Achieving Carbon Emission Reduction Goals through Calibrated Energy Modelling and Parametric Analyses

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Abstract
Carbon emission reduction targets are becoming a common goal for larger corporations and regulations associated with carbon emissions are in place in several municipalities across the United States. Calibrated energy modelling paired with large scale parametric analyses can provide insight into the most cost-effective approach to reducing carbon emissions from commercial buildings. This paper provides a standardized approach to calibrated energy modelling for this application using a case study of a large commercial office building in New York City.

Key Innovations
• Energy modelling calibration supported by equipment sub-metering
• Existing building carbon reduction guidance through whole building energy modelling
• Office tenant energy reduction measures modelling
• Modelling occupant behaviour and effectiveness of automatic controls strategies
• Receptacles load intensity impact on energy and carbon emission

Practical Implication
Existing building renovations are becoming more prevalent as a method of delivering energy, utility cost, and carbon emission savings for building owners.

The methodology and results of this work will be useful to practitioners, building owners, and research groups to understand the time commitment and possible results from an in-depth calibration study. The presentation is intended to be part of a larger conversation currently happening about tenant engagement in reducing energy consumption and carbon emissions in New York City and worldwide. It is also expected to generate discussion amongst conference attendees about their own experiences with the intent to foster knowledge sharing.

Introduction
New York City introduced a new regulation to limit carbon emissions associated with energy usage of existing buildings. Local Law 97 law applies to all buildings over 25 000 ft² (2 323 m²) and has a carbon density target that depends on the type of building. There is a fine of $268 per metric ton for buildings that exceed the target. A first target is set for the 2024–2029 period and a more stringent target for the 2030-2034 period.

This paper will use the example of a large (1.6 million square foot, 32 story) commercial office building in New York City to demonstrate how energy modelling can be used to guide design team and owners on their strategy to reduce their carbon emissions as part of large capital expenditure (Capex) project.

Multiple strategies of tenant load reduction were also modelled to determine the most cost-effective strategies to include for tenant fit-outs.

Background
Calibrated energy models can be used to predict the effect on energy consumption and carbon emissions related to complex modifications to an existing building. This calculation methodology is appropriate when the nature of a building renovation includes energy measures that have interactive effects such as facade upgrades combined with interior load and HVAC modifications. With new legislation in New York City related to carbon emissions limits for existing buildings (Local Law 97), there is a need to better quantify energy usage and carbon emissions of current building operations and the energy-conservation measures needed to achieve the related carbon emission reductions.

For the calibration of the energy model, ASHRAE guideline 10 is used to validate calibration criteria. ASHRAE Guideline 14-2014 and the IPMVP guidelines are standard methodology for calculating energy and demand savings from retrofit projects. The guidelines provide uncertainty limits for a calibrated energy model. If the model meets all three requirements, then the energy model is deemed to be a good representation of current building operations and savings estimates from the retrofit project(s) are deemed to fall within the 95% confidence interval for future operations.

The calibration process requires hundreds or more iterative runs to meet calibration criteria. These multiple iterations modify unknown parameters such as air infiltration or operating schedules to test the sensitivity of the building energy consumption until the results meet the recorded data. Sub metered data reduces the number of unknown parameters by providing precise operation hours and loads for receptacles, lighting and HVAC system operation. The process can also help identifying equipment not working as expected.
Simulation Methodology

The building energy model developed for this project was built in eQUEST 3.65 Build 7173 running TMY3 and actual year 2018 weather files for New York City. This software package was chosen for the ease running hundreds of parametric runs and sensitivity runs while still providing accurate results for the HVAC systems and envelope systems in the building.

The first step in the energy analysis process for the project was to establish an energy and greenhouse gas (GHG) emissions baseline. Utility bills (electricity and district steam), tenant and base building electric sub-meters, and electrical interval data from the utility provider was collected for four years from 2015 to 2019 with the baseline year of 2018 used for the benchmark reference year. This year was chosen based on the fact that there were very few changes in tenancy, so the occupant loads and load profiles were fairly consistent over the year.

Table 1: Utility and GHG Benchmark for 2018.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Whole Building</th>
<th>Tenant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (MWh/yr)</td>
<td>23,055</td>
<td>14,397</td>
</tr>
<tr>
<td>Steam (Mlbs/yr)</td>
<td>37,523</td>
<td>n/a</td>
</tr>
<tr>
<td>Total Energy (MMBtu/yr)</td>
<td>123,489</td>
<td>49,136</td>
</tr>
<tr>
<td>Site Energy Intensity (kBtu/sq.ft.)</td>
<td>77</td>
<td>40</td>
</tr>
<tr>
<td>Total Carbon Emissions (tCO2/yr)</td>
<td>8,676</td>
<td>4,348</td>
</tr>
<tr>
<td>Electric Cost ($/yr)</td>
<td>$2,022,832</td>
<td>$1,263,184</td>
</tr>
<tr>
<td>Steam Cost ($/yr)</td>
<td>$1,340,556</td>
<td>n/a</td>
</tr>
<tr>
<td>Total Cost ($/yr)</td>
<td>$3,363,388</td>
<td>$1,263,184</td>
</tr>
</tbody>
</table>

With the base utility consumption verified, the next step in the calibration process was to develop annual load profiles for the available metered data (electric and steam). Electric load profiles for each tenant electric sub-meter, base building sub-meter, and an overall electric load profile from the utility electric interval data were created. These 15-minute electric load profiles were translated into hourly schedules on an annual average basis for input into the energy model to account for the tenant electric consumption (lighting, miscellaneous electric loads, server and data closets) and base building sub-meters (elevators, exterior lighting). Figure 1 provides the tenant electric load profiles developed from the tenant sub-meters.

A steam load profile was created for the overall building as a comparison during the calibration process but was not used directly in the model. There was a sub-meter where the building provided steam to an adjacent building and this usage was subtracted out to create the actual building consumption profile.

A few key outcomes of this load profile analysis were:
1) Tenant related electricity consumption accounted for 40% of the total building energy consumption.
2) The average electric load in the building between 8pm and 6am was 55% of the daytime peak electric demand. This indicated lights, miscellaneous electric loads, and server rooms and data closets ran continuously through the night.
3) Elevator and exterior lighting electricity consumption were able to be isolated in the model with separate schedules.

The chilled water plant (two electric centrifugal and two steam absorption machines with common condenser water systems) was also metered on a 15-minute basis which allowed detailed profiles for the plant to be developed. These daily and monthly profiles were key in the calibration process to ensure the correct split of energy was being applied to each end use (chiller, pumps, cooling tower). The monthly profiles for the electric chillers are shown in Figure 2. Similar data was available for the steam absorption chillers which ensured the runtime on each type of chiller was correct for each month.

The model calibration also used information collected from the energy audit and discussions with operating staff to better understand HVAC operation. Over the course of several months, additional data lighting and miscellaneous electric load data, key operating parameters of major equipment, and detailed sequences of operation were gathered. This information is transferred to the model sequentially, running the model after each change. This iterative process allows comparison of each energy end use with individual model changes while checking the sensitivity of certain model inputs. This
process is repeated with each building system, starting with known variables and moving to unknowns. Examples of known variables are the chiller efficiencies, pump power and flow rate, and tenant electric load profiles. Unknowns include envelope performance (U-value and SHGC) and infiltration rates. By working from known to unknown variables, the energy profile quickly shows seasonal accuracy to the utility bills with the unknown values being tweaked at the final calibration step with sensitivity analysis. Figure 3 shows this process graphically.

Monthly energy outputs from the modelling software are weather-normalized to take into account difference between the software weather file and real weather during the measuring period. TMY3 data and actual year weather were used to normalize the data. Overall results for the calibration are provided in Table 2. Mean biased error (MBE) is calculated monthly where the coefficient of variation of the root mean square error (CV(RMSE)) is an annual metric.

Table 2: Energy Model Calibration Statistics.

<table>
<thead>
<tr>
<th>Utility</th>
<th>MBE</th>
<th>CV(RMSE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>Steam</td>
<td>6%</td>
<td>21%</td>
</tr>
<tr>
<td>Total</td>
<td>5%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Energy Conservation Measure Analysis

From this data set, approaches to reducing energy consumption are tailored for the base building and each tenant. From a list of over 100 measures, 32 tenant specific measures were selected for implementation after detailed parametric analysis and sensitivity studies.

These strategies include lighting power allowances, lighting controls (occupancy and daylight), receptacle and plug load controls, and management plans, server room planning and cooling strategies, and overall space planning. The effectiveness of the lighting and plug load controls, which are dependent on occupant behavior, are analyzed in further detail through parametric analyses.

The energy conservation measures were grouped into three packages based on current acceptability of the technology, first cost, and simple payback. The first package of measures, which includes currently available and applicable technologies with the second and third packages including measures with higher first cost, longer paybacks, require more tenant engagement, and may not be market ready. The full list of measures is given below with the summary of results given in Table 3.

1. Energy Star Equipment; Automatic Receptacle Controls; Power Management Plan; Daylighting; Lighting Occupancy Sensors; Lighting LPD Reductions;
2. High-Efficiency Supplemental Cooling, increased temp setpoints; Increased Set Point in Tenant Server Room; Fan Motor Efficiency Improvement
3. Low Flow Tenant Fixtures; Local Electric Water Heaters; Premium Efficiency UPS; Server - Cloud Servers; Zones for Overtime Work; Application Based Temperature Control

Results

Table 3: Impact of the 3 energy conservation packages.

<table>
<thead>
<tr>
<th>Energy Conservation Measure</th>
<th>First Cost</th>
<th>Annual Savings</th>
<th>Payback</th>
<th>Carbon Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package 1</td>
<td>$1.59/ SF/Yr</td>
<td>$0.53/ SF/Yr</td>
<td>3.0</td>
<td>14.6%</td>
</tr>
<tr>
<td>Package 2</td>
<td>$0.36/ SF/Yr</td>
<td>$0.14/ SF/Yr</td>
<td>10.4</td>
<td>7.4%</td>
</tr>
<tr>
<td>Package 3</td>
<td>$0.56/ SF/Yr</td>
<td>$0.05/ SF/Yr</td>
<td>3.5</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

Discussions

Load profile and data processing was one of the key objectives of this project. Our team wanted to be able to generate a replicable methodology for processing the 100+ tenant and base building sub-meters into energy model inputs. The final technique used a combination of pivot tables with VBA scripting to clean the data by removing blank and out of range data, find the peak electrical values in a monthly basis, and generate weekly profiles for lighting, occupancy, receptacles, and supplemental cooling to be used in a variety of modelling software. The tool accepts 15-minute interval data or hourly data and can now be used to process large sets of data for future projects.

This level of analysis also provides insights into the building operation particularly around day versus night usage. The studied building had an average ratio of day to night electrical demand of 1.8:1, meaning a peak value of 100% during the day and 55% of the peak at night. The load profiles helped the operator 1) identify lighting and other electric loads left on at night that could be turned off, and 2) optimize the night set back to account for the substantial supplemental cooling in certain tenant spaces.

Finally, the load profile data generated from sub-meter data can be used to confirm HVAC system operation. Understanding the internal gain profiles reduces uncertainty in the calibration process as related to loads on the HVAC systems, so additional time was able to be spent on HVAC controls and optimization of other building systems.

Conclusion

A pilot office project is underway in the building to implement the entire package of measures and future work will include a presentation on the actual energy consumption of the space. The presentation will also review the calibration process and data processing for the sub-meter data to generate hourly load profiles.
References

ASHRAE (2013).

*Energy Standard for Buildings Except for Low-Rise, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 90.1-2013)*;

ASHRAE (2002).

*Measurement of Energy and Demand Savings, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE Guideline 14, 2002)*.

IPMVP (2001).


IECC (2018).

*International Energy Conservation Code (IECC 2018)*

New York City Local Law 97 (2019);