REALITY IMPACTS ENERGY USE: FROM DREAM TIME TO REAL TIME FOR SIMBUILD 2012 CONFERENCE

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ABSTRACT

This paper examines how the operational performance of ten buildings in Iowa compares to design projections after at least one year of operation. The design models were created as part of the Alliant Energy Commercial New Construction program and were used to help building owners and design teams understand the potential energy savings of a wide range of technologies. Utility bills, owner surveys, and field observations were used to update the models to understand the actual energy use in these buildings and the savings realized from the energy efficiency investments.

This study describes the value of updating model projections for these ten buildings by connecting operational changes with actual building energy use through the use of energy models. The report discusses the importance of adjusting the baseline used in the comparative analysis evaluation of energy conservation measures. Operational parameters are a key component of building energy use but not governed by energy codes and often change from assumptions made during building design, construction and even the early operation period.

INTRODUCTION

This report provides a study of owner decisions made in building operations and their effect on projected savings from energy conservation investments made during design, through participation in Alliant Energy's Commercial New Construction (CNC) program. Alliant Energy is an investor owned utility company offering this program to their customers. They use an independent third party program consultant for this work in the state of Iowa.

The CNC program provides Energy Design Assistance to owners and design teams to evaluate alternative energy efficiency strategies for new and renovated building projects during design. Owners and design teams select a set of energy efficiency strategies at the beginning of the Construction Documents phase, and the program consultant verifies inclusion of the selected strategies after construction. In response to the installed energy efficiency potential, Alliant Energy offers an incentive for the implementation of these strategies to help their customers reduce energy use.

CNC program participation concludes with the payment of an incentive and tracking of projected savings based on the design-stage operational attributes. Of course, the building owner retains ongoing operational decisions. As a result, energy consumption and actual savings can migrate from the estimates due to actual occupancy, operations and weather conditions.

Alliant Energy directed an additional study to quantify how a building transitions from the "dream time" of design to the "real time" of actual operation. In order to develop this comparison, additional energy model simulations were developed, tuned for actual operation findings, then compared to the design energy models. The additional study did not affect the incentives originally provided to the owner nor did it result in any additional incentives to the owners.

DEFINITIONS

This section defines energy model simulations as they relate to this study. Some energy models were developed during design, while others were created based on operational findings. All have been compared to the actual metered use. These simulations provide consistent reference points for building design and operation as they relate to a baseline minimum standard. The following terms will be used throughout the remainder of this paper.

M1– CNC Baseline

The original baseline model developed for the CNC program uses a standard typical meteorological year (TMY2) weather file. This model follows the Iowa State Energy Code in place at the time of design: ASHRAE 90.1-1989 for this set of buildings. The model is operated according to criteria in the code and discretionary parameters not governed by the code.

M2– CNC Selected Bundle

Contains the set of energy efficiency strategies selected by the Design Team and Owner and uses a standard TMY2 weather file. This model has the same operating and code parameters as M1. This definition is provided for context but this model is not used in this paper.

M3– CNC As-verified

The as-verified model adjusts for physical design changes (implemented energy efficiency measures), but otherwise uses the same operating and code parameters as M1 and uses a standard TMY2 weather file. The difference between the M1 and M3 models is the projected savings calculated during the project's design phase.

M4– Adjusted Baseline Model

The adjusted baseline model is the M1 model updated with operational information from the survey and site visit, using actual weather from the meter period. This M4 model uses the Iowa State Energy Code in place at the time of design, ASHRAE 90.1-1989, and then is adjusted for the operational parameters and building characteristics found during the operational walkthrough.

M5– As-operated Model

This model reflects the actual building as it is operating today, given the depth of the operational survey and walkthrough. The model has the same operating parameters and weather as M4, but includes the implemented efficiency measures. The difference between the M4 and M5 models is the updated projected savings from the CNC studied measures.

Meter

Meter represents the actual utility bill for the building. This reflects the first year of operation and is represented by the M5 model.

ENERGY DESIGN ASSISTANCE MODELS

This section provides some background information on the energy models used for the CNC program. The program energy models are developed during early stages of design, in order to be timely during decision-making periods. These early models include the owner and project team's best estimates for how a building that has not yet been built will be used. They also often include default information on certain building characteristics such as outside air and supply air quantities. The State Energy Code is used to develop other baseline information. This is necessary to allow for a common starting point for all projects and also to allow the models to be developed at a time when they can be used to influence the design.

Alliant Energy wanted to study 10 CNC program buildings in detail that were now in operation for at least 1 year to understand potential operation effects on performance.

Figure 1, portrays the variables for the energy models in terms of three areas: physical design parameters; operational parameters; and weather parameters. Each set of variables contains preferences or requirements that are either known, discovered during operation or are assumed. Moreover, each of these three sets of variables interact with each other. The initial models developed during design use TMY2 weather files and the owners' best assumptions for operations. The operational parameters are held constant between the baseline (M1) and as-verified bundle models (M3). The physical design is studied in great detail and the M3 model reflects the physical (as-built) design of the building at the time of construction completion.

Ten buildings were selected for this study. These buildings were a mix of office, school, retail, dormitory and hotel buildings. The study started by weather-correcting the M3 models and comparing this to the meter. This was done to help Alliant Energy understand which buildings might be showing a large difference in actual energy use compared to the expectation set by the models and which projects were showing relatively minor differences.

Differences were to be expected, given the effect of the "operations sphere" of decision-making by each building's owner. Following this initial comparison, a more detailed study was done, and the M4 and M5 models were created to better understand these "operations sphere" differences.

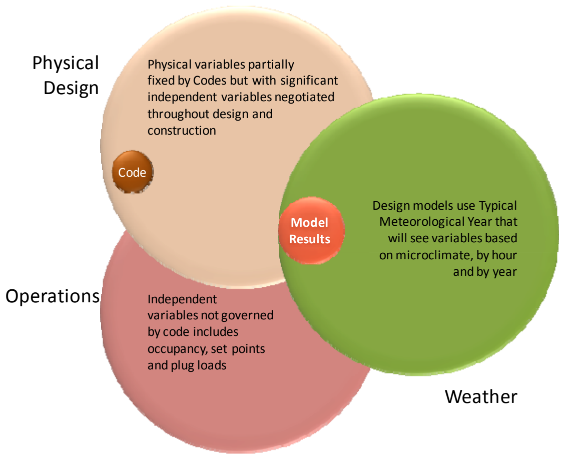

Figure 1: Energy Modeling Variables

In general, the study design included:

- Projects that exhibited both strong and weak correlation between projected and actual energy consumption
- Projects that exhibited a wide range of space use and therefore operational variables

These two selection criteria allowed the study to gather the most knowledge while keeping the effort within a reasonable study budget. The initial correlation of the M3 models and the meters was within 98% of the total site energy use; this is a 2% difference between the model and the site energy use. The building meters showed 16% more electric use and 12% less natural gas use in total than the M3 models. Based on these initial comparisons, it was determined that the overall population energy use showed strong correlation with the forecasted energy use. However, there were individual projects that showed deviations from the model which warranted further investigation.

The comparison of design models (M3) to metered use is a good benchmarking exercise to help understand the potential value of creating updated models based on actual operation, but in itself is not a fair comparison. When this comparison is made, the “operational sphere” from Figure 1 is no longer constant. Since there is no energy code for operational characteristics, direct comparisons should not be made between actual metered building performance and projected results from a model created in design phases.

The goal of the detailed study was to better understand the operational differences and to determine the actual energy savings for these buildings when the operations are updated. As such, the study approach was to rely on a building walkthrough, construction documents and conversations with the building operators to create the M4 and M5 models. The strong initial correlation found through the comparison of the M3 model to the meter indicated that detailed audit type measurements were not needed for this sample of projects.

The detailed study process consisted of the following steps.

- Engage the building owner via a survey to confirm general building operational decisions:
  - Hours of operation and occupancy by area
  - Lighting systems control sequences
  - Mechanical systems control sequences
  - Actual operating temperature set points and schedules
  - Equipment plug load survey and schedule
- Analyze survey results to develop energy model inputs
- Conduct a site visit to confirm the survey results and gather observational field notes
- Revise the energy model to create as-operated models based on survey and site visit results
- Develop a findings report for the population of projects and each building

The remainder of this report provides findings and conclusions for the population of projects, as well as more detail on a few case study projects that exhibit varying levels of correlation.

SUMMARY RESULTS

The project population as a whole was studied to see how close the overall M5 models were to the meter. This population was looked at in terms of overall electricity and natural gas. Table 1 below shows the results for each.

Table 1 Population Annual Consumption Comparison

	ANNUAL ELECTRIC - MWH	**ANNUAL NATURAL GAS - THERMS**
M5	10,946	129,119
Meter	10,911	115,982
Percent variation from M5	-0.3%	-10.2%

The electric results in Table 1 show over the study population excellent correlation with the meter, within .3%, meaning that the operational models predict 100.3% of the consumption shown by the design phase models.

Not all of the projects had natural gas meters associated with them and the natural gas proved to be more difficult to correlate to the meter for this population of projects. As shown in Table 1, the total population showed the M5 models predicting 10.2% more natural gas use than the metered use.

Natural gas use is generally more dependent on outside air conditions for the heating systems making it more difficult to understand without more detailed monitoring than was called for in this study. In addition, service water heating for this population of projects used natural gas systems. Without more detailed measurements this is difficult to understand, especially in hotel and dormitory building types.

The difference between the M4 adjusted baseline model and the M5 as-operational model is the overall kWh savings associated with the energy efficiency measures incorporated in these ten projects.

	ANNUAL ELECTRIC - MWH	ANNUAL NATURAL GAS - THERMS
Savings calculated during design (M1 – M3)	7,469	-18,135
Updated savings (M4 – M5)	7,427	-1,788
Percent change from design savings	-0.6%	-90.1%

Table 2 Population Annual Savings Comparison

Table 2 shows the impact on savings after the models have been adjusted to account for the actual physical design, operational parameters and weather. The models are showing that the actual electric savings is 99.4% of the original predicted savings. On the natural gas side, the population as a whole was expected to use more natural gas than the baseline. This results from strategies that decrease heat to the space; i.e. lighting design improvements and controls, requiring additional heating from the natural gas systems. In this case while there is a significant difference between the predicted savings and the updated savings, it actually shows that the impact on natural gas was less severe than expected.

While the overall study population on the electric side is very close for M5 to the meter and savings of M4-M5 is very similar to the original design savings prediction of M1-M3, there are still variations within the ten projects.

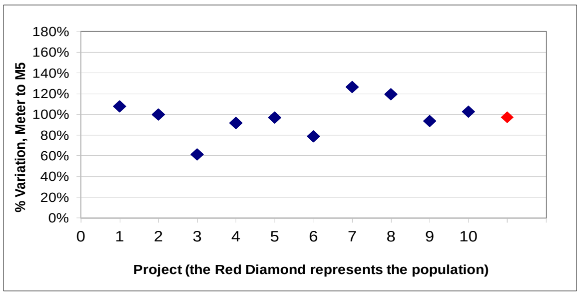

Figure 2 – Site Energy Consumption Scatter Plot, Meter to M5

Figure 2 shows the variation of the population in terms of the electrical consumption correlation of the M5 as-operated model to the meter. A 100% correlation indicates that the meter matches the M5 model. The projects showing the greatest variation are the residence hall (#3), hotel (#6), one school (#7), and one office (#8). The following pages provide case studies concentrating on four projects; school (#5), office/lab (#9), retail (#10) and hotel (#6) from above. Three show good correlation after calibration, but in the initial benchmarking comparison showed moderate, moderate, and weak correlation respective to the meter and one project, the hotel, which continues to show weak correlation even after calibration.

CASE STUDIES - OVERVIEW

For each of the case studies, monthly meter data for electric and natural gas (where projects were served by Alliant Energy), was gathered for a 12 month period. Weather data was collected for the same 12 month period from the closest NOAA weather station. The weather station data provided updated temperature, humidity, pressure, wind conditions (speed and direction), and precipitation. Cloud amounts were derived from the provided sky conditions. DOE2 was allowed to calculate the ASHRAE clear sky model and the cloud inputs derived from the NOAA site. This approach was used as solar data was not available, the savings from daylighting controls and perimeter heat gains were checked against the original files to verify the validity of the approach. A custom weather file for use in DOE2 was then created, matching the weather file used in the simulations to that of the meter period.

Statistical indices provided in ASHRAE Guideline 14 were used to evaluate the deviations between the metered data and the M5 model. The coefficient of variation of the root mean square (CVRMSE) was computed to measure the fit of the simulated M5 model. Part of this calculation involved squaring the difference between M5 and the meter for each month such that offsetting errors were eliminated. A lower CVRMSE indicates a stronger correlation and the guideline recommends a maximum value of 15%.

Although this index is geared towards a project by project analysis, an average CVRMSE for the population of the projects was calculated. For electricity consumption, the meter-weighted average CVRMSE was 14.6%, within the 15% guideline threshold. The average CVRMSE for natural gas consumption was 49.5%, exceeding the guideline. Calibrating natural gas consumption was found to be more challenging and examples of these difficulties are discussed in the Case Study section.

Calculating the CVRMSE also allowed for the energy savings uncertainty to be determined for each project. ASHRAE Guideline 14 recommends an uncertainty fraction of 50% or lower. These fractions are calculated at a 68% confidence level as the compliance guidelines require. The savings uncertainty results are discussed in the following Case Study section.

.CASE STUDY – SCHOOL, PROJECT 5

This project is a 70,000 sq. ft. addition and renovation of a middle school in Eastern Iowa.

During the construction work, a second utility meter was added serving only the addition and renovation areas. Having this dedicated meter allowed for inclusion of this project in the study.

During the design phase modeling a number of energy conservation measures were studied. The school decided to implement ground coupled water to air heat pumps with an energy recovery ventilator to supply outside air to the spaces. No natural gas was used in the building. Demand controlled ventilation through the use of CO_2 sensors was used to control the amount of fresh air in relation to building occupancy. Dual level switching and an efficient lighting design were used throughout the school, however no occupancy sensors were implemented. The school officials believed the teachers would turn off lights when the spaces were unoccupied.

During the design phase the owner expected the building would be open from 6:30am to 11:00pm, with classrooms empty by 4:30pm. The gym would be used until 8:00pm. The school year would be mid-August through early June. A computer lab was designed for the students with regular desktop computers.

The building walkthrough revealed that the classrooms are used fewer hours, 7:30am to 3:00pm and all cleaning is completed by 7:00pm, rather than the expected 11:00pm. The gym and commons areas hours are the same as the classrooms, except on 3 nights per week renters use the space from 7:00pm to 8:30pm. The whole building is empty by 8:00pm. The computer lab was renovated into another classroom. Laptop carts were purchased instead for the students' use. The laptops are charged each night in the original high school, thus their energy use does not show up on this meter. Temperature setpoints were found to be similar to the model expectation of 72 degree heating and 76 degree cooling with a 2 degree setback on each during unoccupied periods. The model had anticipated a 4 degree setback.

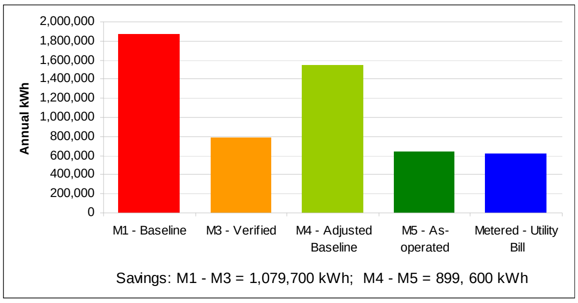

Figure 3 – School Total Annual Electric Consumption

As shown in Figure 3, the M5 model closely matches the annual consumption of the meter. Both the M4 adjusted baseline and the M5 as-operated model incorporate the survey findings. With the decrease in plug loads and hours of operation, the overall result is a decrease in the expected energy consumption of the building. This also resulted in a slight decrease in the overall energy savings associated with the implemented strategies, when the value of M1-M3 is compared to the value of M4-M5.

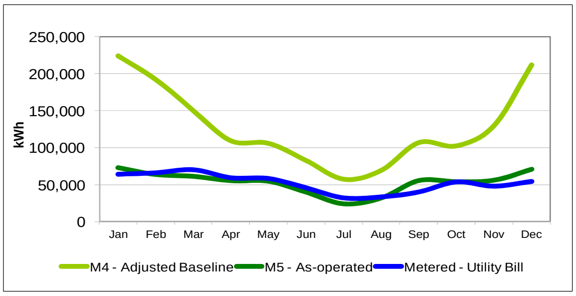

Figure 4 – School Monthly Electric Consumption

Figure 4 shows the monthly electric use of the models as well as the meter. This shows that again on a monthly basis the M5 as-operated model compares well to the meter. The largest differences occur in September at the start of the school year.

Based on ASHRAE Guideline 14 the savings uncertainty in terms of annual electricity is +/- 11% of the total savings, which is compliant with the Guideline.

CASE STUDY – OFFICE/LAB, PROJECT 9

This project is a 120,000 sq. ft. single story office and lab building in Eastern Iowa.

During the design phase, the Owner implemented an efficient envelope with increased wall and roof insulation as well as exterior building shades. Automatic stepped daylighting controls were implemented throughout the office areas. Occupancy sensors and an efficient lighting design were incorporated throughout the building. The HVAC system used VAV air-handling units with hot water and chilled water coils. Hot and chilled water was provided via a separately metered central plant, the energy used to produce this hot water and chilled water is on a separate meter and not included in the model. Thus only electricity was metered at the building. VFDs were implemented on all fans and pumps and demand controlled ventilation was designed for the offices.

During design, the owner, expected the building would be occupied 7:00am to 6:00pm Monday through Friday. Some labs would operate through the night depending on experiments. The labs were expected to have a peak equipment load of 60 kW. The owner expected 400 full time occupants.

The building walkthrough determined that the building is actually used more that expected, from 6:00am to 6:00pm Monday through Friday and at about 10% occupancy from 8:00am to 5:00pm on Saturday and Sunday. The building now has 530 full time occupants. The peak lab equipment load is now 92 kW. Exterior lighting was also on the building meter, but not included in the original design models. This load was added to the M4 and M5 models. Airflow quantities and outside air quantities were updated to account for the additional occupants and equipment.

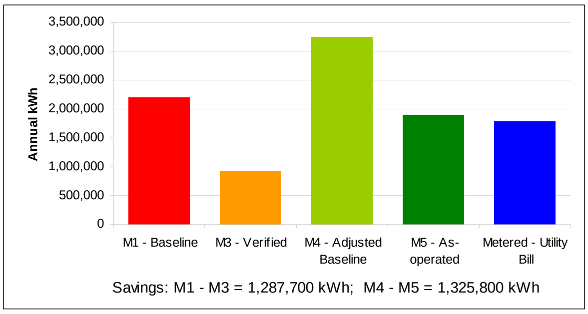

Figure 5 – Office/lab Total Annual Electric Consumption

As shown in Figure 5 and as expected from the walkthrough findings, the overall energy use of M5 as-operated and the meter are greater than the design M3 model. However, as the energy use has increased, the savings associated with the strategies has also increased. The difference between M4 and M5 is now larger than that of M1 and M3, resulting in additional savings. Again, the overall energy use of the meter correlates well with M5.

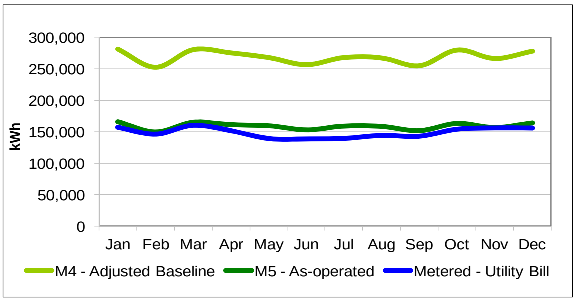

Figure 6 – Office/lab Monthly Electric Consumption

Figure 6 shows the monthly profile of the models compared to the meter. M5 shows increased energy consumption compared to the meter in the summer months. Further detailed measurements may help to explain this, however based on information gathered, a theory is that there are fewer weekends worked and fewer overnight lab experiments in these months. Even with these differences, the savings uncertainty is within ASHRAE Guideline 14 compliance. The savings uncertainty in terms of annual electricity is +/- 7% of the total savings. Note that this uncertainty is for the modeling only, any uncertainty associated with the owner's measurement of the peak lab equipment was not available and thus not included in this calculation.

This project is a strong example of why the initial comparison of the meter to the M3 as-verified design model may lead to the wrong conclusion. The Owner has increased the use of the building due to a growth in business. This has led to an increase in energy use, but as shown here, does not indicate an incorrect model or an inefficient building.

CASE STUDY – RETAIL, PROJECT 10

This project is a 100,000 sq. ft., single story, big box retail building located in central Iowa. The building is open 24 hours a day

A number of energy conservation measures were studied and incorporated during the design phase, including dimming daylighting controls for the sales floor, occupancy sensor controls for back of house areas and efficient lighting design throughout. High efficiency constant volume single zone DX cooled rooftop units and outside air controls were incorporated.

The owner anticipated the store being operated 24 hours a day with tenant type areas (photography, food court, etc. . .) being open 12 hours a day.

The building walkthrough determined that the pharmacy and deli areas were not open 24 hours. The electronics department was found to have additional plugs loads and there was a larger grocery section with increased refrigeration and process loads for cooking.

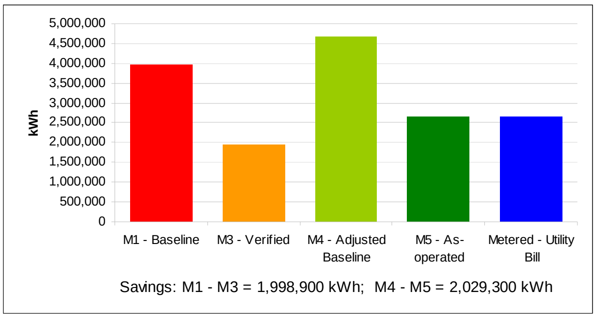

Figure 7 – Retail Annual Electric Consumption

Figure 7 shows that as expected with the increased loads, the building is using more electrical energy, resulting in a slight increase in savings for the M4-M5 models compared to the original design prediction of M1-M3 when the baseline is also adjusted for the operational parameters. Again, excellent correlation overall between the M5 model and the meter.

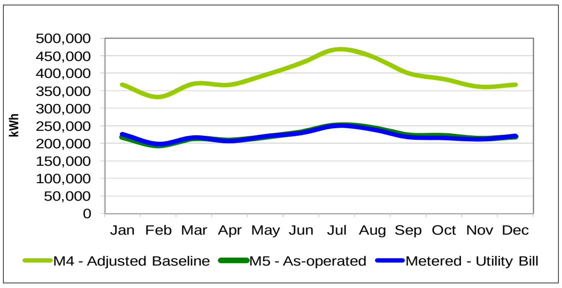

Figure 8 – Retail Monthly Electric Consumption

Figure 8 shows the monthly profile of the models and the meter. Here, M5 tracks very well with the meter, in fact, M5 is not visible on the graph as the correlation is so similar to the Meter.. The savings uncertainty, as calculated using ASHRAE Guideline 14, also reflects this strong correlation. The uncertainty in electric savings is +/- 2% of the total savings. The strategies implemented by the owner help to level out the summer use creating a more even load profile for the building.

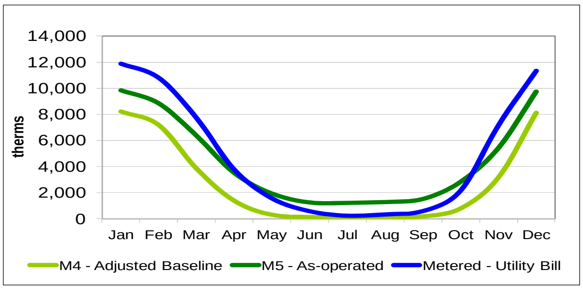

Figure 9 – Retail Monthly Natural Gas Consumption

Figure 9 shows the monthly natural gas profile. Note that since the gas use was minimal for this buildin only the monthly profile is shown. Space heating and service hot water including dishwashing are part of the building's natural gas use. Here the M5 model and the meter are showing increased natural gas use compared to the M4 baseline. This is likely due to the reduction in lighting energy having to be made up in space heating. The M5 model and the meter do not correlate as well as on the electric side, although they do follow a similar pattern. This is most likely due to the service hot water loads. These are likely to reach full correlation with more detailed measurement and investigation. A savings uncertainty analysis shows +/- 15% variation in annual gas savings. Although the correlation shown in Figure 9 does not appear as strong, the savings uncertainty falls within ASHRAE Guideline 14 compliance limits.

CASE STUDY – HOTEL, PROJECT 6

This project is an 80,000 sq. ft. four story hotel in Western Iowa. During the design phase a number of energy conservation measures were studied and incorporated into the design. These include an efficient envelope, occupancy sensor controls in conference areas and back of house spaces, and efficient lighting design throughout. Mechanical strategies include 13 SEER PTAC units in the guest rooms, water loop heat pumps with boiler and cooling tower for the common areas, energy recovery for the outside air and 83% efficient service hot water heaters.

During the walkthrough, test and balance reports were provided showing a number of changes relative to the design. Fans operate continuously for all areas, with ventilation rates always at occupied levels. Thermostats hold continuously at 76 F for cooling and 72 F for heating, with no setbacks when guest rooms are empty. Fan statics are in general 1" higher than expected on all ERVs. Pump head on the cooling tower loop is higher than expected. Kitchen make up air is also greater than expected. Exterior lighting was not factored into the original model, but added to the M4 and M5 models. Reservation information over the 12 month period was provided and used to update schedules.

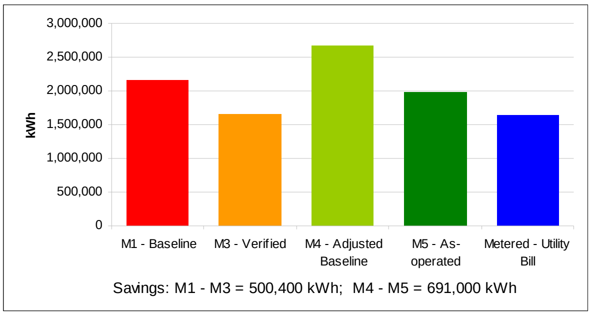

Figure 10 – Hotel Annual Electric Consumption

As shown here, the meter and M5 models do not match up as closely as the other case studies. The nature of a hotel with variation in occupants resulting in variations in guest room loads such as lights, TVs, and other equipment makes it difficult to align models based only on a walkthrough and survey.

As shown in Figure 11 below, the M5 model follows a similar monthly pattern to the meter. This suggests that there is a difference in the base load between the models such as equipment. Detailed measurement and investigation that was outside of the scope of this study would assist in correlating the models. Using Guideline 14,the annual savings uncertainty of +/-24% meets guideline compliance. It is notable that the electricity savings uncertainty is greater compared to the other projects presented.

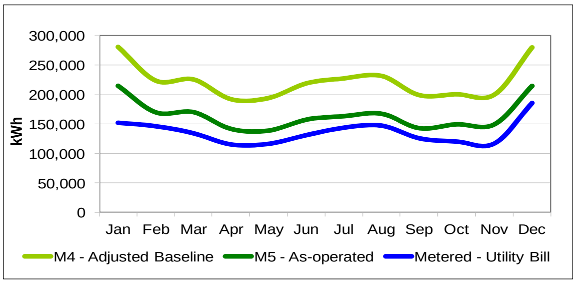

Figure 11 – Hotel Monthly Electric Consumption

Natural gas meter information was also available for this project.

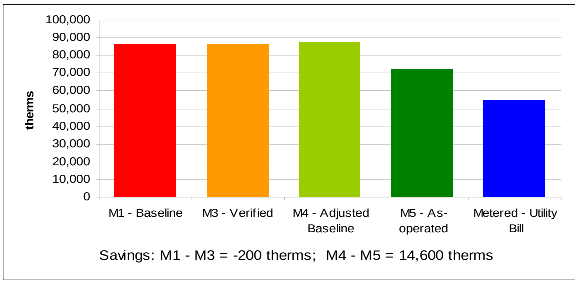

Figure 12 – Hotel Annual Natural Gas Consumption

Figure 12 illustrates that similar to the electric side, the M5 model is showing more natural gas use than the meter. Without detailed measurement in a hotel facility with varied kitchen equipment and shower usage, the natural gas use was challenging to update.

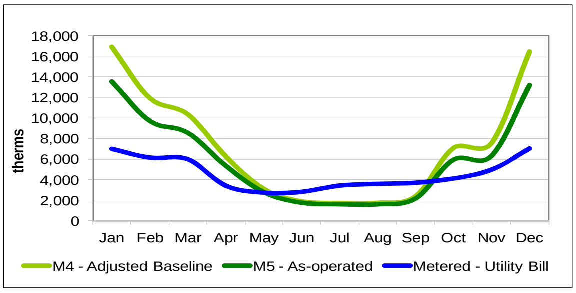

Figure 13 – Hotel Monthly Natural Gas Consumption

Figure 13 illustrates that the meter is showing less natural gas use in the winter months and more natural gas use in the summer months. The increased summer use compared to the model is likely due to service hot water use in showers and kitchens. The HVAC system may also result in some of these differences as individual users have control of thermostats within the various guest rooms. The uncertainty analysis reflected a weaker correlation for gas consumption on this project. The annual savings uncertainty for gas consumption saving is +/- 76% of the total savings, which is higher than the 50% limit recommended by Guideline 14. These findings indicate that there may be opportunity to fine tune the model to achieve better calibration.

CONCLUSION

A number of variables contribute to an energy model and the physical building and design is only one set of key variables. If changes in weather or operational parameters such as occupancy are not accounted for in the energy models, comparing them to meter data is not a fair comparison and will likely lead to the wrong conclusions.

Overall, when updated to reflect actual weather and operations, the baseline (M4) and as-verified models (M5) provide good estimation of the actual energy savings and metered energy use as determined by industry standard statistical guidelines.

The largest impacts on the models were from the "operational sphere." Over the study population as a whole it was found that the average building operated 10% longer than expected in design with a 10% increase in plug loads.

The models that utilized ground source heat pumps or had central plants showed the best correlation when updated for the actual conditions.

If detailed models are created during the design phase using relatively limited metering information it may allow for creating actualized models that accurately reflect a building's true operation. These models may then be used to study additional savings opportunities going forward. Furthermore, the detailed models created during the design phase can be useful to assist the owner with energy efficiency design and operational decisions.

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