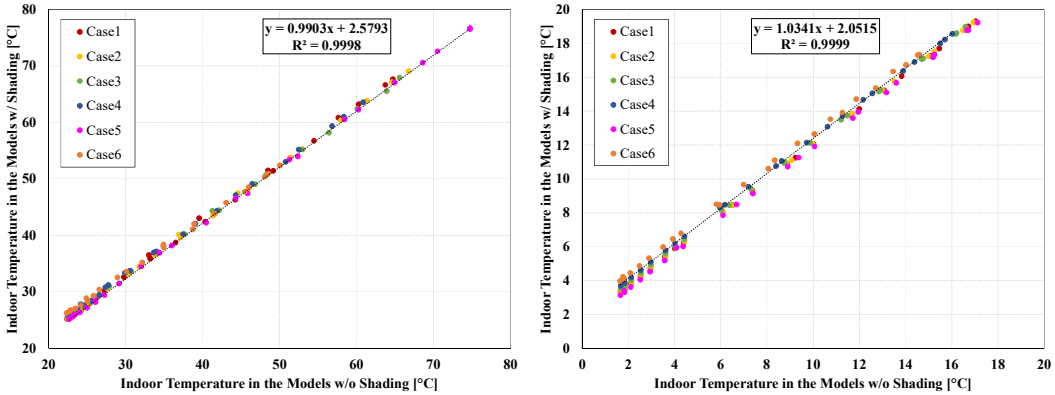

Figure 5. Correlation between the indoor temperature profiles of the summer (left) and winter (right) solstices

CONCLUSION

This study presents an algorithm for evaluating the performance of CABEs using modified weather data. As a preliminary analysis, we performed an energy simulation of a closed office building with fixed shading. The results revealed that the indoor temperature profiles of the models were considerably close to one other. This contributed to the notion that the use of modified weather data in CABE performance analyses would produce credible results. However, as observed, there were approximately 2.0°C and 2.5°C persistent differences between the indoor temperatures of the models during summer and winter solstice days, respectively. This indicates that the differences in heating and cooling energy loads would be quite significant. Therefore, it can be concluded that modified weather data must be tuned to obtain accurate results from a building energy analysis.

The primary limitation of the algorithm is that modified weather data is available for testing only at one orientation. Heat transfer though other walls and the roof cannot occur if the result is to be reliable. This implies that the energy simulation incorporating the algorithm cannot be performed on a whole CABE building. In spite of this limitation, the algorithm produces a significant basis for future research in performance-driven CABE design, including: (1) the modification of weather datasets based on a tilted window surface in order to obtain more accurate CABE simulation results, and (2) the development of building energy simulation benchmark models for CABE design.

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