

Energy Modeling of University buildings: A Case Study

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Many Universities in the US are striving to make their campuses more sustainable. Their sustainability efforts typically include increasing energy efficiency of new and existing buildings. There are several strategies for increasing the energy efficiency of buildings and energy models can be used to compare different strategies. While energy models are widely used during design of new buildings, they are not often used to evaluate actual building performance. The paper discusses a case study involving the use of a popular energy model system (eQuest) to evaluate the performance of an 80,000 sf university building. The building was constructed in the 1960s and has undergone several renovations throughout its life. The paper describes the data collected, the modeling process and the results.

Key Words: Energy modeling, Life cycle cost, Design alternatives, Sustainable, Energy consumption, Existing Building, Energy Modeling, Retrofits.

Introduction

Many universities in the US are striving to make their campuses more sustainable. This is evidenced by the large number of University Presidents who signed the American College & University Presidents' Climate Commitment. The Commitment recognizes the unique responsibility that universities have as role models for their communities and in educating the people who will develop the social, economic and technological solutions to reverse global warming and help create a thriving, civil and sustainable society. (ACUPCC, 2014). The commitment requires universities to take immediate steps to reduce greenhouse gas emissions. Presently, buildings account for 73% of the total electricity consumption in the U.S. and 38% of CO2 emissions. In 2004, global emissions of greenhouse gases (GHG) from burning fossil fuels were approximately 49 GtCO2eq. Of those, 5.6 GtCO2eq were emitted in the US alone (Easton, 2012). Thus, any successful climate change mitigation plan should include activities that significantly cut down energy consumption in buildings.

Improving the energy-efficiency of buildings is one of the most effective and affordable ways to mitigate GHG emissions on a large scale. The 4th Assessment Report of Intergovernmental Panel on Climate Change (IPCC) predicts that by 2030, cost-effective energy efficiency measures in buildings would alone save 5.3–6.7 GtCO2eq/year globally. An idea that is gaining popular support is 'net-zero' annual energy consumption by combining more efficient building energy use with on-site renewable energy generation. There is thus, a growing demand for Energy Modeling tools to support the analysis of building's energy use (Coffey, et al., 2010).

A Building Energy Model (BEM) is a computer based simulation tool used to calculate thermal loads and energy use of a building. BEMs are used by a variety of professionals including architects, construction

managers, engineers, policy makers and energy auditors. Utilities and municipalities rely on the predictions of building energy models to calculate energy efficiency rebates. Architects and engineers rely on BEMs to develop energy savings plans for their clients.
BEMs can predict a buildings' energy consumption by accounting for actual construction materials and actual HVAC systems. BEMs also account for the effects that building's occupants have on energy use by defining occupant schedules. Occupants affect thermal load and ventilation requirements significantly and in turn influence the load on HVAC systems and fans (Ryan & Sanquist, 2011).

Building Energy Modeling (BEM) tools have been around since the early 1980s. Over the years, they have been vastly improved and expanded to model more complex and detailed energy using systems. With the increase in computational speed and capacity, powerful building energy models can now be used on personal desktops and laptops

While energy models are widely used during design of new buildings, they are not often used to evaluate actual building performance. For existing buildings, any attempt for identifying optimal energy efficiency strategies should start by understanding how the building currently utilize energy using an energy model that model actual building performance. Actual system performance varies throughout the life cycle of the building because buildings' systems degrade and their efficiencies are reduced with time particularly if they aren't properly maintained. Faults in mechanical systems and lighting equipment alone can account for 2–11% of the total energy consumption for commercial buildings (Heo, Choudhary, & Augenbroe, 2011).

The paper discusses a case study involving the use of a popular energy model system (eQuest) to evaluate the performance of an 80,000 sf university building. The building was constructed in the 1960s and has undergone several renovations throughout its life. The objective of the research is to use energy modeling software to predict energy consumption in the building and compare it to actual utility data. The paper describes the data collected, the modeling process and the results.

Energy Modeling Data Collection

As building energy modeling tools became more sophisticated, the amount of user input and data required to define the models grew (Heo, Choudhary, & Augenbroe, 2011). Some required data can be easily obtained while other data is more difficult to get with acceptable accuracy (Eisenhower, O'Neill, Fobonorov, & Mezic, 2010). Obtaining all required data with acceptable accuracy is particularly challenging in existing buildings, as the information available in drawings could be outdated due to renovations/upgrades that have been performed. The data that needed include:

- **Architectural Data:** The building's architectural design has a great influence on its energy demand. When thoroughly informed about the complex synergies between building design and energy use, architects and designers can make informed and cost effective primary decisions about energy savings features in their buildings (Aulbach, 2013). Primarily, the architectural data needed for modeling are–
  - General building information – The building orientation, the city it's located in (for weather details), relative position of any tall building that casts a shadow on the building.
  - Floor area and height – This includes the number of floors, all conditioned, unconditioned and ventilated areas (sf) on each of those floors, floor-to-floor height, floor-to-ceiling height, plenum space
  - Envelope Construction Materials – Building materials of all exterior walls, roof and floor slabs, windows, doors, insulation thickness and type in walls, flooring material, wall-slab construction joint type

  - Fenestration areas – Number, size and position of all exterior doors and windows, any overhangs, fins, blinds or drapes on windows.
  - Fenestration U-value and Shading Coefficient (SC) – U-value (conductance) and SC of exterior window and door materials.
- **Mechanical Data:** In many commercial buildings HVAC systems are among the highest energy-consuming systems (Fong, Hanby, & Chow, 2005). Hence, accurate information regarding their size and zoning is very essential.
  - HVAC zoning – The distribution of conditioned floor area into different spaces (zones) according to the Air-handling Units (AHUs) serving them.
  - Activity in zones – Each HVAC zone is assigned to a particular activity (e.g. classroom, library, office, etc.) and has sf/person and minimum cfm/person assigned to it.
  - Design flow rates – Each AHU has a Min Design Flow (cfm/sf) and Minimum Flow (%) for Core and Perimeter areas defined.
  - Equipment description – This includes System type, cooling source, heating source, hot water source and return air path.
  - Control sequences – Each zone has maximum and minimum Set-point Temperature defined for both occupied and unoccupied condition.
- **Electrical Data:** Electrical equipment is another major consumer of electricity in buildings.
  - Electrical Equipment – Types of lighting present in building (interior and exterior end uses), Interior Lighting, Office Equipment, Self-contained refrigeration and Exterior Lighting Loads and Profiles (W/sf).
- **Internal Loads Data:**
  - Peak occupancy (by zone) – Design max occupancy (sf/person)
  - Peak lighting load (by zone) – Watt per square foot (W/sf) of all different lightings installed in building
  - Peak equipment load (by zone) – W/sf of all different electrical equipment in building.
- **Operations Data:** Operation schedules influence energy consumption greatly, so accurate information about them is very essential (Clevenger & Haymaker, 2009).
  - Occupancy, Lights, equipment schedules – Number of seasons the year is divided into and their starting and closing dates, opening and closing time, and people density for all seasons, holidays, schedule for occupants, lights and miscellaneous (office) equipment.
  - Thermostat schedules –Temperature set-points for both occupied and unoccupied conditions.
  - Fan schedules – Schedule of fans' operation relative to occupancy schedule, i.e., how many hours before/after occupants occupy building do fans kick in and, how many hours before/after they leave do fans shut down.
  - Fan kW – Information about size (kW/horsepower/brake horsepower) and numbers of all types of fans (exhaust, ventilation, return) in the building.

eQUEST Model

eQUEST is a popular building energy modeling tool. eQUEST provides two design wizards, the so called Schematic Design (SDW) and Design Development Wizards (DDW). Both represent well-known stages during design that differ significantly in the level of detail they contain. Both wizards can be used to simplify data input through usage of default parameters. eQUEST wizards contain several wizard screens which lead the user to input and/or change data. These screens include predefined default values (identified by green font) to which the user can make appropriate changes. (Energy Design Resources).

eQuest was used to evaluate the performance of an 80,000 sf university building. The building was constructed in the 1960s and has undergone several renovations throughout its life. The building primarily contains classrooms and administrative offices.

The University's Architect provided the research team with the data required including CAD drawings of all floors; floor plans showing details of building construction, HVAC plans, and test and balancing reports. The University's Architect also provided drawings of functional usages in each floor; this was important to help determine adequate schedules (occupancy, lighting, equipment). Figure 1 shows a picture of the building used in the case study.

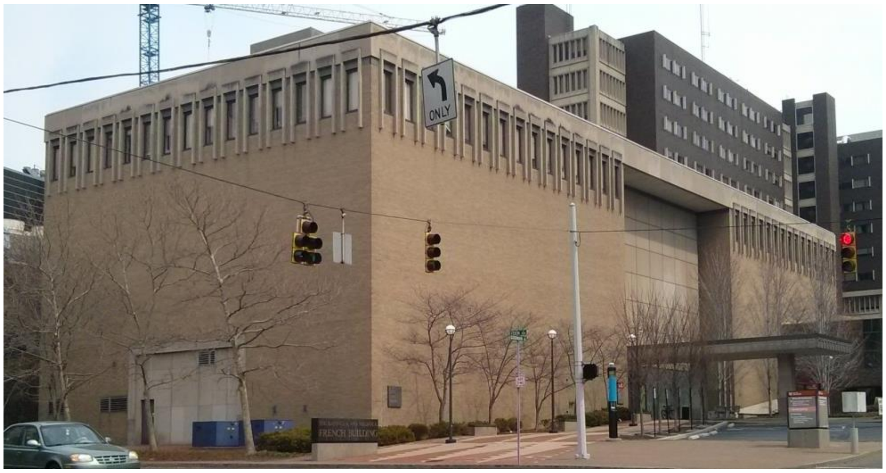


Figure 1: The building used in the case study (actual site photograph).

In addition, the research team toured the building twice accompanied by the University's Engineers, who explained the set-up of the complete HVAC systems and changes made since their original installations. The University also provided the research team with utility consumption data for 2011, 2012 and 2013 with separate figures for electricity and, steam and chilled water consumption.

The eQuest Model as shown in Figure 2, was created using the *Design Development (DD) Wizard* were the following input was inserted into the model:

- CAD drawings of all floors
- building orientation and geographical location of site
- floor-to-floor and floor-to-ceiling heights
- building exterior and interior envelope construction (roofs, walls, slabs) – both, materials and insulation
- fenestration details
- number of seasons in the year
- HVAC zoning of all floors
- assigning these zones to different activities
- building operating schedule
- building occupancy details
- lighting and office equipment load details
- details of all HVAC system, including numbers and types of AHUs and fans
- ventilation and air-flow values for all spaces
- temperature set-points of all AHUs

After the basic input was inserted in the *DD Wizard,* eQuest's *Detailed Interface (DI)* was used to edit or change data that can't be inserted in the wizard to more accurately reflect the real conditions. Such data included detailed daily/weekly/annual occupancy, lighting and equipment schedules.

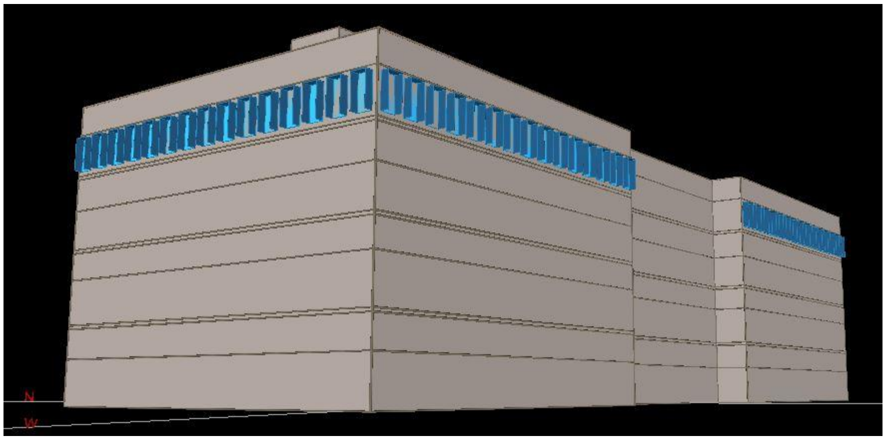
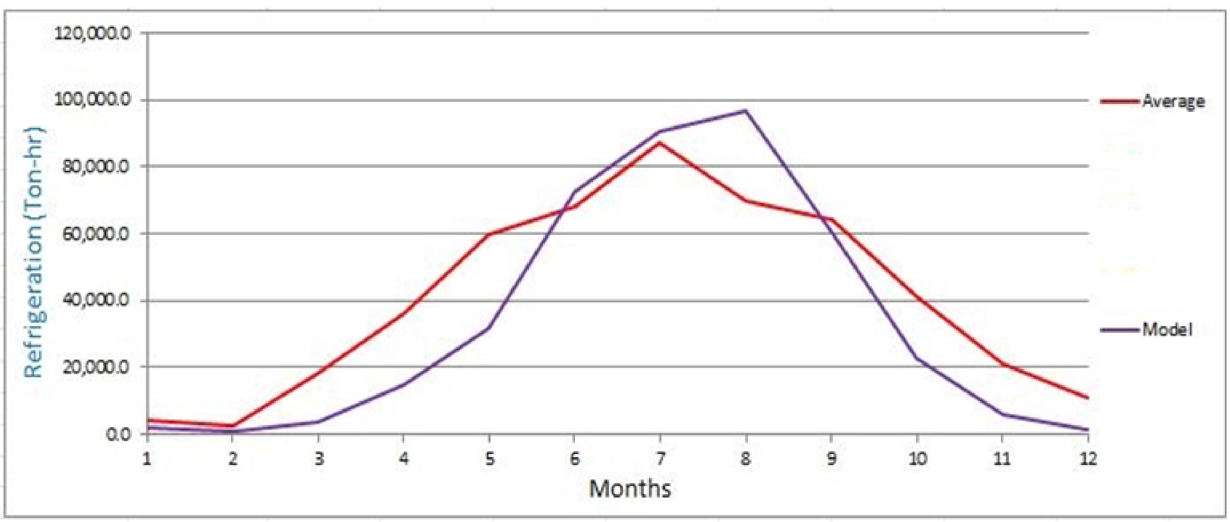


Figure 2: eQUEST rendering of the building.

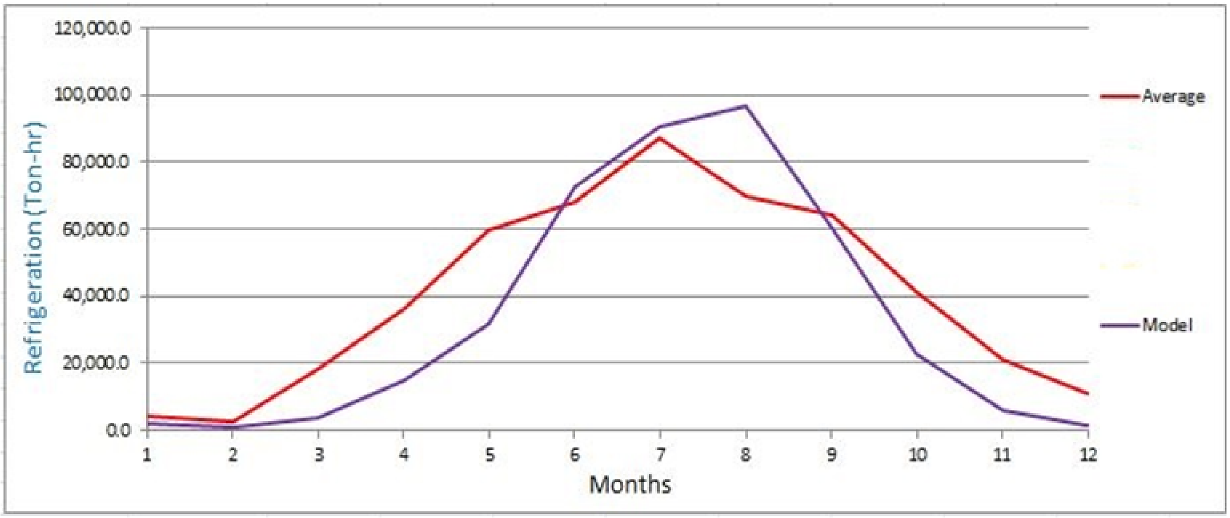
Results

Figures 3, 4, and 5 display the results of the simulation. Both actual and modeled energy consumption are shown in the figures for steam, chilled water and electricity respectively. As shown in the figures, although the modeled total annual consumption of utilities is similar to the actual data, there are more variances in the month to month utility consumption between the actual and modeled results. These variance are attributed to many factors that are further explained in the following section.



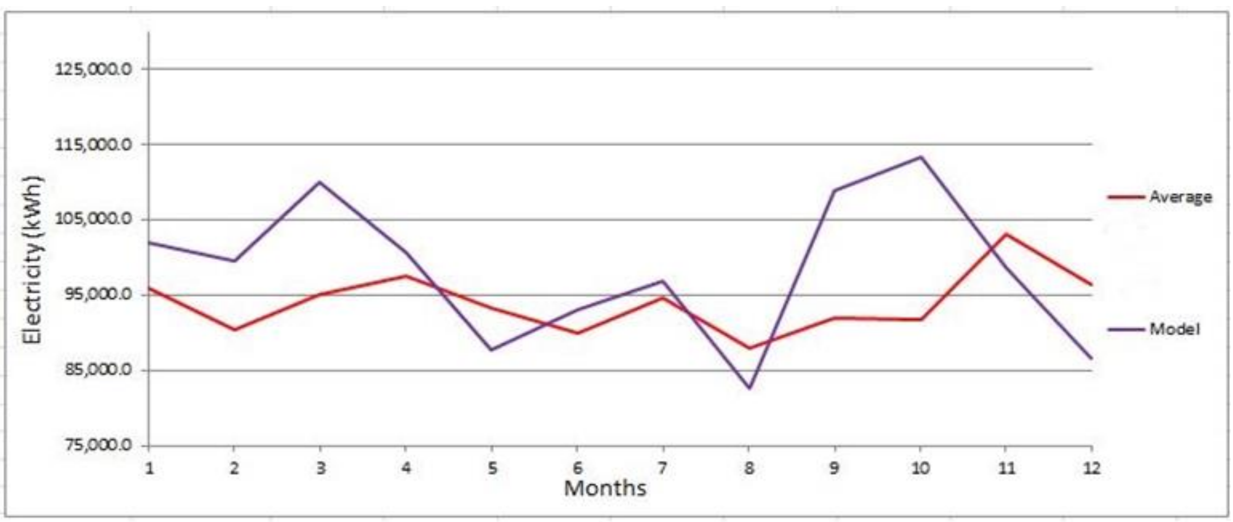
Actual total Chilled Water Consumption	Modeled Chilled Water Consumption
483,880.084 Ton-hr	**402,833.333** Ton-hr

Figure 3: Graph comparing actual steam consumption with that predicted by the model.



Actual total Chilled Water Consumption	Modeled Chilled Water Consumption
483,880.084 Ton-hr	**402,833.333** Ton-hr

Figure 4: Graph comparing actual chilled water consumption with that predicted by the model.



Actual annual Electric Consumption	Modeled annual Electric Consumption
1,128,021.033 kWh	**1,179,634.000** kWh

Figure 5: Graph comparing actual electricity consumption with that predicted by the model.

Factors Affecting Energy Consumption

The factors influencing the total building energy consumption can be classified into the following categories:

– Climate (e.g., outdoor air temperature, solar radiation, wind velocity, etc.),
– Building-related characteristics (e.g., type, area, orientation, construction materials etc.)

– Building services systems and operation (e.g., space cooling/heating, hot water supplying, etc.),
– Building occupants' behavior and activities (e.g. time they come and leave the building, whether they turn light off when they leave, etc.)

Among these categories, the authors' experience has been that building occupants' behavior and activities are the most challenging to predict with acceptable accuracies. Ryan et al. also pointed out the difficulty of obtaining reliable data related to building occupants' behavior (Ryan & Sanquist, 2011). Other researchers have also found it difficult to completely identify the influences of occupants' behavior and activities through simulation due to users' behavior diversity and complexity in real life; and the fact that current simulation tools can only mimic behavior patterns in a rigid way. As shown in the works of Yu, Fung, Haghighat, Yoshino and Morofsky (2011) recently several models have been established to integrate the influence of building occupant behavior into simulation programs. However, these models focus only on typical activities such as the control of sun-shading devices, whereas realistic building user-behavior patterns are more complicated.

An evolving technology that can help better predict occupant's behavior is traffic monitoring using people counters to monitor each room and area for occupancy (sensourceinc, 2014). Using people counters, highly accurate information is available near real-time to develop more realistic occupancy schedule that can be then input to eQuest for better evaluation of existing buildings' performance.

Conclusions

With about 40% of energy usage being accounted for by buildings in the US, it is important that any sustainability effort aiming to reduce greenhouse gases include significant activities to improve energy efficiency of buildings. There are several strategies for increasing the energy efficiency of buildings and energy models should be used to compare different strategies. For existing buildings, any attempt for identifying optimal energy efficiency strategies should start by understanding how the building currently utilize energy using an energy model. The paper described a case study that included developing an energy model of an existing university building. eQuest was used to evaluate the performance of the building. Although the modeled total annual consumption of utilities is similar to the actual data, there were more variances in the month to month utility consumption between the actual and modeled results because of the current difficulties associated with obtaining data describing building occupants' behavior and activities with acceptable accuracies. An emerging technology that can help better predict occupant's behavior is traffic monitoring using people counters to monitor each room and area for occupancy.

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