When Building Energy Models Outperform Their Buildings: What Happens and How to Prevent It

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ABSTRACT

Energy models have become a commonly used service for several new construction and existing renovation projects. The accuracy of energy models has improved greatly over the past decade and they have the potential to provide important information about utility consumption and costs on the design of a building. So, why do the buildings sometimes not operate as predicted? Even after one year of operation, the building performance can drop off rapidly over the next few years. Building owners who paid for the energy modeling service to help make design decisions want to see the anticipated payback. This article will investigate several causes that have the potential to alter the energy model results throughout design, construction, and facility operation. Possible solutions to these issues will also be discussed.

INTRODUCTION

Over the past two decades, energy modeling has emerged as a key service within the building construction energy. The concept of being able to estimate a building's energy usage prior to construction is a popular idea that resonates with many building owners. However, in order to accurately estimate a building's energy usage, the energy model has to contain a large amount of input detail, including site orientation; building envelope materials; heating, ventilating, and air conditioning (HVAC) systems; and lighting systems. Additionally, several assumptions have to be made concerning the actual use of the facility and how the occupants will operate the building's systems.

To understand why an energy model may not match its respective building energy usage, the main uses of energy modeling must be identified. Each use not only requires a different level of energy modeling but also serves a specific purpose. Even though an energy model may show annual building energy usage, the model may not have been created for that specific purpose. Once the purpose of an energy model is understood, investigations begin into the reason for estimated energy consumption discrepancies.

Building Asset Ratings

This growing field for energy models uses estimated building energy consumption to predict an alphabetic or numeric rating, such as a rating of A+ or 95 out of 100. Energy models are supported by programs such as: Energy Star™; the Association of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE); Building Energy Quotient (BEQ); and the Department of Energy Asset Rating program.

Code Compliance

This type of energy modeling compares the estimated building energy consumption to that of a reference baseline building established by a code authority. The goal is to demonstrate that the proposed building design for construction complies with all the requirements set forth by the code authority.[1] Code compliance modeling also may be simplified if all the prescriptive requirements of the code are followed during the design.

Estimating Design Performance

This method of energy modeling, done throughout the design phase, typically compares multiple building design alternatives to determine the energy use through a set of building parameters such as building envelope performance or HVAC system efficiency. This energy model allows a design team to determine the amount of energy reduction of an associated energy reduction measure and the cost effectiveness of incorporating the energy reduction measure into the project. Estimating design performance is typically used for a facility that is intended to surpass the minimum code requirements or standard practice. However, in some cases the mandated energy modeling requirements do not produce an accurate energy model for utility verification purposes.

Measurement and Verification

This type of energy modeling is typically performed after the facility has been constructed and all of the equipment and parameters included within the facility are known. The model is created and compared to actual utility consumption. However, this model is required to be calibrated throughout the life of the facility to account for actual operating conditions until the results of the model yield the same results as the utility data.

COMMON DESIGN PHASE CONCERNS

The first area of focus will be on common concerns that have been identified in an energy model during the design phase of a project. By eliminating typical miscalculations or assumptions that could lead to incorrect results, the energy model more likely will be successful.

Building Envelope Assumptions

One of the first steps in constructing an energy model is to establish the building envelope. This requires calculating the heat transfer qualities of the building materials to determine the amount of heat loss through the walls, roofs, and fenestrations. In some cases, incorrect assumptions are made about how to calculate a building envelope thermal resistance value, most commonly with walls and fenestrations.

For walls, wrong assumptions typically occur with stud-framed walls. Many individuals calculate the resistance value by taking into account the indoor and outdoor air film; exterior wall finish (i.e. face brick); continuous rigid insulation if applicable; insulation between studs; and interior finish material, as shown in Figure 1.

However, the wall studs have not been taken into account, which is the location at which a thermal short circuit occurs. Tables A3.3 in Appendix A of ASHRAE 90.1-2007 provides assembly U-factors for steel framed walls. This table bases the calculation on the thickness of the steel stud, the frame spacing, and the thermal resistance value of the continuous insulation. Table A3.4 of Appendix A lists the same criteria based on wood framed walls. Tables 3.1A through 3.1D provide information on assembly U-factors for mass walls, and Table 3.2 provides information on assembly U-factors for metal building walls.[2]

The common misconception for fenestrations is using the center of glass U-value instead of calculating the overall assembly U-value. The center of glass u-value only takes into account the glazing. The assembly U-value takes both the glazing and the framing system into ac-

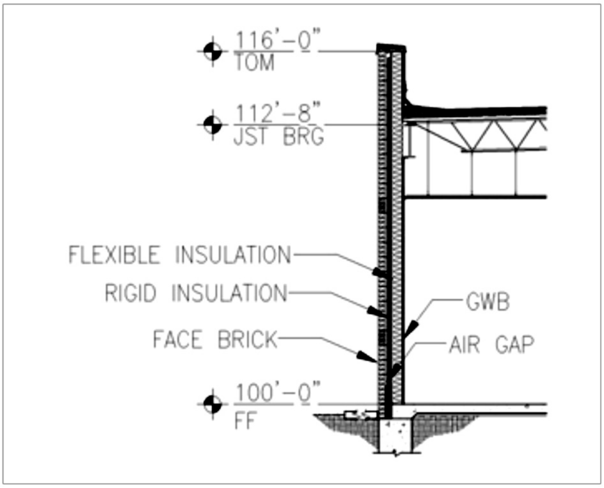

Figure 1. Wall Section

count. As seen in Figure 2, to calculate the overall assembly U-factor, first determine the percentage of glazing in the assembly. Then match the glazing percentage to the glazing U-value curve. The corresponding value at the right side of the chart is the system U-value.[3]

The energy modeler will also need to understand the difference between a shading coefficient (SC) and solar heat gain coefficient (SHGC). The shading coefficient is the ratio of solar heat gain to that of the solar energy that passes through a glazing unit. The solar heat gain coefficient refers to the solar energy transmittance through a glazing assembly. Although the SHGC has superseded the SC in the United States, some modeling software still uses the SC in their algorithms. The correlation between the SC and the SHGC is approximated in Equation 1.

$$SHGC=0.87*SC$$

Equation 1. Solar Heat Gain Coefficient Calculation

Lighting Power Densities and Controls

Although it is relatively simple to calculate a lighting power density for a facility based on a set of construction documents, it is very difficult to predict how the lighting system will be controlled. The type of lighting control must be closely coordinated with the energy modeler to ensure that the lights are controlled as intended. Lighting control can be a simple switch, occupancy sensors, or an automatic lighting control

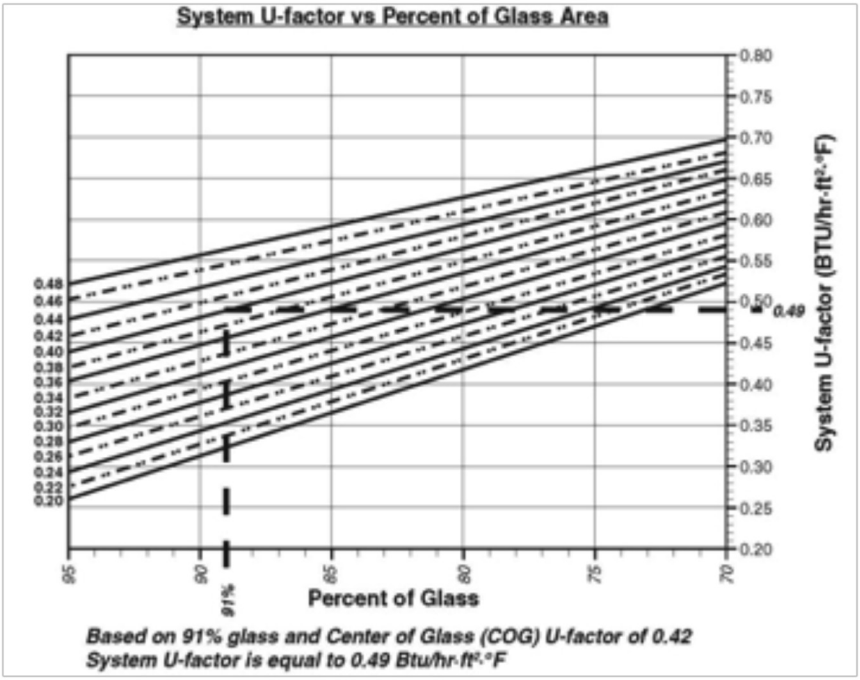

Figure 2. Glazing Assembly U-Factor

system. If an automatic lighting control system is used, the control parameters need to be included in the model, such as a step dimming or a continuous dimming system. Additionally, there are limited ways to model occupancy sensors.

Miscellaneous Loads

Although miscellaneous loads do not typically represent a large portion of the overall building energy usage, they can still contribute to discrediting an energy model. In many cases, several of a facility's miscellaneous loads remain unknown throughout the design phase and several assumptions need to be made by the energy modeler. To help eliminate an incorrect assumption, the energy model should be updated throughout the construction phase to ensure that the proper loads have been entered into the energy model. Additionally, to eliminate discrepancies on known types of equipment to be installed in the facility, it is recommended to provide cut sheets of the equipment to the energy modeler.

Occupancy Schedules

One of the biggest, if not the biggest, unknowns during the design phase of a project is how the building is going to be occupied and operated. This includes when people occupy the building, when they leave the building, how the lights are operated, thermostat profiles, and even cooking schedules. An energy modeler is required to make several assumptions based on previous projects as well as on research concerning the type of facility that is being modeled.

Other equipment schedules can be dependent upon the occupancy schedules as well. For example, if the HVAC system uses carbon dioxide monitoring as the means of controlling ventilation, as the building is loaded and unloaded with people, the amount of fresh air introduced into the facility will vary. As more fresh air is introduced into the facility, the HVAC system will have to condition the additional load. This also holds true with the lighting system. As the lighting load increases, so does the cooling requirement.

HVAC Equipment Efficiencies

This seems simple enough; however, there have been several instances where equipment efficiencies have been incorrectly modeled. Energy modeling software typically uses energy efficiency ratios (EER), coefficient of performance (COP), or kilowatt per ton (KW/ton) efficiency ratings for equipment. However, many manufacturers market smaller tonnage equipment in seasonable energy efficiency ratios (SEER) and do not give a corresponding value for EER or COP. EER is the ratio of output cooling (Btu/hr) to input power (watts) whereas SEER is typical output cooling in a given season to the input power of the same season. This means that the SEER is looking at a best-case scenario, which only occurs on certain days of the year. The energy modeler must calculate the actual efficiency of the equipment based on a measure acceptable to the software.

In addition to the base efficiencies for equipment, the software also has built in unloading curves. By selecting a piece of preloaded equipment and modifying the base efficiency, the software will continue to use the built in unloading curves in the algorithms. Figures 3 and 4 show the difference in the provided unloading curve and the actual unloading curve for a 140-ton air-cooled chiller.

Figure 3 shows that the unloading curve in the sample is very linear. However, Figure 4 shows that the actual chiller unloads more

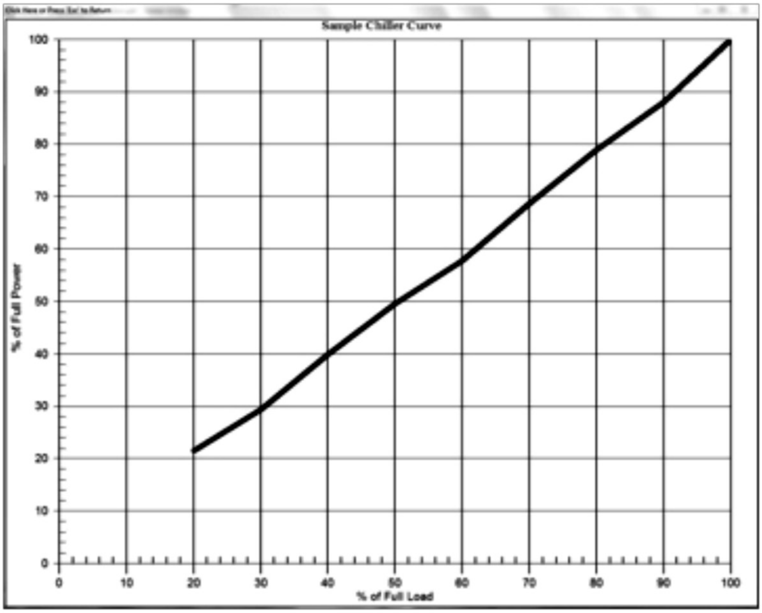

Figure 3. Sample Chiller Unloading Curve

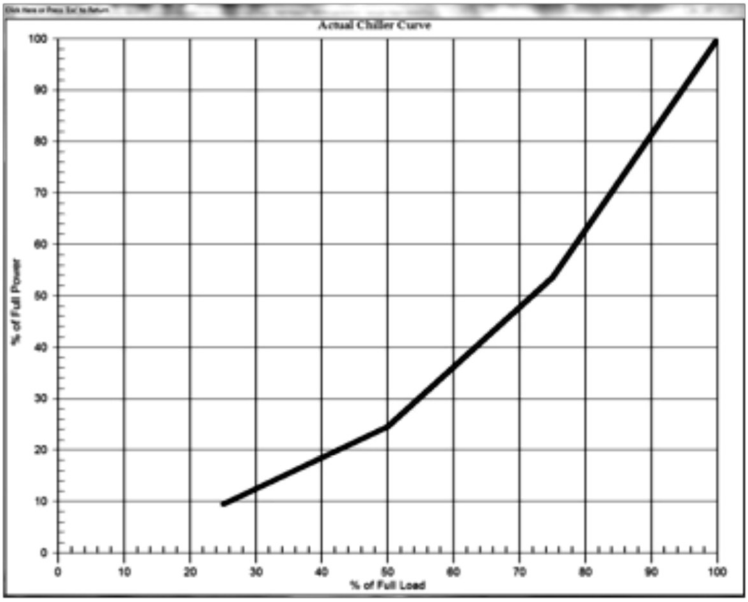

Figure 4. Actual Chiller Unloading Curve

quickly, allowing for a more efficient operation. In this case the equipment actually performed better than modeled, but it also can happen the other way around.

Utility Rate Structures

One of the final steps in energy modeling is constructing the utility rate. This includes all costs associated for energy sources including electricity, natural gas, fuel oil, district steam or water, etc. Energy modeling software typically provides a template for utility rate structures or has the means to pull the most recent average rate structures for the region. However, it is very important to use the actual rate structures to ensure that the estimated costs are correct. Although the energy consumption values may be accurate, the costs associated with those values may be miscalculated.

CONSTRUCTION PHASE CONCERNS

During the construction phase of a project, things can happen that affect the overall integrity of an energy model. These can range from improperly designed building systems to processes that eliminate some of the required building materials that give the energy model its estimated energy consumption. When a change is made during the construction phase, the energy model needs to be updated to estimate any change in outcome performance.

Value Engineering

The mission of value engineering is to reduce costs, improve quality, and increase productivity.[4] For a building design, this means reviewing equipment and systems and making recommendations for potentially more cost effective substitutions that will achieve the same result. This process has the opportunity to salvage project costs in some areas so that a project can be implemented under budget or additional project related needs can be obtained. However, some product equivalents that can meet the initial requirements of a design have been discovered to deteriorate their effectiveness more rapidly than the basis of design. This holds true in rigid insulation products, coatings for glazing, control systems, and HVAC equipment. It is recommended to research the equivalent products prior to accepting the substitutions.

Improperly Installed Building Systems

The most energy efficient system in the world could be specified for a building, but if it is installed incorrectly, it will not work. This doesn't apply just to HVAC systems; it applies to the whole building. Below is a list of areas that may cause concerns when installed incorrectly.

- Installing rigid roof insulation so that the seams do not overlap
- Installing a low-e coating on the wrong glazing surface. Depending on the building's physical location, the low-e coating needs to be installed on the correct glazing surface to either reflect the heat or allow the heat into the building.
- Motors wired so that they rotate the wrong direction. Applies to air handling units, exhaust fans, pumps, etc.
- Auto-flow valves installed backwards
- Controlling separate heating and cooling systems with the same discharge air temperature sensor
- Temperature and/or humidity has a too narrow dead band control.
- Boilers or chillers piped incorrectly
- Lack of a control system
- Lighting switching not installed correctly
- Lighting control system not installed correctly

This is by no means all of the areas that can cause energy usage related concerns. One suggestion to assist in making sure that these systems are installed properly prior to operation turnover is to utilize building commissioning. Although there is a cost associated with this service, it is typically recouped very quickly. A good commissioning agent will assist with making sure that the systems are installed properly and are operating correctly by going through a testing and equipment acceptance phase. The agent will also provide several pieces of documentation to assist in future operation of the building systems.

FACILITY OPERATION CONCERNS

The last area of focus is after the building has been constructed and turned over for facility operations. This area is of special concern for energy usage throughout the life of the building. The building systems can be designed to be the most efficient on the current market; however, if the systems are not operated properly and maintained, the integrity of the systems will decrease and the energy consumption will increase.

Training

With the sophistication of the new building systems entering the market, more advanced training needs to be provided to operating personnel. Providing a minimum of eight hours of training for a new building no longer works. The buildings are constructed and turned over to the operating staff with little time dedicated to understanding how it works, leaving them to figure it out on their own time, which is probably already taken up by other existing facilities.

Preventive Maintenance

To keep building systems operating correctly, the operations of the facility need to be based on proactive rather than reactive maintenance. This means that ongoing, regularly scheduled maintenance needs to be performed on equipment to prevent failure of the systems. If air filters are not changed frequently and become obstructed with debris, the motor has to work harder to overcome the additional static pressure. All systems should be checked and tested on a regular basis as recommended by the manufacturer. This includes operable window systems, HVAC systems, control systems, and lighting systems.[5]

Quick Fix-Its

Another issue that can arise during the operations phase of a project is using the quick fix-it approach when a problem occurs, from a small compressed air leak to roofing system repair. When these quick fix-its are applied to a system that actually needs proper repair, the resulting later repairs can cost a large amount, as indicated in Figure 5.[6]

Unfortunately, funding is not always available for a proper repair, so a more economic repair must be applied to the circumstances. However, the location of the repair should be documented so that when funding is available, the system can be repaired properly.

Behavioral Energy Change

The final and possibly the most difficult area of the operations phase related to energy savings is behavioral energy change. The most

Air Leak Cost

LEAK DIA	AIR-LOSS CFM/DAY	CFM LOSS/DAY	LOSS /DAY $	LOSS/YEAR $
1/64	.45	576	0.13	48.00
1/32	1.60	2,304	0.51	186.00
3/64	3.66	5,270	1.16	424.00
1/16	6.45	9,288	2.04	744.00
3/32	14.50	20,880	4.59	1,674.00
1/8	25.80	37,152	8.17	2,981.00
3/16	58.30	83,952	18.47	6738.00
1/4	103.00	148,320	32.63	11,904.00
5/16	162.00	233,280	51.32	18,721.00
3/8	234.00	336,960	74.13	27,036.00

NOTE: Based on 100 PSI, $0.22/MCF, 8760 hours/year

Figure 5. Compressed Air Leak Cost Chart

efficient facility could be designed and properly constructed, but if the occupants do not use it in a way that promotes energy conservation, then it will not be energy efficient. The occupants need to be a part of the energy conservation strategy so that they understand the goal and vision of the project. However, behavioral aspects will have to be addressed in order for this to happen, which include:

- We've always done it this way
- It's not my money
- Conservation doesn't make that much of a difference

One of the best things to do is find a champion for change. This individual, or team, will be charged with educating the occupants about the benefits of energy conservation and how to operate the systems. They will also be responsible for identifying areas of concern to help keep facility energy use low, such as:

- Lights remain on after hours
- Compressed air to tools remains operating
- Equipment motors remain on
- Spray valves are left open

By educating the occupants about the vision and identifying opportunities for improvement, the energy use in the facility may be more in line with the estimate use from the model.[7]

CONCLUSIONS AND RECOMMENDATIONS

It is very difficult to estimate the energy performance of a building. As discussed, the energy performance is affected by several different parameters. The energy model that was created to estimate the energy performance may not accurately reflect the actual performance of the building. This depends on the intent for which the model was created, the skill of the energy modeler, decisions made during the construction process, and how the building is operated after construction. By continually updating the energy model throughout the design, construction, and initial operation of the building, the energy model will have the potential to more accurately estimate the building energy usage.

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