ACCURATE SIMULATION OF METERED ELECTRICITY USAGE OF A LEED® CERTIFIED CANCER INSTITUTE

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ABSTRACT

The purpose of this paper is to provide a case study for increasing the simulation accuracy of healthcare buildings. In building design profession, the demand for accurate energy simulation of buildings at design-phase is gradually becoming an essential part of the design documents as building owners and energy codes are increasingly requiring accurate energy predictions.

The case study in this paper is a cancer institute which is chosen as an example of healthcare buildings. Healthcare buildings have been major energy consumers with a significant contribution to the total annual energy consumption in commercial buildings. The total energy used by a typical healthcare building per square-foot is about 2 times the usage of a typical office building. The study simulates the annual energy consumption, and compares it against the actual consumption. This comparison further enables identification of important simulation inputs that affect the accuracy. The following parameters had an important contribution on the simulation accuracy: equipment and occupancy schedules, equipment loads, and temperature and humidity set-points. Using a set of recommended input parameters, the simulation accuracy of the electric energy was within 12% of the actual energy usage of the building. In addition, pattern of predicted energy, which represents the electricity demand, also followed the actual energy use pattern.

INTRODUCTION

Building energy simulation history

The history of building energy simulation programs started after the oil embargo in 1973, which brought the attention of the U.S. government to the critical importance of energy usage. The first simulation program was only capable of performing thermal calculations for only a single zone (Kusuda, 1976, Bennett et al., 1977). In the early 1980s, simulation programs were capable of modeling multiple thermal zones and perform calculations for the heating, cooling, ventilating and air-conditioning (HVAC) systems operating under different conditions (Buhl, 1979; Clarke et al., 1988; Palmiter et al., 1982). In the 1990s, simulation programs evolved to have more user-friendly graphical interfaces that allowed designers and engineers to use them easily. In the late 1990s and early 2000s was the development of the Department of Energy's famous simulation program, Energy Plus, which is the program used for this research study (Crawley et al.,2001).

Importance of Building energy simulation

Building a new building creates a source of energy-use and adds a burden on the total energy consumption. Owners try to reduce the energy needed to operate their buildings to lower the financial expenses and reduce the impact on the environment. Therefore, building owners often try to have sustainable and energy-efficient buildings that consume less energy than similar conventional buildings. Many buidling owners, especially high-energy consumers such as helathcare, ask for accurate predictions of energy-use. The predications are used in financial budgeting to estimate the cost of utilities (Degelman. 1991). In addition, green building guidelines, such as LEED, and energy codes are increasingly requiring accurate energy simulations. Therefore, performing an accurate energy simulation during the design phase of the building is becoming an important requirement in the industry.

Current practices in increasing accuracies of simulations are performed as a calibration process in which the building is already built and is operating. The process includes creating an initial model, which then gradually becomes more accurate as input parameters are constantly improved after several site visits and interviews. It is not a process to predict future energy use, but rather to discover which parameters had the biggest impact on accuracy. Therefore, by identifying important simulation inputs that affect the accuracy, energy analysts may be able to produce accurate simulations during the design phase of future buildings.

The method this study followed to produce good accuracy is by creating the building model following the design procedures that mechanical, electrical, and plumbing (MEP) designers would follow to design the MEP systems for the building. Depending on the type of the building, MEP designers typically start with the identifying the applicable design guidelines and specialty codes. For instance, the current case study is a healthcare building with research laboratories. MEP designers would strictly follow the National Institute of Health (NIH) guideline "Design

Requirement Manual: The formulae for building state of the art biomedical laboratories" as a guide for properly designing the MEP systems of the building to maintain the required functionality and safety of the occupants. Therefore, the NIH guideline's recommendations were used for this simulation.

Healthcare as a major energy consumer

Healthcare buildings are one of the biggest energy consumers, especially when compared to typical office buildings. In 2003, the U.S. Energy Information Administration performed a Commercial Buildings Energy Consumption Survey (CBECS) to evaluate energy consumption of different types of commercial buildings. The survey covered 824,000 office buildings with a total square footage of 12.2 billion ft^2 (1.13 billion m^2) and a total energy consumption of 1,134 trillion Btu (332 million MWh). The survey also covered 129,000 healthcare facilities with a total square footage of 3.16 billion ft^2 (293.6 million m^2) and a total energy consumption of 594 Trillion Btu (174 million MWh). Therefore, an average office building uses 1,376 MMBtu per year (92,950 Btu/ft^2 per year). In contrast, the average healthcare building uses 4,605 MMBtu per year (187,970 Btu/ft^2 per year) that is a little more than 2 times what the average office building uses (CBECS, 2003).

Healthcare buildings that include laboratories consume even more energy. Laboratories typically consume 5 to 10 times more energy per square foot than do office buildings. Specialty laboratories such as clean rooms can consume as much as 100 times the energy for a similar size commercial building (Lab21-inro, 2008). Therefore, accurately simulating healthcare buildings is important to have reliable energy consumption data to measure the effectiveness of different energy efficiency measures.

Parameters impact on accuracy

Simulation programs have many parameters that may require an enormous amount of time to input. Therefore, the goal of some researches became to narrow down the number of parameters that need accurate values from the user and let the program use default values for the rest.

As an example to observe what may be the most influential parameters on simulation, Yoon et al. (2003) performed a study where they used calibration to increase the accuracy of a simulation model and compared it against actual metered data from their case-study, a 23-story office building in Seoul, South Korea..

Yoon et al. calibrated their model by constantly visiting the site and conducting interviews of the building operators. They changed input values for simulation parameters and ran the model 13 times. Ten times out of the 13 involved changing the schedules and load density of the model. As a conclusion from this calibration, accurate inputs for equipment schedules and load densities play a major role in simulation accuracy.

Another study is performed by Wang et al. (2012) where they examined effects of different input parameters on the accuracy of building energy simulations.

The base model was a medium size office building that is created in compliance with ASHRAE 90.1-2007. Input parameters that have been varied are: lighting controls, plug-in loads, HVAC equipment schedules, occupancy schedules, temperature set-points and set-backs, economizer cycle, and minimum flow of VAV boxes.

The study found that the HVAC system schedules, specifically room set-points and VAV minimum, and plug-load schedule play a major role in accuracy. Moreover, the study found that the cumulative impact of these parameters is larger than the sum of individual effect of each.

This study shows that mainly load schedules, coming from the plug-loads and HVAC equipment, have a significant impact on simulation result.

CASE STUDY:

The case study for this research is a 182,000 ft^2 (16,900 m$^{2)}$ cancer institute building located in Central Pennsylvania. The building is part of an educational complex that includes college of medicine, clinical science, and several laboratories. The cancer institute used 2.1 version of LEED-New Construction & Major Renovations (NC) to obtain a LEED certification. The building includes five floors with two main functions: radiation and infusion therapy in the first three floors, and cancer research laboratories located in the top two floors. The building was completed and certified in 2009. The cancer institute currently has the highest electric energy usage per square footage in the complex with a value of 37.6 kWh/ft^2, 39% higher than the average of other metered buildings that is at 27 kWh/ft^2.

Being part of a medical school and research campus, the cancer institute receives its steam and chilled water from a central plant that feeds the entire campus. The central plant does not have sub-metering for the steam and chilled water supply. Therefore, it was not possible to obtain steam or chilled water consumption for the cancer institute. However, the cancer institute has sub-metering for the electric panelboards, with each panelboard metered separately. The facilities and operations office was able to provide the metered electrical data, panelboard schedules, and the architectural, electrical, and mechanical drawings. Each panelboard provides power to a different building system, such as lighting or mechanical. Using the panelboard schedules, it was found that most pump and fan motors, over (0.5 horsepower) of the mechanical systems were on their own panelboards, thus, it was possible to define what percentage of electrical power went to the mechanical systems' fans and pumps. Figure 1 shows the annual electric usage per panelboard. Looking at the metered panelboards, the highest values are from panels MD4P1 and MD4G1. These two panels serve the motors of pumps, fans and compressors of the building mechanical system. and they count for 57% of the total electricity used by the building.

SIMULATION:

In this study, DesignBuilder, an interface of EnergyPlus has been the main program used for simulation. The program offers the option to model the building with a simple or detailed HVAC system. It has built-in templates for construction material, weather data, typical loads, and schedules that are based on ASHRAE 90.1-1999, the International Energy Code, and other building and energy codes.

The building material's thermal properties used for this simulation are the ASHRAE 90.1-1999 templates as it is the required by the LEED-NC 2.1, which the cancer institute has followed.

The present study investigated key input parameters that increase the simulation accuracy when compared to the actual energy usage of the cancer institute, including the laboratory spaces. In addition, for these parameters, the study investigates the impact of using the applicable design and energy guidelines values, that MEP designers would use, instead of the program's defaults. This investigation has found that the key input parameters are equipment and occupancy schedules, equipment loads, and temperature and humidity set-points.

Equipment and occupancy Schedules

The United States Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) both sponsored a project named "Labs for the 21st Century (Lab21)," which created a guideline to reduce energy consumption in laboratories. One of the objectives of this project is to enable accurate simulations of laboratories. Therefore, the project created recommended occupancy, equipment, and lighting schedules for laboratories based on real schedules obtain from case study laboratories that participated in the Lab 21 project (Lab21-schdl, 2008). Figure 2 represents the typical schedule template that simulation programs use for healthcare and laboratory occupancy. Figure 3 shows the weekday occupancy schedule proposed by the EPA Lab21 project. In the present study, the EPA Lab21 schedules were used since they are based on actual schedules obtained from the field.

Equipment Load

Another important input for accurate simulations is the equipment-load values. The cancer institute with its research and radiation therapy facilities is a high-energy consumer with high electrical energy requirement and high plug-loads. The National Institute of Health (NIH) has published a biomedical laboratory design guideline titled "Design Requirement Manual: The formulae for building state of the art biomedical laboratories" to specify the architectural, mechanical, electrical, and plumbing requirements to maintain the quality of work and safety of occupants in biomedical laboratories. Part of the electrical design requirements is the electric energy density required to represent the plug-loads. Comparing the default values used in the simulation program and values recommended by the NIH design manual, the default value that the simulation program uses for equipment load is 2.2 W/ft^2 with 20% being the radiation gain. The NIH guide requires 4-8 W/ft^2 for laboratory equipment electrical loads. Therefore, to quantify the electrical usage of the laboratory spaces in the cancer institute, an average value of 6 W/ft^2 was used as the electric usage with a 20% radiation fraction (NIH, 2008).

Temperature and humidity set-points

Another important factor that affects the amount of energy usage in healthcare buildings is the temperature setbacks. The cancer institute is a 24-hour facility that has therapy and laboratory zones with strict temperature and humidity requirements. The NIH requirements for temperature set-points and humidity were used for the laboratory zones in the cancer institute. Since laboratory spaces in healthcare buildings are zones with high sensitivity and low tolerance to the temperature and humidity conditions, the NIH guide requires that temperature and humidity set points detailed in Table 1 must be controlled at all-time without use of a setback control regime. Other auxiliary spaces such as administrative and office spaces have the same temperature and humidity requirements in Table 1 but only during occupied hours. Therefore, the values used for the cancer institute's laboratory zones are as shown in *Table 2,* while the radiology and therapy zones are set at the default temperature and humidity set points for treatment areas as shown in *Table 3*.

Table 1 Indoor Design Conditions required by NIH Design Manual

Season	Temperature ^{o}F (^{o}C)	Relative Humidity %
Summer	73 ± 2 (23±1)	50 ± 5
Winter	70 ± 2 (21±1)	33 ± 5

Table 2 Indoor Design Conditions used for simulating laboratory zones

Season/Set-point	Set-point Temperature °F (°C)	Set-back Temperature °F (°C)	Relative Humidity %
Summer	73 (23)	73 (23)	50-55
Winter	70 (21)	70 (21)	50-55

Table 3 Indoor Design Conditions used for simulating therapy and treatment zones (program defaults)

Season/Set-point	Set-point Temperature °F (°C)	Set-back Temperature °F (°C)	Relative Humidity %
Summer	73 (23)	82.4 (28)	10-90
Winter	70 (21)	63 (17)	10-90

Simulation results

After using the input parameters with the modified values mentioned in the previous sections, the simulated electricity results are compared against the program defaults for these parameters and against the actual metered electric usage. In 2011, the cancer institute used 7.23 million kWh of electric energy that is 38.76 kWh/ft^2. Running the simulation with Lab21 schedules and appropriate load inputs and temperature set-points, the results for the electric usage equals to 6.35 million kWh that is 34.05 kWh/ft^2. Figure 4 shows a comparison between the actual metered electric usage of the cancer institute in 2011, the predicted electric usage from the simulation program using the defaults values and using the modified values for the parameters discussed in the previous section. The modified parameters show electric energy prediction that is within 12% of the actual use. This is 28.7% improvement in accuracy compared to the program defaults for the same parameters.

DISCUSSION

Looking at Figure 4, the actual building electric data obtained from the site and the simulated data both have uniform usages throughout the year regardless of the outside weather conditions. The actual electric data include the lighting, plug-loads in the building, the pumps and fans of the mechanical system. The electricity obtained from the simulations represented computers, room electricity (plug-loads), lighting, system fans, and system pumps. These results show the impact of using the correct occupancy, load, and lighting schedules. In addition, the strict temperature requirements in the laboratory spaces demand the HVAC system to be running continuously to maintain the required temperature and humidity levels at all time.

CONCLUSION

The study examined the simulation accuracy for a cancer institute as an example of healthcare buildings. The aim was to produce accurate simulation results without calibration. The process was done by creating the energy model according to design codes and guidelines applicable to the building. The facilities and operations office overseeing the cancer institute provided the actual metered electric data. To increase accuracy of the cancer institute energy simulation, the following simulation input parameters have been changed to meet NIH and EPA's Lab21 requirements, and they are: equipment and occupancy schedules, equipment loads, and temperature and humidity set-points. After simulation, the predicted energy usage showed a pattern that matches the actual usage pattern of the cancer institute. In addition, the predicted electric energy-per-square-foot was within 12% of the actual usage. Therefore, the input variables: equipment and occupancy schedules, equipment loads, and temperature and humidity set-points have an important impact on the accuracy of modelling the case study, which is a cancer institute with a laboratory space occupying 40% of the building. These inputs are applicable to other healthcare facilities to increase the accuracy of the building energy simulations.

ACKNOWLEDGMENT

This study was partially supported by the DOE HUB for Energy Efficient Buildings (EEB HUB) under Award Number DE-EE0004261. The author would also like to thank the department of facilities at the Penn State Milton S. Hershey Medical Center and Health System for their help and support in gathering data for this study.

DISCLAIMER:

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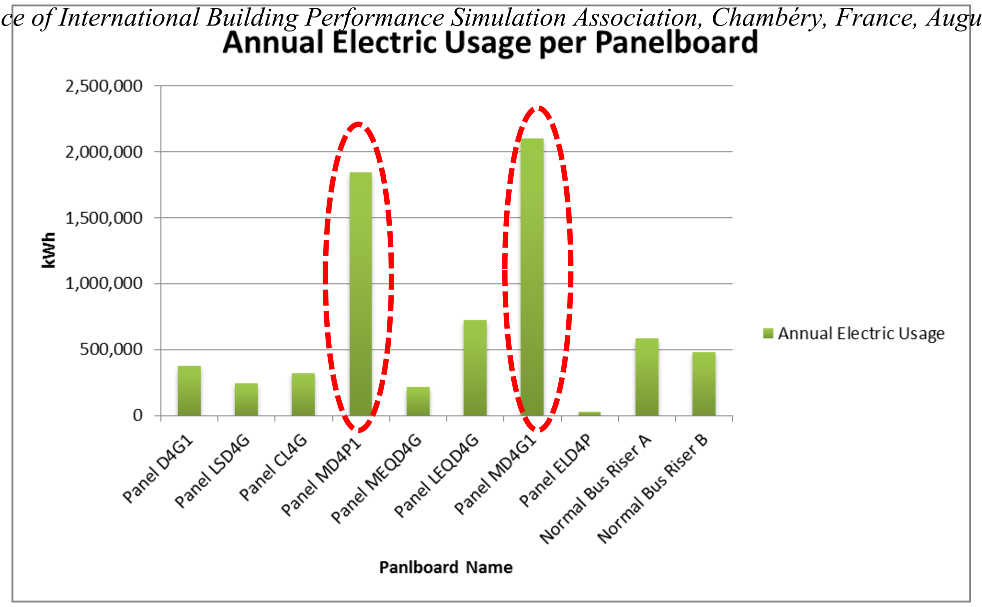

Figure 1: Annual electric usage in Cancer Institute per panelboard. Circled bars represent panelboards for the mechanical system.

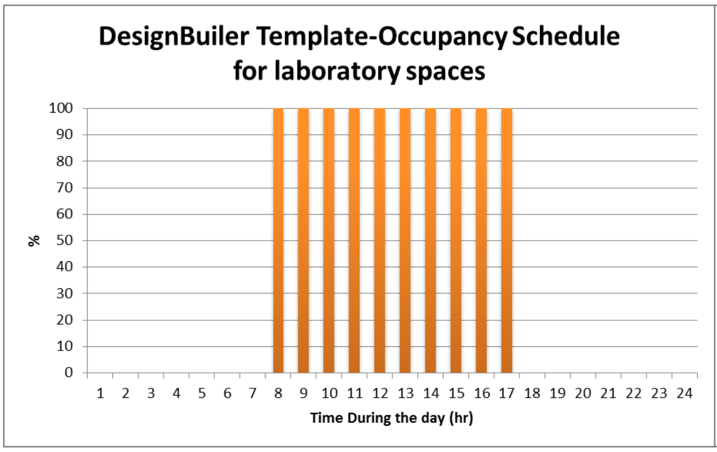

Figure 2: The default occupancy schedule that DesignBuilder uses.

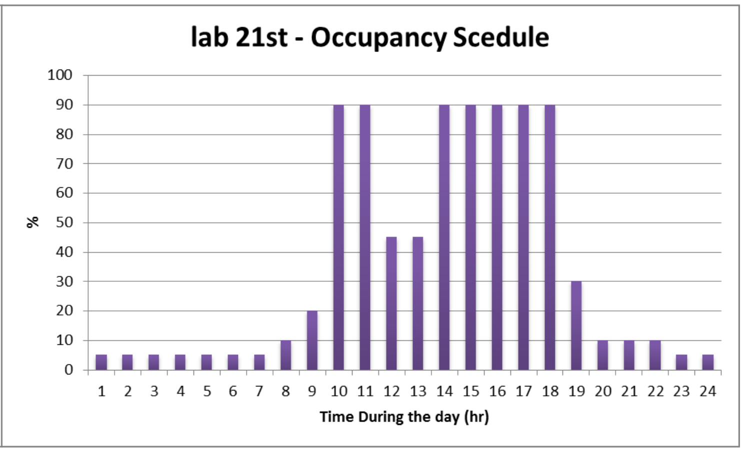

Figure 3: The occupancy schedule suggested by the EPA Labs for the 21s century project

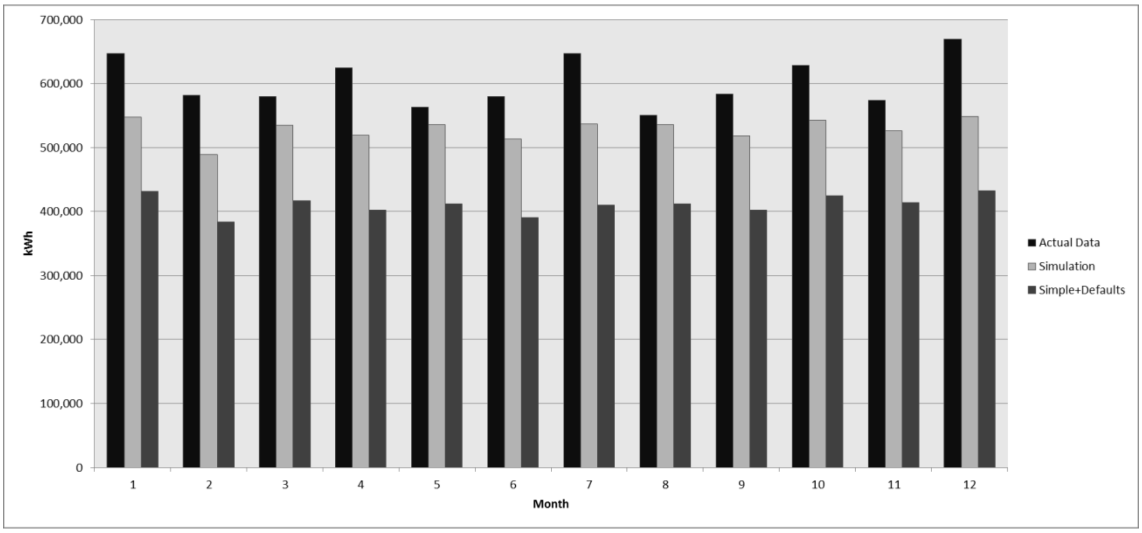

Figure 4: A comparison between the actual electric energy used by the Cancer Institute (Black) and the electric usage obtained from simulated model using both default (Dark Grey) and modified values for parameters (Light Grey).