Who Left the Lights On? Typical Load Profiles in the 21st Century

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ABSTRACT

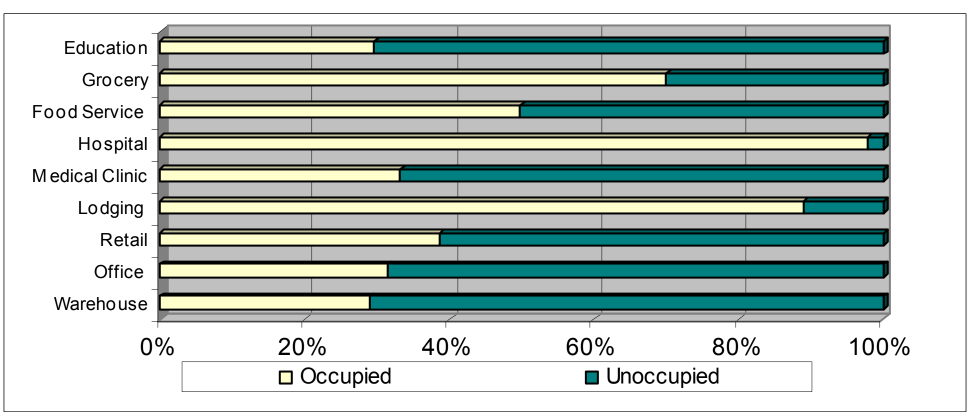
Building energy analysts typically assume that lights and equipment are turned off after hours and usually estimate a 10% to 20% unoccupied load. In the last five years, metering technology for interval data collection of building electric use has become more available and less expensive. As more buildings have been added to interval-data collection systems, energy management staff have noticed that the building load during unoccupied periods is often substantial at more than 40% to 80% of occupied load.

Fifteen-minute interval data from 91 commercial buildings served by Eugene Water & Electric Board are analyzed. Based on average weekday profiles for a mild-weather month, low-load period usage is much higher than predicted by seasoned analysts or defaults in an hourly modeling program. The impact on modeling accuracy is discussed. A simple statistical method is developed to separate high-load from low-load hours and determine a Low-load to High-load Ratio (LHR) for several building types. Based on results from this initial study, recommendations are made for a larger regional study to determine typical LHR by season and building type.

Introduction

Most commercial buildings in the United States are unoccupied far longer than occupied as shown for selected building types in Figure 1 (EIA 1999). Out of an 8,760-hour year, only 2,000 to 4,000 hours are occupied, while 5,000 to 7,000 hours are unoccupied. It should be easier to reduce load during unoccupied hours when comfort and productivity will not be affected. With the longer hours available and lower impact, load reduction during unoccupied hours may have greater potential for annual energy savings than occupied period load reduction. A new energy statistic that focuses on the ratio of low-load to high-load use, can help energy managers focus on finding savings during unoccupied hours.

Figure 1. Mean Reported Occupied v. Unoccupied Hours



In this paper, authors present a procedure for finding a Low-load to High-load Ratio (LHR) and apply the procedure to 91 buildings with interval metering in Eugene, Oregon. The off-hour electric energy use of several building types is documented. This paper focuses on electric energy, although the same concepts might be applied to other fuels. Average profiles for actual office and retail buildings are compared with profiles generated by defaults in a contemporary hourly energy analysis program. Modeled off-hour use is found to be grossly understated. Based on results from this initial study, recommendations are made for larger regional studies to determine typical LHR by season, climate, and building type.

Now that interval data are more easily available, the analysis of energy effectiveness can focus on energy load by time of day, rather than just looking at changes in load by month. As fuel costs increase, building managers can focus on both hardware and people management to reduce unneeded energy use during unoccupied hours. The LHR that is determined for each building gives one indicator that can be used to rank a number of buildings similar to an Energy Use Index (EUI)[1] or Energy Cost Index (ECI).[2] LHR can be used to manage energy usage of those buildings over time.

Profile Data Sources

LHR can be determined with a typical daily energy profile of the building power in kW, an average of weekday profiles, or a sample of profiles. Profiles can be based on hourly or 15 minute data. Data sources include:

- Several regional studies of commercial building energy intensities and end-use hourly load profiles were undertaken in the 1980s and early 1990s (Akbari, et al. 1990; Pratt, et al. 1990). These detailed studies produced valuable information for a set of commercial buildings in regions of the United States. As results were being analyzed, it was seen that unoccupied equipment and lighting loads were higher than expected. While energy intensity (EUI) information was widely distributed among and used by building modelers, the hourly information was relegated to regional and utility planning analysis. A project (DrCEUS) to make data more available for California end use load shapes derived from a sample of 3000 buildings is scheduled for completion in 2004 (Mayer 2003).
- For a fee, electrical research groups make typical industrial load profiles available, but the target audience is utility planners, not energy managers, researchers, or analysts (EPRI 2000, Itron 2004).
- Many utilities have extensive interval load data from Automated Meter Reading (AMR),[3] especially for larger buildings. Yet, this informative data has yet to be incorporated into the modeling process or used extensively for energy management.

This paper analyzes interval load data for 91 commercial buildings served by Eugene Water & Electric Board (EWEB) in Eugene, Oregon. The goal is to determine if off-hour energy

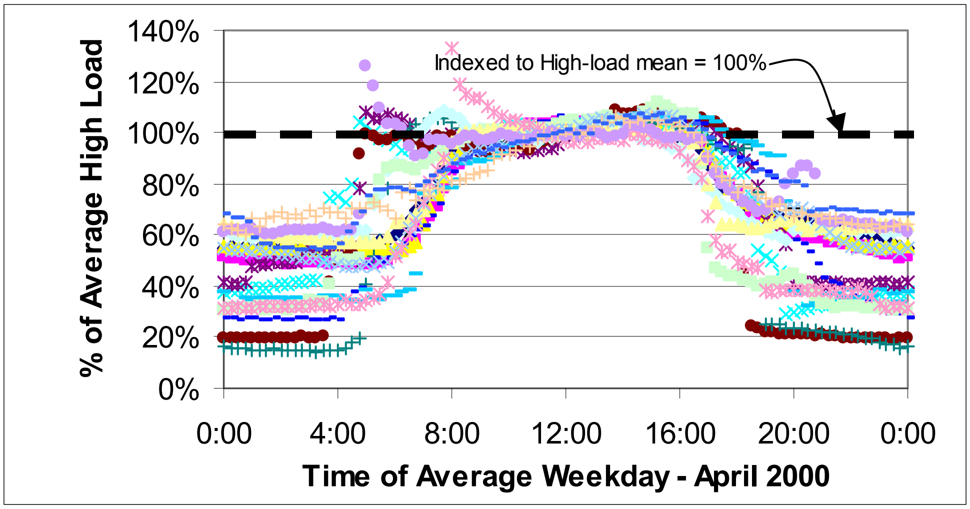
[1]EUI is the total annual energy use of the building divided by floor area, typically kBtu/square foot.
[2]ECI is the total annual energy cost of the building divided by floor area, typically $/square foot.
[3]AMR typically includes 15 minute interval metering with a data storage device at the meter and a means to communicate data to the utility for billing. For electric meters, energy consumption (kWh) is usually collected for 15-minute intervals.

use is higher than expected, and what the ratio of high-load to low-load use is for a range of building types. The results show clearly that low-load kW is a higher percentage of high-load kW than expected.

Typical Load Profiles

To give a general indication of the spread of the average weekday profiles, the 15-minute interval data for 17 office buildings are shown in Figure 2. For comparison, the load data are indexed with 100% equal to the high-load average ($\bar{x}_H$ as defined below under LHR Methodology). Several of the buildings show a brief morning warm-up peak related to electric heating.

Figure 2. Average Weekday Indexed Load Profiles for 17 Office Buildings



Low-Load to High-Load Ratio (LHR) Methodology

Individual AMR data profile analysis has been shown to be a very effective diagnostic tool; however, it is time consuming (Price & Hart 2002). Reducing the relationship of the low-load hours to the high-load hours to a single indicator allows easier benchmarking and comparison of groups of buildings. The main question of the current study is: "What is the relation of low-load use to high-load use for commercial buildings?" Low-load use periods typically align with unoccupied periods. Weekend occupancy varies from building to building, so weekday profiles were used to determine if equipment, lights, and fans were being turned off after hours. To simplify analysis, the study focused on average weekday profiles for April 2000.[4]

To get a numerical indicator of off-hour load share, a method was developed using simple statistical functions to separate energy used during high-load hours from low-load hours

[4]April was selected as a month when weather was not extreme. April 2000 preceded the California summer blackouts of 2000 and would allow comparison with post-energy-crisis data from April 2002. The analysis of pre- and post-energy-crisis use showed no significant results and is not included due to space limitations.

without requiring schedule information. The Low-load to High-load Ratio (LHR) could then be found for several building types. The steps to find LHR follow:

- Data (collected from 91 selected meters[5] with AMR as electric use in kWh for every 15 minutes of April 2000) were extracted using an in-house program with a rudimentary validation routine that adjusted for missing or out of range data.
- The extracted data were loaded into the Energy Profiler™ program and a weekday average kW load profile was generated for the month (ABB 2004).
- The average weekday profile was analyzed to find a high-load average ($\bar{x}_H$) and low-load average ($\bar{x}_L$) of the building load in kW[6] using the following procedure.
  - Find the average or mean ($\bar{x}$) and standard deviation (σ_x) of data for an average weekday profile of electric power in kW (x) for15-minute periods.
  - The kW data from the 96, 15-minute periods of an average weekday are divided into three exclusive sets, independent of time of day. The sets designate if energy demand is greater than (H), within (T), or less than (L) a band one standard deviation (σ_x) in width, centered around the mean ($\bar{x}$) of the full set. The criteria for each set are shown in equations 1, 2, and 3:
    - High-load data set: $$H = \left[\text{all } x \text{ where } x > \left(\bar{x} + \frac{\sigma_x}{2} \right) \right] \quad (1)$$
    - Transition data set: $$T = \left[\text{all } x \text{ where } \left(\bar{x} - \frac{\sigma_x}{2} \right) \le x \le \left(\bar{x} + \frac{\sigma_x}{2} \right) \right] \quad (2)$$
    - Low-load data set: $$L = \left[\text{all } x \text{ where } x < \left(\bar{x} - \frac{\sigma_x}{2} \right) \right] \quad (3)$$
  - Transition data in set ***T*** are assumed to reflect times when the building is transitioning from low- to high-load and are eliminated from further analysis.
  - The remaining high- and low-load sets are averaged where $\bar{x}_L$ is the mean of the low-load set and $\bar{x}_H$ is the mean of the high-load set.
- LHR is the ratio of the low-load mean to the high-load mean: $$LHR = \frac{\bar{x}_L}{\bar{x}_H} \quad (4)$$

Comparison to Load Factor

The purpose of LHR is to assist building managers in tracking how well energy-using equipment is turned off during unoccupied hours, either through manual, motivational, or automatic means. LHR should not be confused with load factor, a comparison of peak demand to energy consumed, usually on a monthly or annual basis. Load factor gives utility planners a picture of how well capital invested in generation and distribution equipment is being utilized.

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[5]Each meter was reviewed to verify it was a commercial building and determine the building function. Building function was based on utility records; however, site visits were not undertaken.

[6]The method does a good job of separating contiguous low-load from high-low hours until the LHR exceeds 80%. When LHR is greater than 80%, as for a grocery, the high-load and low-load data often represents equipment cycling rather than separate time periods.

The two indicators are at odds with each other. From a utility capital investment point of view, a high load factor is desirable. From an energy or fuel utilization point of view, a low LHR is desirable, as this indicates that less energy is being used when the building is not in use. Reducing LHR will typically result in a lower load factor as well. Exceptions to the desire for a low LHR are energy storage strategies that seek to minimize peaks or reduce overall energy use through off-peak storage and improved system efficiency during unoccupied hours.

Calculation and Seasonality

Given a swing month of interval data (or even a sample of typical days) and spreadsheet or database analysis tools, the LHR can be easily calculated for a particular building. It is appropriate to calculate individual building LHRs when performing a building model or working with a customer in a key account relationship. For batch processing, LHR may be estimated with more efficient sampling algorithms.[7] LHR will obviously vary depending on the time period or season selected, especially with electric heating and cooling. Seasonal or monthly LHRs were not evaluated here, but for effective use, further research should establish monthly regional typical LHRs by building type. Using a swing month when heating and cooling are minimized will give a good indicator of after-hour lighting and equipment energy use.

LHR and Energy Savings

The Low-load to High-load Ratio (LHR) is intended to be a useful metric that indicates how effectively loads are shut down after hours in particular buildings. The LHR factor determined for each building gives one indicator that can be used to rank a number of buildings similar to an EUI or ECI. This ratio can be generated for a typical swing month in a local climate that has low heating and cooling loads. As more experience is gained with the LHR, it can be generated monthly and compared with other buildings, especially once typical monthly ratios are developed by climate zone.

A significant reason to look at LHR is the large proportion of time that buildings are unoccupied (see Figure 1), especially for educational, office, retail, medical clinic, and warehouse occupancies. The data show that unoccupied period loads are much higher than expected, indicating a rich target for potential energy savings. Using LHR as a building energy-management statistic can help indicate significant savings potential for time periods when energy saving measures will have less impact on occupied period activity.

LHR by Building Function

Just as EUI varies by building function, load profiles and LHR also vary. Unlike a business type or Standard Industrial Code, the building function category is intended to group buildings of similar energy use intensity. The LHRs for the 91 buildings are analyzed in building-function groups where there are more than 8 in a group. The remaining buildings are

[7] A screen for buildings with LHRs above a target level can be quickly undertaken by using a sample Coefficient of Variation ($CV = \frac{S}{\overline{X}}$). The LHR can be estimated with an exponential formula that showed a high non-linear correlation (R^2=0.97) for the 91 buildings in this study ($LHR_{est} = 1.0434 e^{-2.4851 CV}$).

grouped as "other buildings." Table 1 shows simple statistics for LHRs of each building-function group. Statistics include sample size (n), Minimum, Mean, Median, Standard Deviation, and Maximum. For reference, the LHR is also determined for an annual average hourly weekday profile of several buildings types from the ELCAP data (Taylor 1992).[8] Figure 3 shows the LHR distribution by quartile for each building type.

Table 1. LHR Statistics by Building Function Group

	EWEB Data Set – April 2000, LHR						ELCAP 1988-91	
Building Function	**n**	**Min**	**Mean**	**Median**	**Std Dev**	**Max**	**n**	**LHR**
Office	**17**	19%	47.4%	52.9%	15.2%	67%	18	51.6%
Grocery	**11**	82%	88.3%	89.2%	3.7%	94%	11	77.9%
Hospital	**9**	42%	61.4%	61.0%	13.5%	80%		
Retail	**20**	20%	44.1%	39.4%	18.2%	71%	20	36.6%
Assembly	**9**	26%	58.5%	62.0%	17.1%	79%		
School	**8**	14%	34.4%	33.7%	11.0%	53%		
Other Buildings[1]	**17**	7%	62.0%	59.8%	21.1%	91%	24	44.7%
Overall	**91**	7%	55.7%	56.9%	23.4%	94%	74	51.1%

[1] Other Buildings" had fewer than eight incumbents per function group and included Restaurant, Fast Food, Retirement, Jail, Warehouse, Distribution, Commercial w/ Process, and Shop/Repair/RV Sales. For ELCAP data, "Other Buildings" include Restaurant and Warehouse.

Figure 3. LHR Quartile Distribution by Building Function

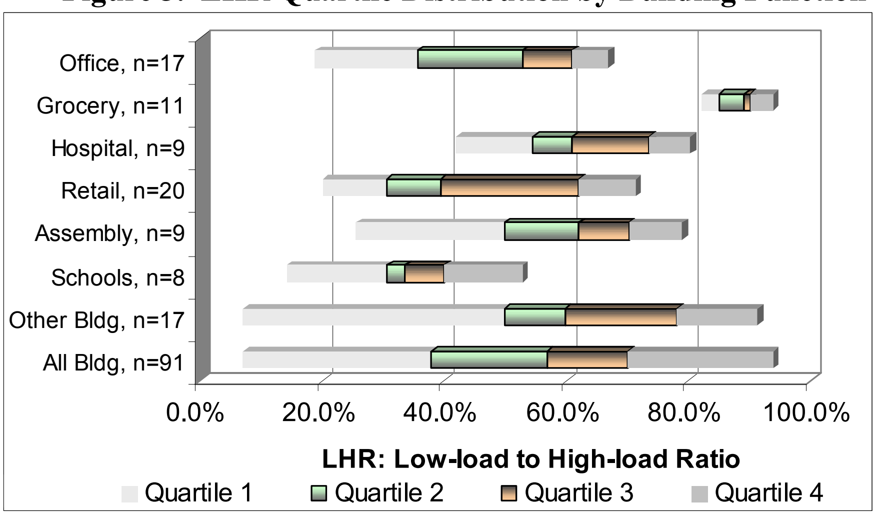


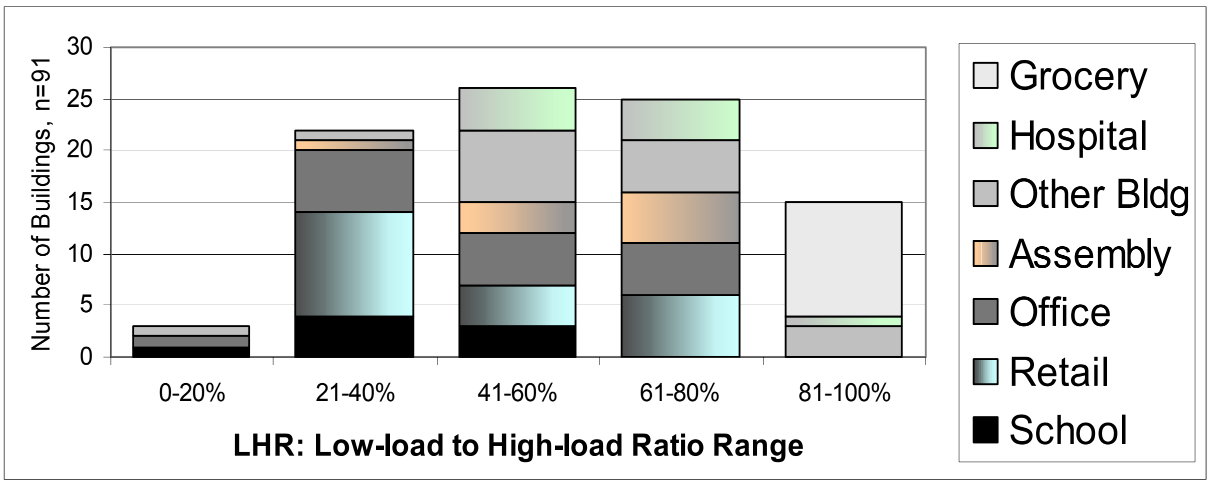
Figure 4 shows the frequency distribution of buildings in the sample by LHR. The total bar height shows the distribution for the entire sample, while shaded areas indicate detail by building type. While modeling approaches and expectations in the past have assumed that unoccupied energy load is less than 20% of peak load, the actual results find very few buildings in the below 20% LHR category. Comments by building type follow.

- Schools do the best job of getting loads turned off, although there are several schools with unoccupied use over 40%.

[8] While this comparison does not match time period (month of April v. annual) or sample basis (average profile v. individual buildings), it does give an indication that high LHRs are not a recent phenomenon.

- Retail building LHRs are mostly in the 20% to 40% range, although there are several buildings above 60%.
- Office buildings generally have a higher LHR than retail buildings, probably due to the preponderance of personal computers that are difficult to control centrally, custodial activities, and accommodation of building use outside regular hours.
- Assembly buildings had much higher than expected LHRs, although two building function groups were combined for analysis.[9]
- Other buildings had most LHRs from 40% to 80%.
- Hospital buildings had higher LHRs, mostly in the 40% to 80% range. All hospital buildings included were operated by one organization.
- Grocery stores had all LHRs greater than 80%. Three different owners are represented. LHR may not be a helpful indicator for grocery buildings, as they have a relatively high base refrigeration load and a trend toward increasing store hours.

Figure 4. Distribution of Building Type by LHR



On reflection, the overall LHRs seem to be higher than expected for all of the building function groups, with the exception of hospitals, other buildings, and grocery stores. There is great potential for energy savings during unoccupied periods, especially when considering that most buildings are unoccupied the majority of the time.

Wishful Modeling

The energy management industry relies on computer modeling for much of its savings estimates and demand-side management recommendations. When reviewing the retail and office buildings load profiles, seasoned modelers found the actual off-hour use surprisingly high compared with expectations and past training. In Figure 5 and Figure 6, the average indexed

[9] Light assembly (church and lodges) made up four of the nine assembly buildings. The remaining buildings were larger spaces including a convention center and airport terminal. The smaller assembly buildings had a higher LHR at 67.5% compared with 47.1% for the larger facilities. This may be because peak loads do not occur on weekdays in the light assembly facilities.

weekday profiles from April 2000 for the entire population of office and retail buildings is shown. These actual results are compared with an estimate of the profile that would be expected by two seasoned energy engineers and with modeled results that used eQuest default profiles.

Figure 5. Office Building Actual Profile v. Expected and Modeled Profile

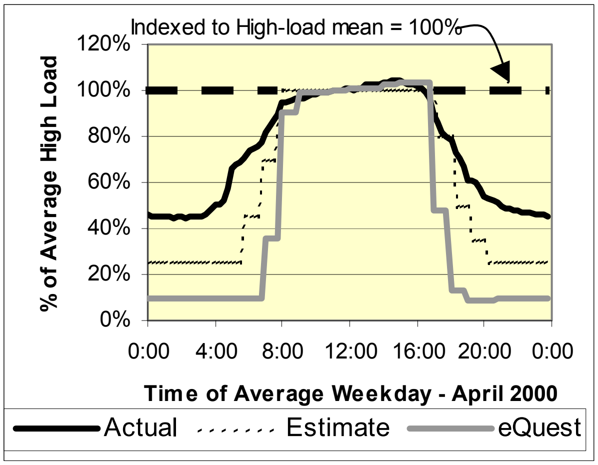
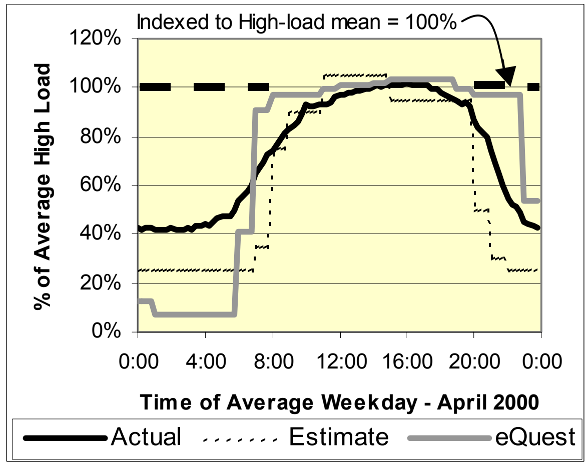


Figure 6. Retail Building Actual Profile v. Expected and Modeled Profile



For hourly modeling of commercial buildings, the industry-standard defaults for unoccupied loads such as lighting, receptacle, and HVAC system are assumed to be "off" or at most about 5% to 10% of peak load. The expectation of near-perfect unoccupied-period energy management represents wishful thinking and does not reflect actual behavior. A brief historical review indicates that both regional and national authorities seem to support this idea of very low unoccupied modeling profiles.

- ASHRAE Standard 90.1-1989 (Table 13-3) recommends modeling unoccupied lighting, receptacle, and fan loads at 0% (ASHRAE 1989).
- In 1992, The Bonneville Power Administration (BPA) issued *Guidelines for Energy Simulation of Commercial Buildings*. Table A3-1 matches the 1989 ASHRAE profile, yet discussion references the ELCAP profile data, suggesting a minimum setting of 30% for unoccupied equipment loads. ELCAP profiles are not included.
- In a 1994 northwest training for consultants in DOE 2, the sample profiles showed 10% to 15% for unoccupied lighting and equipment (ESS 1994).
- In the latest release, ASHRAE Standard 90.1-2001, sample load profiles have been replaced with a statement that says the "schedules will be determined by the designer and approved by the authority having jurisdiction" (ASHRAE 2001).
- The California Energy Commission provides computer-modeling schedules for Title-24 compliance and stipulates that lights and equipment must be scheduled to 5% of peak load during unoccupied hours (CEC 2001).

The eQuest front end for DOE 2.2 was used to analyze a typical two-story office and large retail building using the supplied defaults (Hirsh 2004). The hourly total building electric load for April weekdays was extracted and analyzed so that a default modeled building profile could be developed. The default modeled weekday profile is overlaid with the actual data in

Figure 5 for offices and Figure 6 for retail establishments. In Table 2, the LHR for the modeled office and retail space is shown compared with the actual group data. In both building types, the model LHR is much lower than the actual mean and is also below the minimum for this sample set. The modeled results significantly understate the energy use of the building. For the office building, the model with default values understates the total electric use by 37%. The greater number of unoccupied hours means that unoccupied profiles have a greater impact on model accuracy than occupied profiles.

Table 2. Comparison of eQuest Default LHR to Actual Building LHR

Building Function	eQuest Model	Actual Building Sample LHR		
		Min	Mean	Max
Office	**9.5%**	**19%**	**47.4%**	**67%**
Retail	**12.6%**	**20%**	**44.1%**	**71%**

It should be noted that eQuest is designed with California Title 24 compliance as a major goal. Despite cautions in Title 24 documents to not use compliance profiles to estimate actual energy use, these default values are likely to be used by an increasing number of analysts and designers now that eQuest has made hourly modeling more accessible. Increasing the default off-hour profiles in Title 24 requirements and the eQuest front end would improve modeling accuracy.[10] As interval data becomes more available, checking the LHR of the model against the actual building for a retrofit analysis (or typical profiles for a new building) would be a good point of calibration. Models with lower than typical unoccupied profiles will be more difficult to calibrate and may result[11] in modeling errors:

- Heating efficiency measures may have savings overstated.
- Cooling reduction measures such as night flush, thermal mass, or natural ventilation may have savings understated.
- Closed-loop control measures such as occupancy sensors for lights or equipment may have savings understated.
- Measures that primarily impact occupied hours may have savings overstated.
- Higher efficiency cooling and lighting equipment that affect load both during occupied and unoccupied hours may have savings understated.

Model use for new construction is increasing due to the popularity of green buildings and LEED certification (USGBC 2002). If off-hour use is understated in these models, the result is that the baseline energy intensity is understated and savings from a package of energy measures may be inaccurate. The accuracy of percentage saving thresholds needed for awards or certification may be affected. EWEB staff have seen several recent new building examples where the actual building use was far higher than the model predicted. An evaluation of the

[10]Note that the problem found is with the provided default values, not the inherent calculations of the hourly program. Given the proper input profiles, there should not be a problem generating building models that match actual building operation. It could be argued that the eQuest (Title 24) default values represent a well-tuned building with good application of operation and maintenance procedures. Further, actual buildings may have exterior lighting loads that are not included in the model defaults. Unfortunately, many analysts are likely to use the provided default profiles, and even seasoned analysts are likely to expect a lower LHR than the actual data suggests.
[11]The assertion of potential modeling errors is based on the Authors' combined 60 years of building modeling experience. Evaluation of the quantitative impacts by other investigators is welcome.

regional energy smart program showed that analysts significantly under predicted the energy use for more than half of the evaluated office buildings (Diamond et al. 1990). This under prediction of energy use results in facility managers not budgeting enough for their energy bills. It also leads to the conclusion that energy measures are not performing, when in actuality, off-hour energy use may simply be understated.

Who Left the Lights On?

The LHR allows energy managers to find buildings with excessive unoccupied-period energy load levels. Once the search is narrowed, individual building profiles can be analyzed to determine how much energy is used that does not contribute to the productivity or comfort of the building occupants. While no systematic study of who left lights or equipment on was completed for this paper, experience with O&M programs shows that in commercial buildings, occupants often have a lack of ownership or accountability for energy use. Facility operating staff are generally more accountable to occupant complaints than energy budgets. As a result, the tendency is to leave lights and equipment operational so that occupants are not inconvenienced. There are a number of strategies listed below that can reduce unoccupied period energy use; however, the authors' experience has shown that saving measures that rely on human behavior are difficult to implement (Hart, Hawley & Logan 2002).

- Occupancy sensors may be more effective than time controls in reducing use.
- Lighting for custodial activities might be better managed.
- When more computer network infrastructure is installed, provide small cooling units so fans serving large areas are not operated to condition new server rooms.
- Get occupants to turn off task lighting, computers, printers, and copiers after hours.
- Activate automatic computer-power-standby features and provide remote-activating network cards to limit after-hour computer operation to actual remote backup.
- Clearly evaluate if more security lighting actually provides more security.
- Reduced security and outdoor lighting with timers after the building is fully vacant.
- Verify that schedule control is active for HVAC units, pumps, fans, and lighting and establish regular review of control schedules, including holiday schedules.

Conclusions

Several conclusions result from this work.

- Actual after-hour energy use is much higher than expected.
- Default computer model unoccupied load profiles are much lower than actual profiles and LHR can be helpful in calibrating simulation baselines to reasonable levels.
- LHR can help compare buildings to find out where after-hour use is high.
- LHR can inform energy managers about progress in reducing off-hour use.
- As fuel costs increase relative to capital investment in generation and more solar sources come online, reducing after-hour energy use will become more valuable.

Recommended Future Work

While AMR data has been collected extensively over the last several years, the energy use profiles of different building types could use further analysis. This initial study is limited in sample size, sample diversity, and climate. Additional work that would improve our understanding of unoccupied energy loads includes:

- Review data from regional end-use load studies completed in the late 1980s and early 1990s and calculate LHR for a broader sample of building functions, by month and climate zone.
- Get older load data reports available online, either scanned or in a database format.
- Undertake limited metering to update end-use studies for changes in lighting and computer technologies.
- Develop tools and methods to batch process load spread or LHR, and include in major energy-profile analysis tools.
- Improve funding amounts and stability for tabulating and disseminating actual energy load profiles and statistics.
- Develop more realistic code baseline lighting and equipment profiles, and train modelers in calibration methods using LHR. Improve the default profiles included in energy analysis programs or offer a clear choice between typical profiles and profiles that represent ideal management of after-hour lights and equipment.

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