CALIBRATED SIMULATION OF AN EXISTING CONVENTION CENTER: THE ROLE OF EVENT CALENDAR AND ENERGY MODELING SOFTWARE

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ABSTRACT

This paper discusses the calibrated simulation procedure developed for the retrofit of a large convention center building. One of the critical tasks is the development of building operating schedules based on event calendar. The model adapted adjusted-ASHRAE hourly operating schedules for event, non-event and Move-In-Move-Out (MIMO) days, and used the event calendar and actual occupancy data. This drilldown approach of replicating event calendar proved effective in model calibration. Calibration revealed that the energy model had a monthly variance of less than 8% for electricity. The calibrated model was used to evaluate an array of Energy Efficiency Measures (EEMs).

INTRODUCTION

Buildings consume about one-third of world’s energy. In the U.S., buildings consume 68% of electricity. Retrofitting of existing buildings is promoted by the U.S. Department of Energy by awarding research funds to organizations as tax incentives. Several businesses have taken the opportunity to conduct, review and implement such capital projects to benefit their triple bottom-line. Retrofit of existing buildings commence with calibrated simulation model. The calibration of simulated model to actual energy use is the first crucial step in the development of a benchmark model which may further be used to develop EEMs for higher energy savings. Building energy modeling software aids in this rigorous calibration process.

Several calibration approaches exist; most widely used techniques are the ASHRAE Guidelines 14-2002: Measure of energy and demand savings (ASHRAE Standards Committee, 2002), M&V Guidelines for Federal Energy Projects (FEMP, 2008) and the International Performance Measurement and Verification Protocol (IPMVP, 2002). The acceptable tolerance ranges (coefficient of variation of the root mean squared error) for monthly data calibration per IPMVP, FEMP, ASHRAE-14 are +/-5%, +/-10% and +/-15% respectively.

Hourly data calibration method is an intensive on-site audit procedure with detailed modeling requirements and numerous model iterations is also available. This method involves more time and cost to calibrate, especially to a 5% level of accuracy. Some of the notable calibrated projects include the calibration of science museum (Chimack et al., 2001), office buildings (Pedrini et al., 2002; Norford et al., 1994), high-rise commercial buildings (Pan et al., 2007), etc. Yet, modeling of large-scale convention center buildings using detailed operating schedules was not discussed in literature.

Developing energy models of existing buildings involves extraction, organization, and application of existing building data as model inputs. Caution is required when modeling existing buildings that may comprise of several buildings, especially when they are built during different time-periods. This is due to the fact that the required minimum building thermal envelope, system, and ventilation requirements may differ between portions of building. Besides, the building may not be used the way as-built and/or updated drawings may read. Only detailed, on-site audit may provide necessary clarity and develop inputs for energy modeling. In some cases, adjacent buildings may be using Chilled Water (CHW) from buildings that are under investigation which can only be ascertained during an on-site audit. Moreover, on-site audits may be helpful to establish temperature setpoints, the effect of sensor activations, operating schedules, fan operation, chiller management, temperature resets, etc. Thus, the necessity of completing a detailed building energy audit prior to start of constructing models cannot be understated. However, owing to time constraints, energy model may be developed simultaneously while on-site audits are being conducted, which may pose a problem for model accuracy unless updated are implemented in a timely fashion.

Preparing an energy model for an existing large structure is tedious as it involves multiple, often times iterative and repetitive input of data. This is true if the building is not a high-rise, rather a complex, multi-use building. The possibility of introducing errors significantly increases in such cases. Several approaches may be used to alleviate such errors, the significant being - (a) where two or
more energy modelers work on the same project dividing tasks among themselves such as parsing data from documents, constructing geometry, performing auxiliary calculations, etc., including setting up an in-house Quality Control (QC) procedure to check the individual team members’ input, or (b) where two or more energy modelers construct portions of a large building, especially when they are distinct and serve different functions, and combine them together to form the whole building model.

Modeling in parts and then combining to form the whole building energy model is well suited for buildings that have individual energy meters. Such an approach will benefit in locating modeling issues in less time. Besides, individual virtual energy use meters can be integrated in the model and calibration can be performed at individual building level if measured data is available at that granularity. This will remove any impending errors related to whole building model calibration. The combination of both the approaches mentioned above may offer the best solution.

Among other building types, convention centers are complex enough to model owing to both their mix of spaces and occupancy patterns. Moreover, these buildings consist of event spaces such as exhibit halls, conference rooms, etc.; non-event spaces such as administrative office spaces, etc. Additionally, there are spaces that are primarily used for loading before and after the events. Thus, the occupancy pattern will determine the occupancy, lighting, and other related schedules. The use of actual event calendar including, but not limited to, the number of events held, the location of events in the building, the number of occupants attended each event and other support services requested, etc., play a vital role in the modeling work of convention centers.

As a first step for convention center buildings, detailed understanding of the event calendar and actual occupancy data is crucial. Using this data, the ASHRAE hourly operating schedules for event, non-event and MIMO spaces are adjusted. The relevant data is then normalized and parsed to create weekday, weekend, and holiday schedule types. Essentially, the event calendar is transformed into detailed operating schedule. Similarly, the lighting and equipment schedules can be developed for the project. As expected, in any energy model, the operating schedules are a major assumption in the baseline model.

National attention and support to building energy efficiency acted as a catalyst for rapid improvements in building energy modeling software applications and other related programs. However, in spite of the existence of well structured IFC schema, the energy modeler has to still depend on several auxiliary programs either to pre- (to determine inputs) or post-process (to analyze results). This is especially true for large-scale retrofit projects. Convention center buildings are no exception.

This paper discusses the modeling of a convention center using a combination of software and auxiliary calculations. One of the critical tasks is the development of building operating schedules based on event calendar. The model adapted adjusted-ASHRAE hourly operating schedules for event, non-event and MIMO days and used the event calendar and actual occupancy. This drilldown approach of replicating event calendar proved effective in model calibration. The models were calibrated within the limits of monthly data calibration requirements. The calibrated model was used to evaluate an array of EEMs.

CASE STUDY OF MODELING AN EXISTING CONVENTION CENTER

The convention center is comprised of three buildings totalling approximately 111,483 m² (1.2 million ft²). The buildings were built during different time-periods, between 1970 and 2000. In order to perform detailed energy use analysis of the facility, two separate energy models were developed using eQuest v3.64, the first represents building B1, and the second represents the combined buildings B2 and B3 (hereo referred to as “B2+B3”), into one unit. The physical boundary of these two buildings rendered it easier to develop two individual energy models. Subsequently, these two separate models were joined together to represent one large, single structure. However, separate virtual electricity meters were introduced to all three individual buildings to evaluate energy use independently. Such an approach allowed detailed investigation during calibration of energy model.

Model Inputs and Assumptions

Model input data were obtained from as-built drawings, retrofit specifications, sequence of operation, etc. Since any changes to the documented inputs and/or assumption may have a significant impact on the simulation results, the model inputs were confirmed with project engineers. The following discusses the model inputs and assumptions.

The project is located in San Francisco, California. The thermostat setpoints for cooling and heating are 23.8°C (75°F) and 20°C (68°F) respectively. The opaque construction assembly parameters were determined from the architectural plans and their thermo-physical properties were based on calculations from ASHRAE 90.1-2007, Appendix A (ASHRAE, 2007). The space-by-space lighting type and power were determined from the electrical plans and subsequent lighting retrofit schedules. Hourly lighting schedules were determined for event spaces and non-event spaces based on factoring the building operating schedule into the typical hourly operating
schedule from ASHRAE 90.1-2007. The schedule for event space is a modified version of ASHRAE 90.1-2007, Table G-E-Assembly Lighting. Equipment Loads were estimated as 25% of total loads, as the actual loads were not known. Based on the above, B1’s equipment power density was calculated as 18.29 w/m² (1.7 w/ft²), while B2+B3’s at 12.91 w/m² (1.2 w/ft²). Equipment hourly operating schedule have been assumed to be the same as lighting.

The buildings used air-handlers with reheat systems. B1 used around 100% outdoor air as compared to single-digit percentages in B2+B3. Additionally, B2+B3 had a number of spaces with air volume control through inlet vane controllers in the fans. This adjusts the motor energy use depending on the air volume requirements. B1’s CHW system used a constant primary-variable, secondary pumping system with three 700-ton centrifugal water chillers; three 1.92 kW (20 hp) constant speed primary pumps; two 125-hp secondary pumps with Variable Frequency Drives (VFDs); three 29.84 kW (40 hp) constant speed condenser pumps; and three cooling-tower cells with 55.95 kW (75 hp) fans installed. De-rated chiller efficiency was calculated as 0.70 kW/ton. B2+B3’s CHW system has a constant primary system with two 780-ton centrifugal water Chillers; two 111.9 kW (150 hp) constant speed primary pumps; two 29.84 kW (40 hp) constant speed condenser pumps; and four cooling-tower cells, each with a 14.92 kW (20 hp) fan. De-rated chiller efficiency used for B2+B3 was calculated as 0.6991 kW/ton. Both condensate-enabled and electric water heaters were used. SHW process load was determined using ASHRAE recommended methodology for calculating hot-water flow rate. In this method, the total number of fixtures in the toilets were used to determine hot-water flow rate. For event spaces, the schedule was based on a modified version of California Title 24 (CA Title 24, 2008) Non-Residential Occupancy Schedule, Table N2-5, related to assembly occupancy. The modification was required as the event spaces, during event, since these spaces were operated from 6am to 10pm.

**Event Calendar to Occupancy Schedules**

Year 2007 measured energy use data was used for calibration. This was partly due to the availability of utility data sets for electric, gas and steam. Further, with the official recession period in the United States starting in December 2007, it was assumed that subsequent periods would not be a representative sample of measured usage of the building. The building operating schedule was developed by analyzing the year 2007 event calendar and parsing the number of events, MIMO-days and non-events, normalizing the parsed data into week-days, weekends, and holiday day-types, and using ASHRAE hourly operating schedules, adjusted to the building operating times.

Figure 1 (see page 7) shows the monthly events in year 2007 that was obtained from the actual event calendar. As can be seen in the figure, there is a significant decrease in events for the months of April, June and December. Moreover, the number of events per month in all of the three buildings were similar; prompting a simple averaging of the datasets.

Figure 2 (see page 7) shows the comparison of measured and simulated events per month for year 2007. Based on the actual data, the number of events per week during which these exhibit halls were occupied were identified. While a simple rounding-off to nearest whole number was used for some months; the other months required adjustment to match to utility data.

Figure 3 (see page 7) shows the necessity for an “adjustment factor,” the ratio of MIMO-days to events, introduced in all operation schedules to remove the effect of MIMO-days and to reflect only actual events in a month. This, then, was used to develop detailed day, week and annual schedules in the simulation software. The sensible and latent heat gains from occupants have been determined from Table 3, Chapter 28 - ASHRAE Handbook of Fundamentals (ASHRAE, 2009).

While, this method has captured the behavior of the building in year 2007, it does not represent the three unknown energy end-use variables, namely occupancy, lighting and miscellaneous equipment loads and usage during the year. However, the application of actual event calendar and actual occupancy prompted necessary calibration of simulated and measured energy use data.

**Calibration**

While the building energy use was estimated based on the data parsed from as-built drawings, retrofit specifications, event calendars and sequence of operation documents, the actual energy use data sets were obtained from the utility. They were available in half-hourly intervals, total monthly, and total charges (in US$).

For this project, monthly calibration method was used by comparing simulated energy usage to the monthly utility usage. Since this building’s primary usage is related to hosting exhibitions all-year around, the calibration of energy model focussed on the role of event calendar, specifically for the year 2007, which is discussed below. Electricity use is significantly larger as compared to steam and natural gas combined. While all the buildings use electricity for lighting, equipment and cooling systems, steam is used in the B1 and portions of B2+B3 buildings for space heating purposes; while condensate- based steam is used for SHW purposes.
The error in monthly energy use was calculated as the monthly percentage difference of measured and simulated data. The error percentage for the simulated model is higher than the ASHRAE-14 acceptable tolerance range for the month of April and June for the North Building. The error percentage for the simulated model is lower than the ASHRAE-14 acceptable tolerance range for the month of April and July for the South Building. The error percentage for the simulated model is within the ASHRAE-14 acceptable range of ± 15% for all the buildings combined, except for the month of June. The following reasons have been assumed for the higher error percentages.

Comparing the measured energy use and simulated data for the combined buildings show that the variance percent is less than 8% for electric energy use comparison. However, this result is due to the offsetting of the variances of each of the building when combined together. The energy simulation results show that the modeled B2+B3 energy usage is 6% higher than the measured usage (per the utility bills); and the B1 energy usage is 12% less than the measured performance. Figure 4 (see page 8) shows monthly electricity energy use by energy consumer type. These monthly illustrations show significantly lower energy use for the months of June, August, and December. This is due to fewer events being conducted during those months.

**Simulated Energy Use Data**

Figure 5 shows the electrical energy use by energy consumer type for the calibrated model. Figure 6 shows the breakdown of energy use.

![Figure 6: Electrical Energy Use by Energy Consumer Type (units in kWh x 1000).](image)

The building Energy Use Intensity (EUI) for the Benchmark Baseline model was computed by converting all annual energy use types into a common energy unit and then dividing by building area. The building EUI as determined by simulation was 654 MJ/m² (57.70 kBtu/ft²-yr) while the actual EUI was 651 MJ/m² (57.41 kBtu/ft²-yr). To-date, there are no established industry benchmarks for exhibition buildings. However, the building EUI is lower as compared to the published data for other building types, particularly the “assembly” building type with site EUI at 1.016 GJ/m² (89.59 kBtu/ft²-yr) (US DOE, 2010). Among others, one major reason for lower EUI is due to significant reduction in envelope loads owing to the major portion of the building located below ground, with few exceptions as stated earlier.

**Calibrated Model and EEMs**

Using the calibrated model, several EEMs were analyzed to estimate energy and demand savings. The EEMs included Demand Control Ventilation (DCV), improved sequence of operation utilizing optimized start controls, expanding thermostat dead-band, combining two independent chillers together for improved part load performance, free cooling using water-side economizer, VFD for fans and pumps, solar thermal systems, free heating using steam condensate, etc. The performance of the individual EEMs were analyzed and compared with benchmark model. Only notable EEMs are discussed below. The savings (or penalty) will vary from actual scenarios when underlying model assumptions and conditions vary.
Waterside Economizers, When Indoor Conditions are not Met with Chillers: For this EEM, the airside systems were run using a waterside economizer. The Chillers are turned off 100% of the time to evaluate the building energy use and related unmet (undercooled) hours. The heat exchanger used has an efficiency of 80%. An electrical energy savings of 20% was observed over the benchmark.

Waterside Economizers, When Indoor Conditions are Met with Chillers: This EEM is similar to one discussed above. However, the Chillers are turned on when condenser water cannot be used to meet indoor conditions. A penalty of 5% was observed over the benchmark. This is due to the outdoor air wet-bulb temperatures. Waterside economizers must have outdoor air wet-bulb in the range of 4.4-7.2°C (40-45°F) in order to provide adequate indoor conditioning.

Solar Thermal for SHW: Auxiliary calculation was performed for this EEM. The total requirement for the buildings was about 1.09 m³/min (290 gpm). The desired hot water temperature was 43.32°C (110°F). Using RETSCREEN™ program, the SHW requirements for all buildings was calculated at 152.6 MW (521 MBtu). An evacuation tube-type system was proposed for this EEM. The system was a non-solar tracking horizontal slope system. Using this system, 100% of electrical energy used for SHW may be saved.

Steam Condensate for SHW: As steam was used for space heating, the waste condensate may be recycled for SHW purposes. Similar to the EEM discussed above, auxiliary calculation was performed to complete this EEM analysis which could have been avoided if seamless integration was available or if these modeling components were built-in in energy simulation software. The heat recovered was computed using a spreadsheet. The inputs for this calculation included the actual usage (condensate return), its enthalpy and the effectiveness of the heat exchanger. This value was analyzed to confirm if the recovered heat can offset entirely or a portion of the SHW requirement. The condensate water temperature available for further use was around 60°C (140°F). The total condensate return for year 2007 was measured at 5,927,653 kg (13,070,900 lbs). Based on the analysis, the steam condensate may be used for SHW requirement. However, since kitchen requires a minimum temperature of 71°C (160°F), SHW was still required thus totalling about 70% savings.

Thermal Energy Storage with all new High Efficiency Chillers: Two CHW Thermal Energy Storage systems were integrated to B1 and B2+B3 buildings. For modeling purposes, TES were discharged between 12 noon and 6pm (utility peak hours) and charged from 10pm to 6am. During TES discharge hours, the Chillers were sequenced to operate individually only if the load exceeded the rate of individual TES systems. Based on the utility rates, a cost savings of 11% was observed.

Parametric Models and Savings

EEM analysis was followed with developing parametric runs to identify maximum energy saving retrofit options. One of the parametric models was able to offer substantial reduction in EUI, at 280 MJ/m² (24.73 kBTU/ ft²-yr), translating to a 34% energy savings over benchmark. Figure 7 shows the electrical energy use by energy consumer type for the calibrated model. Figure 8 shows the breakdown of energy use. At this stage, one may notice that the largest energy consumer is Miscellaneous Electrical Loads (MEL). Approximately 50% of all energy is used by MELs. While the EEMs used in this study were able to enormously reduce overall energy use, none of the EEMs focused on MELs and this can be clearly noticed in figure below.

![Figure 7: Breakdown of Simulated Energy Use.](image)

![Figure 8: Electrical Energy Use by Energy Consumer Type (units in kWh x 1000).](image)
CONCLUSION

Although the simulation results show end-use energy of various components, it is to be noted that these are estimates; and only as good as the inputs. For analysis of existing facilities such as this building, care must be taken to develop necessary assumptions for those inputs that cannot be obtained from drawings and/or specifications. That said, the actual operation may vary significantly from the assumptions incorporated in the energy analysis. Furthermore, there are several other variables that may affect the energy use results such as the weather data, thermal impact due to surroundings, microclimate, nearby buildings, etc. Therefore, the percentages of energy use by consumer type is only representative, and may not accurately reflect measured energy use by those energy consumers. The only fool-proof way to verify the energy end-use by component is extensive sub-metering of all energy end-use categories which may be an expensive option. This paper discussed the calibrated simulation procedure developed for the retrofit of a large exhibition building, specifically the role of event calendar, issues related to modeling large building. This drilldown approach of replicating event calendar proved effective in model calibration. The calibrated model was used to evaluate an array of EEMs.

We recommend detailed calibration, both energy use and demand, to document the reasons for hourly variances by monitoring indoor and outdoor temperatures using temperature sensors and using them in simulation model. Also, short-term data-logging equipment that may be setup in portions of buildings to provide detailed measurements related to lighting systems, HVAC systems and motors, equipment, etc. However, this data-logging and subsequent data-analysis may have an expense associated with it.

NOMENCLATURE

ASHRAE, American Society for Heating, Refrigerating and Airconditioning Engineers
CHW, Chilled Water
DCV, Demand Controlled Ventilation
EEM, Energy Efficiency Measures
EUI, Energy Use Intensity
FEMP, Federal Emergency Management Program
HVAC, Heating, Ventilating and Airconditioning
IFC, Industry Foundation Classes
IPMVP, International Performance Measurement and Verification Protocol
MEL, Miscellaneous Electrical Load
MIMO, Move-In-Move-Out
M&V, Measurement and Verification
QC, Quality Control
SHW, Service Water Heating
TES, Thermal Energy Storage
VFD, Variable Frequency Drive

REFERENCES

Figure 1. Events in year 2007.

Figure 2. Comparison of events in year 2007 and simulated data.

Figure 3. MIMO days are higher than actual events. Occupants per event shows variation.
Figure 4. Monthly comparison of measured energy use (year 2007) and simulated data for electricity.