



Comparative Analysis of the Building Energy Performance Patterns: A Case Study

Behzad Rouhanizadeh¹, Sharareh Kermanshachi^{2, 3}

^{1, 2}University of Texas at Arlington, USA

³Sharareh.kermanshachi@uta.edu

ABSTRACT: Energy use has increased exponentially within past decades, raising global social, economic and environmental concerns that make it important to find ways to reduce its use. In developed communities, energy consumption in buildings contributes largely to the overall energy use; therefore, finding ways to more efficiently use energy in buildings would optimize energy consumption significantly. In this study, the energy performance and associated operating costs of a building were calculated and compared with those of experiments. DOE-2, a computer simulation program capable of detailed and quick energy consumption analysis of buildings, was implemented, and it was found that heat-producing energy was the major component of the energy expended in buildings. The results of this study revealed that the amount of energy used to produce heat in the case study building was greater than that of the experimental amounts, while the amount of electricity consumed was very close to that of the experimental amounts. The findings of this study identify the issues with the DOE-2 energy software, provide empirical evidence to validate the program, and give insight to designers to help them design buildings that are more energy efficient.

1 INTRODUCTION

Due to the expanding economy, the expanding population, and its quest for an improved quality of life, the consumption of energy is increasing and is expected to continue. Fueling demands are also projected to increase (Harish and Kumar, 2016), causing the emission of more greenhouse gases that will have serious impacts on the global environment (Zeng et al., 2011). The increase in energy demands, as well as the predominance of coal in the energy mix, makes it necessary to promote and achieve greater energy efficiency (Feige et al., 2013). The higher rate of urbanization, with increased floor space for both residential and commercial purposes, has imposed enormous pressure on the existing sources of energy (Mao et al., 2017). In addition, restricted energy availability, and the highly transient nature of renewable energy sources have enhanced the gravity of energy conservation and efficiency in different sectors (Feng et al., 2015).

Based on the statistics, buildings consume approximately 40% of the overall energy worldwide, and are responsible for a huge portion of carbon emissions (Jian et al., 2015). Many scientists, all around the world, model energy to develop applicable strategies to reduce the amount of energy consumed in buildings. Several methods have been developed to construct energy consumption models that can simulate buildings for cost saving calculations. These models differ in magnitude from modeling a single part of a building; they model an entire building (Lee et al., 2015). The annual energy consumption per square meter of floor area, in all kinds of buildings, is reported to be more than 200 kWh (Frayssinet et al., 2018). Lighting and air conditioning have been identified as the two most energy consuming applications in a building (Hooshangi et al., 2016).

The factors influencing building energy consumption can be divided into four main categories: climate, building-related characteristics, building services, and building occupant activities and behavior (Fan et al., 2015). Occupants largely affect the energy consumption of a building, even when all systems and equipment work perfectly (Hong and Lin, 2013). Building energy simulation (BES) algorithms are generally

based on either steady state or dynamic methods. The availability of cheaper computing power encourages deployment of the dynamic method. In a nutshell, energy calculations are based on heat flow and energy transformations. The first significant implementation of the DOE-designed algorithm, DOE-2, was to study the potential for energy savings in large buildings (Carriere et al. in 1999). Fine-grained data such as building envelope properties, construction design, end-user appliances and equipment, and energy-use patterns were used in their models (Olofsson et al., 2004).

In this study the energy performance of buildings was simulated, and the developed model was validated by comparing it with data collected from the utility companies. Strategies were suggested that could be applied to the development of a framework for commercial buildings. Thus, the objectives of this study were to (1) Simulate the building energy system by building a model, (2) validate the model, and (3) provide strategies to improve energy efficiency. The results of this study will help designers consider a framework for designing a more sustainable building, and will evaluate the DOE-2 software for implementation in modeling the energy consumption of commercial buildings.

2 METHODOLOGY

2.1 Research Approach

A five-step methodology was utilized in this study. First, a comprehensive literature review was conducted through which the different aspects of energy consumption in buildings were studied. Through this process, various software that simulate energy consumption were analyzed, and the most appropriate one for this study was selected. Second, a building case study was selected, and the required data for simulating energy consumption was collected. Third, the model was developed and calibrated, using part of the collected data; and in the fourth step, the model output was validated by the rest of the collected data. Finally, recommendations were made that could be implemented in the simulation to develop an energy reduction framework. The final step was conducted as a basis for future work. Other methodological approaches are described in the following. Figure 1 shows the five-step methodology of this research.

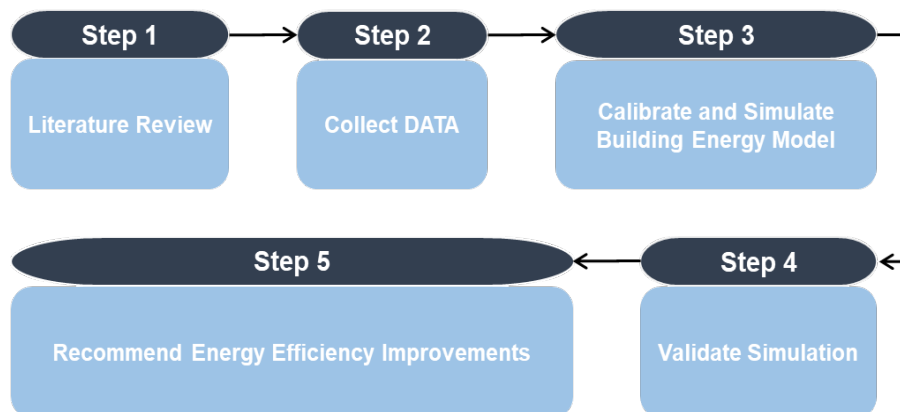


Figure 1. Research Methodology.

2.2 Model Evaluation Method

Various validation metrics can be used, depending on the objectives of a study and the available data. R-squared was used in this study to evaluate how well the model could simulate the experimental observations of energy use in a building.

2.3. DOE-2

DOE-2 is an accepted and widely used building energy analysis program that can simulate and predict the energy use and cost for any type of building. This freeware uses a description of the layout of a building, construction, usage, conditioning systems, and utility rates, as well as weather data, to perform hourly simulations of the building and estimate utility bills. The DOE-2 was developed by James J. Hirsch &

Associates (JJH) in collaboration with Lawrence Berkeley National Laboratory (LBNL). The DOE-2 Building Energy Analysis Program was designed to help architects and engineers perform design studies of whole-building energy use under real weather conditions.

3 COLLECT DATA

The case study implemented in this study was a building named Reed at a U.S. university campus. Table 1 presents the collected data on Reed, based on experimental measurements. The experimental data include the building's on-site measurement and physical data pertaining to its inside situation, such as lighting systems, HVAC, and building envelope thermal mass, systems.

Table 1. Collected Data from the Case Study Building (Reed Building)

Building Envelope	<ul style="list-style-type: none"> • 80,200 sq. ft. • Four floors and a basement; mainly classrooms, offices and laboratories • Walls: concrete block and face brick • Roof: built-up with lightweight poured concrete with 1.5 inches of rigid insulation • Year of construction: 1966
Building Schedule	<ul style="list-style-type: none"> • Monday through Friday, 7 am to 6 pm
Building HVAC and Equipment	<ul style="list-style-type: none"> • 20Hp, 620 GPM, 73 feet TDH chill water pump • 3Hp, 168 GPM, 43 feet TDH hot water pump • 15Hp single zone unit • Three 40Hp double duct units • 30Hp single duct unit • 92 gallon, 199,900 BTUH gas fired water heater
HVAC Schedule	<ul style="list-style-type: none"> • 24 hours per day, seven days per week
Lighting	<ul style="list-style-type: none"> • 88% fluorescent lighting and 12% incandescent lighting
Proposed Maintenance and Operations Measures	<ul style="list-style-type: none"> • Install photo cells to turn off outside lights • Install insulation on chilled water lines

In addition to the data provided in Table 1, building plans included geometry and construction materials, operating schedules, and weather data. The occupancy schedule of the building is shown in Figure 2. The maximum occupancy of the building was from 11:00 am to 4:00 pm, when 500 to 600 persons were in the building.

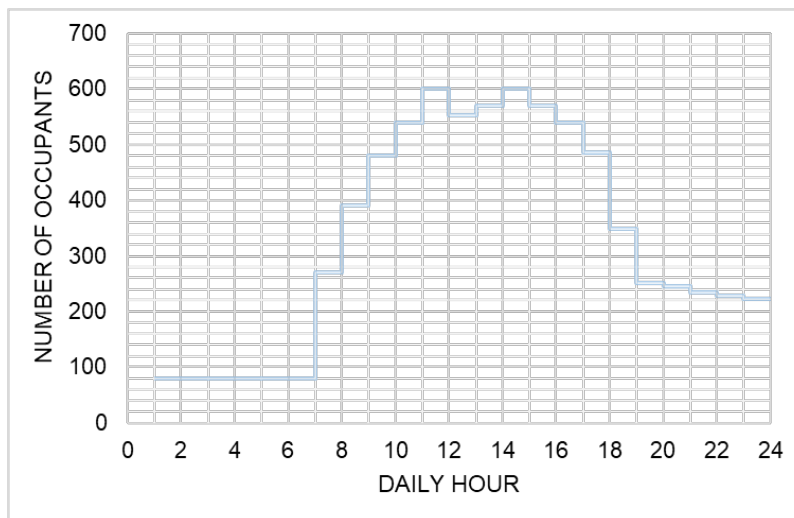


Figure 2. Schedule of Average 24-hour Occupancy of the Case Study Building

4 MODEL CALIBRATION

After collecting the required data from the case study, the DOE-2 Building Energy Analysis Program was implemented to model and analyze the energy consumption of the building. The model was calibrated using 20% of the data, and the rest of the data was used to develop the model. The approach used for calibration in this study was to compare the prediction of the model's hourly usage to the experimental hourly usage data. The building was modeled, including seven zones with inputs of data pertaining to weather, envelop, internal loads, HVAC system, non-HVAC systems, etc. The R-squared was utilized to measure the accuracy of the model's prediction of building energy usage. Figure 3 shows a 3D view of the model.

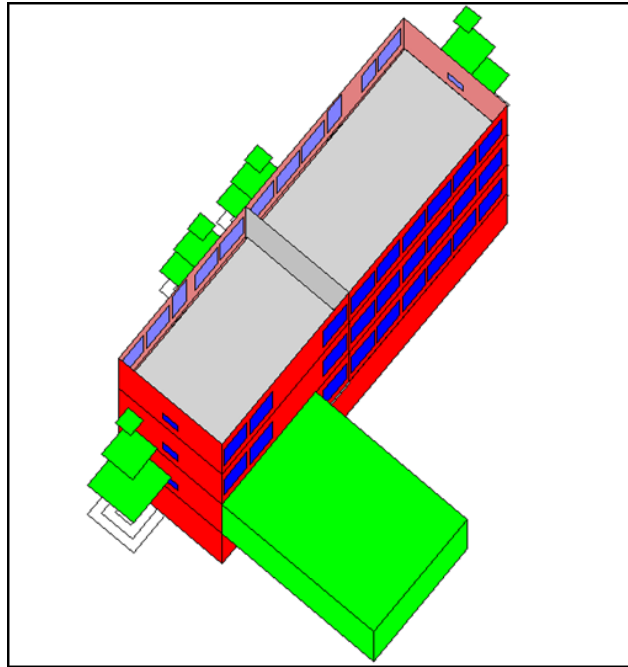
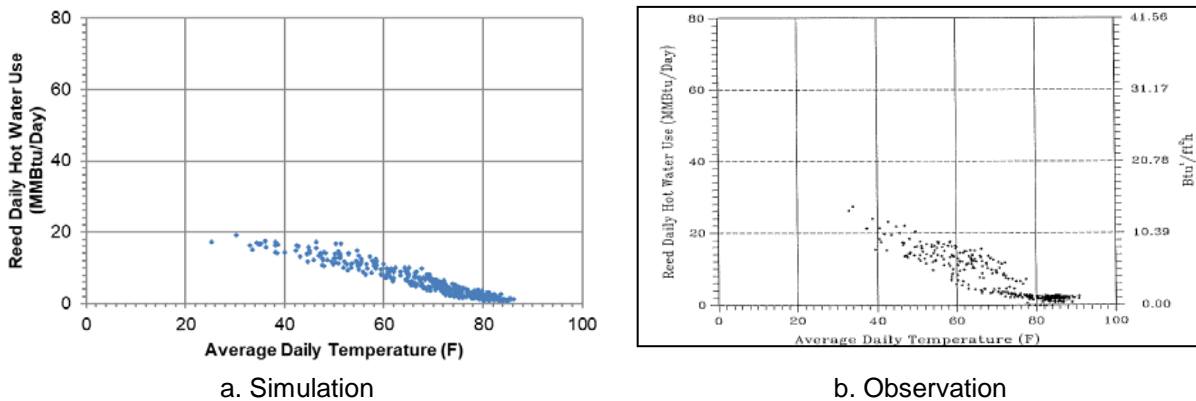


Figure 3. 3D View of the Model

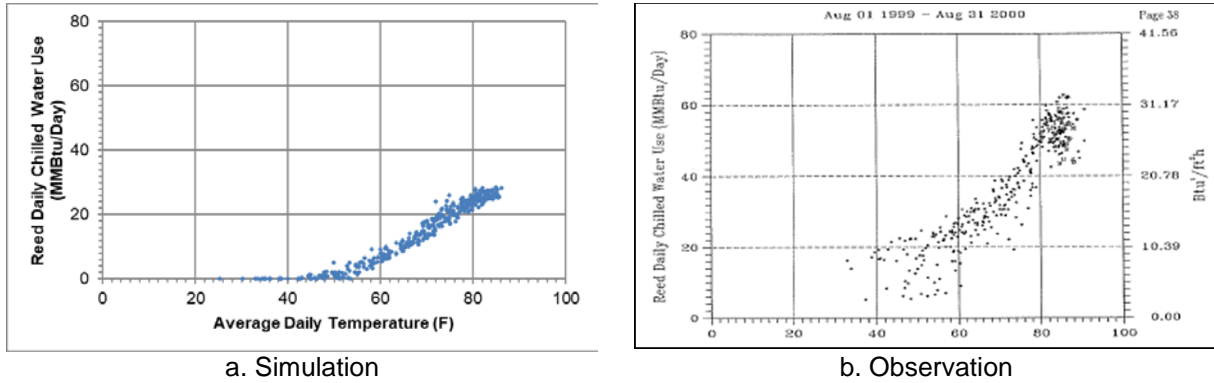
5 MODEL DEVELOPMENT AND VALIDATION

As mentioned, 80% of the data was used for model simulation. Comparisons of different factors of the simulation and the observation data collected from the case study building are shown below. As shown in Figure 4, the average daily temperature of the building versus daily hot water use of the building was well simulated by the model, for which the R-squared was approximately 0.85.



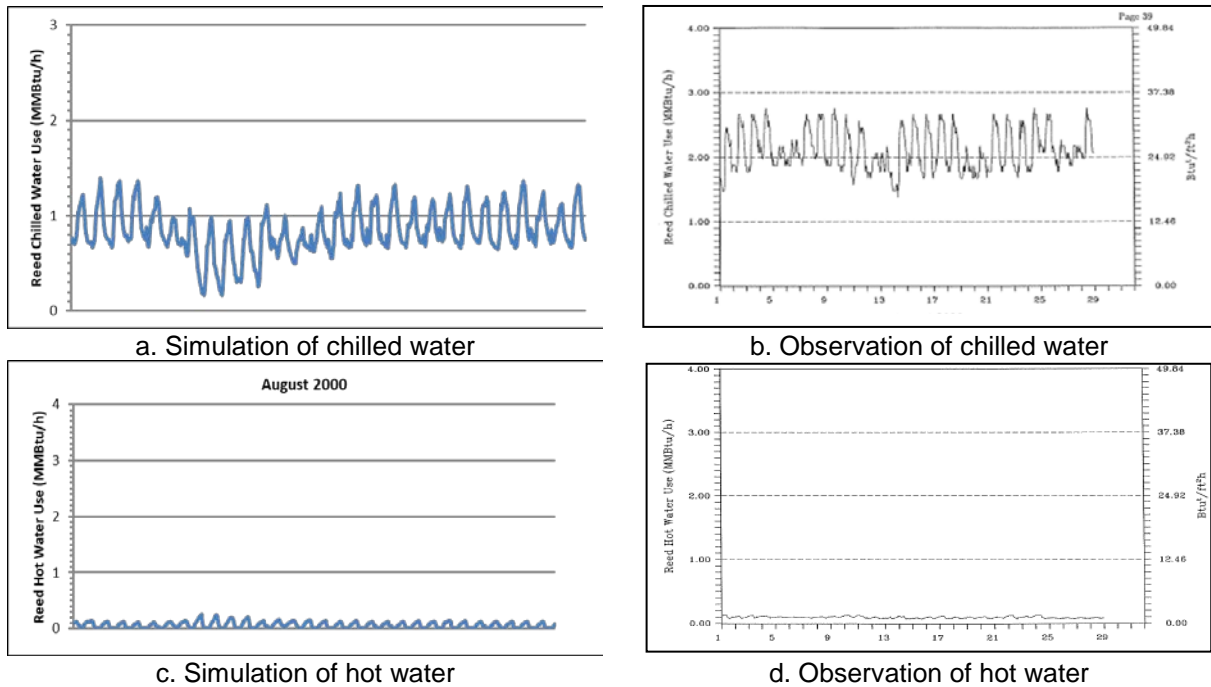
a. Simulation
b. Observation
Figure 4. Comparison of Average Daily Temperature Vs. Daily Water Use

The same comparison was performed for the daily chilled water, as shown in Figure 5, where the results were acceptable, but not as good as those of the hot water. As demonstrated in this figure, the model underestimated the daily chilled water use. With the changes in the average daily temperature, the daily water use changed from zero to 40 MMBtu/Day, while the observation shows a range of zero to 50 for the same range of temperature change. The calculated R-squared between the simulation and the observation, 0.73, is acceptable.



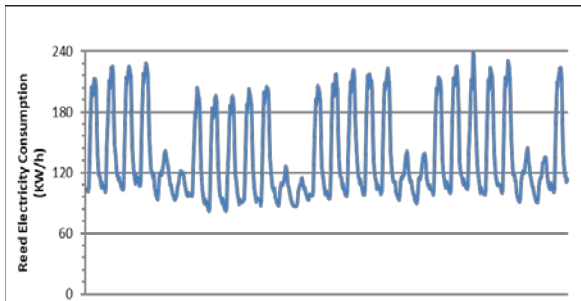
a. Simulation b. Observation
Figure 5. Comparison of Daily Chilled Water Use Vs. Average Daily Temperature

The amount of chilled and hot water use were also simulated by the model. The outputs are shown in Figure 6. As depicted in this figure, the model simulated both cases satisfactorily, even though the hot water usage was better simulated. The R-squared for the chilled water was 0.78, and the R-squared for the hot water was 0.88. Both were acceptable.

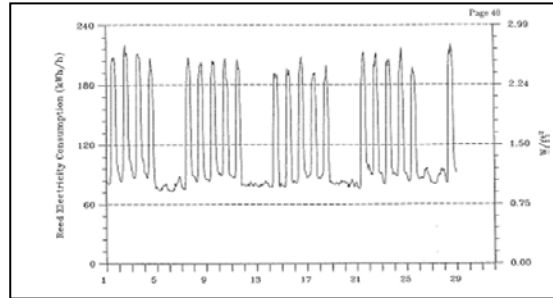


a. Simulation of chilled water b. Observation of chilled water
c. Simulation of hot water d. Observation of hot water
Figure 6. Comparison of Chilled and Hot Water Use

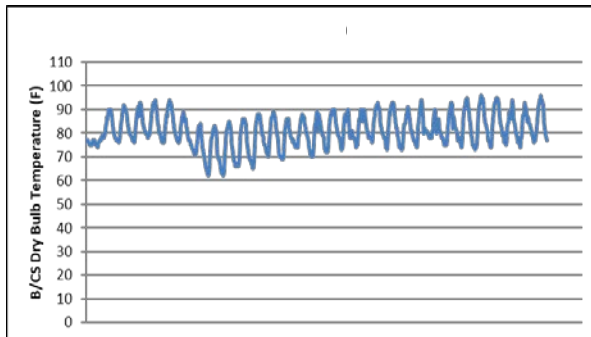
The daily electricity and temperature usage of the building were simulated, and are shown in Figure 7. As demonstrated in this figure, the electricity consumption was well simulated with R-squared of 0.94, while the temperature usage was also well simulated with R-squared of 0.84.



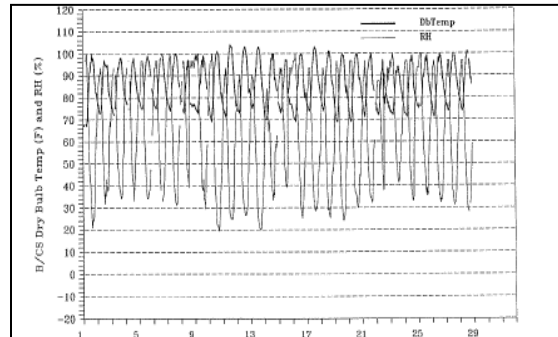
a. Simulation of electricity consumption



b. Observation electricity consumption



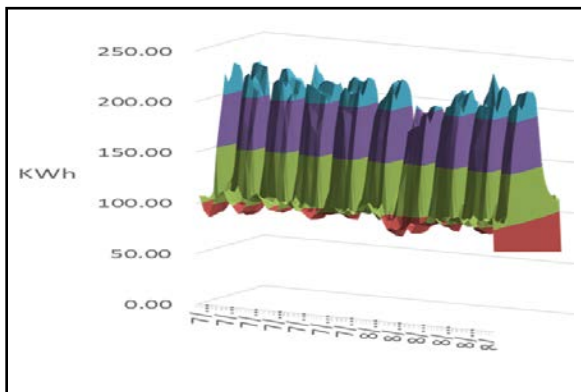
c. Simulation of temperature consumption



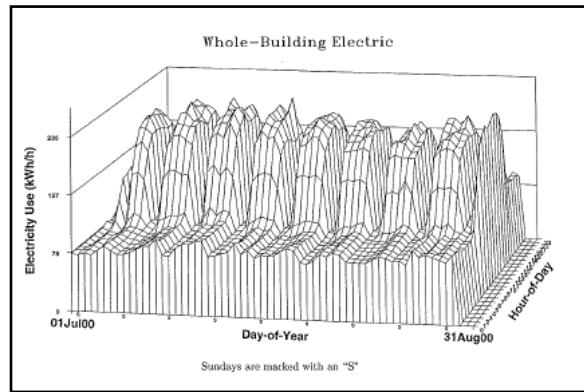
d. Observation of temperature consumption

Figure 7. Comparison of Electricity and Temperature Use

Figure 8 shows a graphical comparison of the simulated electricity use versus the observed electricity use, and demonstrates that the model was able to successfully simulate the electricity usage in the given timeframe.



a. Simulation



b. Observation

Figure 8. Graphical Comparison of Electricity Consumption

The summary of electricity consumption for the given timeframe is shown in Table 2. The total consumed energy was 27605.5 MBTU for the building and the site.

Table 2. Reed Building Electricity Consumption Summary

Building Energy Performance Summary	
AREA LIGHTS	1920.2
SPACE HEAT	3583.8
SPACE COOL	1309.6
HEAT REJECT	281.4
PUMPS & MISC	187.6
VENT FANS	1918.3
Total	9200.9
Total Site Energy	9200.9 MBTU
Total Source Energy	27605.5 MBTU

RECOMMENDATIONS AND FUTURE WORK

It has been proven that new and modern buildings can reduce the consumption of energy by an average of between 20% and 50%, by incorporating appropriate design interventions in the building envelope, heating, ventilation and air-conditioning, lighting, water heating, refrigeration, and electronics. According to the consumptions, and to improve energy consumption in the case study building of the current study, it is suggested that the following considerations be applied to the simulation so that a framework for energy consumption management and improvement can eventually be developed.

Proposed retrofits and recommendations:

- Replace/change lighting
- Retrofit variable air volume
- Retrofit variable air volume fume hood
- Pump variable chilled water
- Utilize programmable thermostats
- Shape an employee green team for building occupants
- Perform interior and exterior damage repair
- Install photo cells to turn off outside lights
- Install insulation on chilled water lines
- Exclude underperforming equipment

6 CONCLUSIONS

Energy consumption of a building was simulated and validated in this study, and recommendations were provided for expanding this research to an energy reduction framework in the future. The results of the study showed that the amount of energy used to produce heat in a building is greater than any other component of energy use. It also revealed that the amount of heat consumed in the case study building was greater than that of the experiments, while the amount of consumed electricity was very close to that of the experiments. The model accurately predicted the energy consumption of the building, and the results of the comparison of the model simulation had an acceptable R-squared for all of the cases. The energy consumption for producing hot water, chilled water, electricity consumption, and temperature were correlated with the observed data with R-squares of 0.78, 0.88, 0.94, and 0.84, respectively. The findings of this study identify the issues with DOE-2 energy software, and provide empirical evidence to validate the program. They also give insight to the designers for planning more energy efficient buildings or energy-aware designs. The model can be used for as a vehicle for applying improving strategies and evaluating their impacts, in order to develop an energy reduction framework for buildings.

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