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On the development of multi-linear regression analysis to assess energy consumption in the early stages of building design

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ABSTRACT

Modeling of energy consumption in buildings is essential for different applications such as building energy management and establishing baselines. This makes building energy consumption estimation as a key tool to reduce energy consumption and emissions. Energy performance of building is complex, since it depends on several parameters related to the building characteristics, equipment and systems, weather, occupants, and sociological influences. This paper presents a new model to predict and quantify energy consumption in commercial buildings in the early stages of building design. Building simulation software including eQUEST and DOE-2 was used to build and simulate individual building configuration that were generated using Monte Carlo simulation techniques. Ten thousands simulations for seven building shapes were performed to create a comprehensive dataset covering the full ranges of design parameters. The present study considered building materials, their thickness, building shape, and occupant schedule as design variables since building energy performance is sensitive to these variables. Then, the results of the energy simulations were implemented into a set of regression equation to predict the energy consumption in each design scenario. A good agreement was seen between the predicted data based on the developed regression model and DOE simulation and the maximum error was less than 5%. It is envisioned that the developed regression models can be used to estimate the total energy consumption in the early stages of the design when different building schemes and design concepts are being considered.

1. Introduction

The rapidly growing world energy consumption has raised concerns over supply difficulties, depletion of energy resources and negative environmental impacts. Energy consumption of the commercial sector averages approximately 30% worldwide. In the U.S., commercial and residential buildings consumed 9.6 (Quadrillion Btu) of primary energy in 2012 [1]. The majority of energy consumption in these buildings is related to space heating, cooling, and lighting. In addition, building sector produced 6526 million metric tons of CO_2 equivalent in 2012 [1]. Therefore, predicting energy consumption in the early stages of building design is important for energy and emissions reduction efforts. Predicting building energy consumption is a complicated task since it depends on multiple variables such as building characteristics, energy systems characteristics, control and maintenance, weather parameters, and behavior of occupants. The ways in which a building and its services operate in practice are very complicated and a modeling for achieving an accurate prediction of the energy consumption is challenging to accomplish. Therefore, notwithstanding the numerous research studies which have attempted to develop energy simulation models, there is still the need for a systematic approach capable of unifying all the diverse phenomena underlying energy performance.

A notable portion of a building's life-cycle impacts is determined by decisions made in the early design stages. Choosing proper building characteristics at this step has potential to substantially decrease a building's life cycle impact. However, evaluation of the energy and environmental performance of these decisions and strategies for making alternatives that improve upon the performance of designs are typically not made until the design development stage. On the other hand, available simulation tools necessitate having enough technical knowledge and considerable software specific training to precisely model even the simplest building. In addition, these tools often require many details and information that are only accessible at the later stages of design. In contrasts, the developed regression equations in this study is

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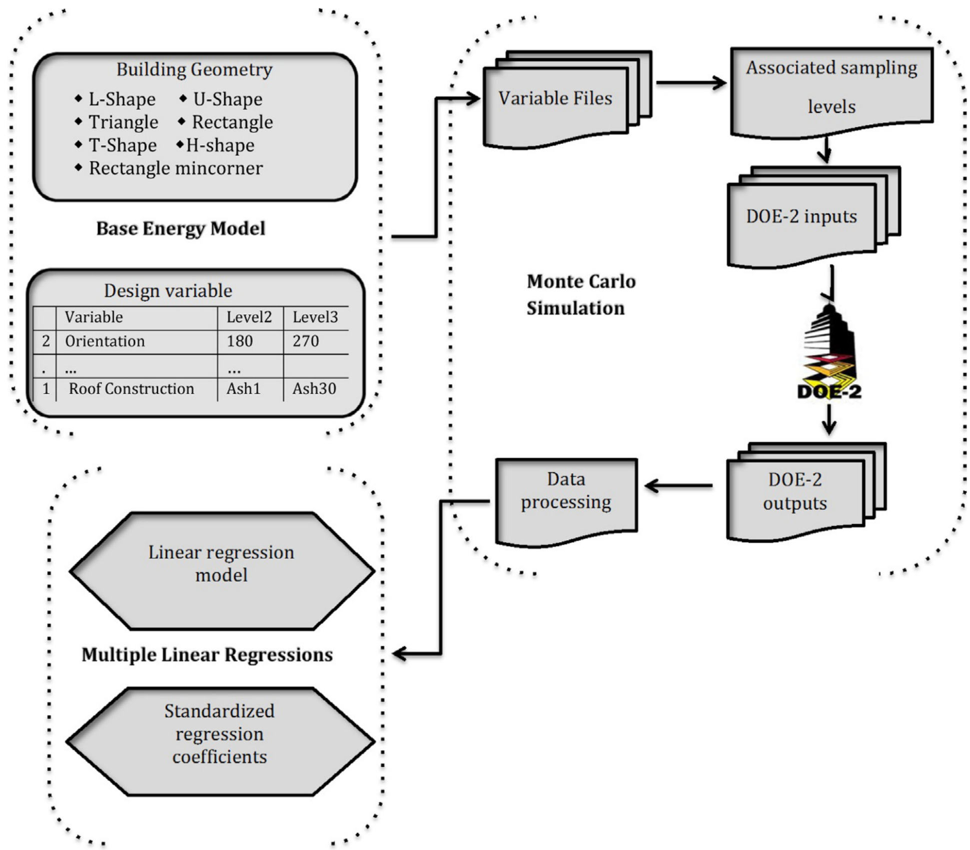

Fig. 1. Framework of the present study.

so intuitive that it can be in close agreement with sophisticated modeling software commonly utilized by architects and engineers.

The analysis and prediction of the building energy performance associated with different design parameters have become the major focus of many recent studies. For example, some studies reveal a broad coverage of subjects such as construction material selections [2–17], energy efficient building envelopes [2,5,6,13,18–25], high performance building systems [2,19,22,26,27], building orientation [18], optimization of building operations [19,22,26–30], life cycle assessment [3,7–9,13,14,17,18,20,31–36], and alternative energy applications [7,16,28,37]. Multiple regression analysis is often utilized to investigate the effects of various design parameters such as building construction, weather, HVAC system, lighting system, etc. on the energy performance of the buildings [38–40,42–45]. It has also been used for developing simplified energy equations and design tools for building energy standards [40,46–48].

Having investigated the effect of 12 design parameters on energy performance in a comprehensive study, Lam et al. [38] reported that 89–97% of the variations in annual building energy use can be explained by changes in these parameters. Catalina et al. [19] developed a multiple regression model to predict heating energy demand based on the main factors that effect on the building's heating energy consumption. They found that the developed model performs well for future heating energy consumption predictions. The results of this study indicated that the building global heat loss coefficient, the south equivalent surface, and the difference between the indoor set point temperature and the sol–air temperature have a significant effect on building heating load. In another study conducted by Hygh et al. [18], an energy assessment tool was developed using multivariate regression model to quantify building energy performance in early design stages. They considered 27 building parameters including size, geometry, and location. Their results suggested that a linear regression model can serve as the basis for an effective decision support tool in place of energy simulation models during early design stages. In another study, Ourghi et al. [49] developed a simplified analysis method to predict the impact of building morphology on its annual cooling demand. They concluded that optimizing the shape of a building is an essential part if we want to minimize construction costs or to find the minimum seasonal demand of heating energy.

The present study proposes a simple, yet realistic, approach to predict energy consumption of a typical office building located in Houston, TX, based on the construction characteristics, shape, and occupancy schedule. Building simulation software including eQUEST and DOE-2 was used to build and simulate individual building configuration that were generated using Monte Carlo simulation techniques. Ten thousands simulations for each building shape (i.e. total of 70,000 simulation runs) were performed to create a comprehensive dataset covering the full ranges of design parameters. Then, the results of the energy simulations were implemented into a set of regression equation to predict the energy consumption in each design scenario.

2. Methodology

In order to assess the energy performance in a building, a comprehensive set of inputs is required to define its geometry, shape, internal loads, mechanical and electrical system, and occupancy schedule. Selecting and defining the input parameters is often a complex task since it requires sound engineering judgment and a good understanding of the simulation system. The Monte Carlo simulation model was used to examine the influence of each individual variable on building energy consumption. It created an extensive