Enhanced Opportunities for Energy Savings in Industrial Facilities through Long-term Monitoring

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ABSTRACT

Industrial Assessment Centers perform one-day energy assessments to analyze easily identifiable energy-saving opportunities. These assessments have a proven track record of generating significant energy and cost savings in manufacturing facilities, but time constraints limit the possible projects that may be analyzed. Long-term monitoring of equipment, which falls outside the scope of traditional one-day energy assessments, provides additional opportunities to identify energy-saving projects. With minimal cost and effort, plant managers in individual plants can purchase and install data loggers to analyze these additional opportunities. With recent decreases in costs and increases in memory storage, months of data can now be collected between downloads with minimal capital and labor cost. Annual or semi-annual reviews of the data can be conducted by plant personnel to quickly identify faults and opportunities for improvement. A long term energy study was performed on two buildings and serves to demonstrate several of these opportunities. Although a non-industrial building, experimental examples from this study illustrate the significance of recommendations that can be quickly identified by analyzing data collected from data loggers. Specifically, case studies for four different energy-saving opportunities are discussed to highlight the added benefit of long-term monitoring. These cases include quantification and analysis of building temperature setbacks, faulty sensors in building equipment, monitoring of health conditions, and analysis of occupancy sensors. Each of these cases is discussed with experimental data from the building study and illustrates the potential for additional analysis through low cost data loggers.

Background and Overview

The Industrial Assessment Center (IAC) program is an initiative through the U.S. Department of Energy to improve the energy efficiency of small- to medium-sized manufacturing plants through energy assessments. There are teams located at a total of 24 universities throughout the country that perform the assessments at no cost to the manufacturers. These one-day energy assessments have shown significant recommended and implemented cost savings for participants over the history of the program (AMO 2015).

One of the primary limitations during the energy assessments is the lack of time for data collection. The majority of visits are completed within a single working day, including interviews with plant personnel, observation of plant operation, data collection, and analysis of potential recommendations. With limited time, the majority of identified opportunities are those which may be analyzed with data collected over a couple of hours. At times, additional possible projects are identified, but are either dropped because of insufficient time for analysis or rough estimates are made on potential savings and included in the report as considered recommendations. With long-term monitoring, these systems could be analyzed with better estimates on potential energy and cost savings. Additionally, there are potential energy-saving opportunities on systems that are particular to a specific manufacturing process. As long-term monitoring of manufacturing facilities falls outside the scope of the IAC program, this paper suggests the viability of individual plant managers to implement long-term monitoring as a cost effective method to identify these additional energy-saving opportunities.

In recent years, the cost and available memory for portable data loggers have significantly improved. As such, the expense in capital for the loggers and manpower to download and analyze the data has decreased. The loggers can be easily deployed and weeks of detailed data can be collected without the need to download the data. These loggers present opportunities to monitor additional energy-saving opportunities with minimal cost and effort. In this paper, an analysis from a long-term energy study of two different buildings is presented. Although the buildings are non-industrial, they present results that come specifically from long-term monitoring and highlight new opportunities for cost savings.

We propose that plant personnel can implement long-term monitoring with minimal cost and expertise in monitoring equipment. As will be demonstrated in the paper, problems with equipment or operating conditions are often easy to identify. Although IAC centers may identify some potential opportunities for long term monitoring during one day visits, the purpose of this paper is to demonstrate the ability of plant personnel in individual manufacturing facilities to perform long term monitoring with minimal cost and expertise. This monitoring enables additional analysis and diagnostic capabilities beyond the typically identified opportunities of one-day energy assessments.

Building Study Setup

The two studied buildings have identical floorplans but are located in different climates. The first building is located in a cooler, dry climate, and the second is located in a hot, humid climate. Under the 2003 Commercial Building Energy Consumption Survey, these buildings fall under the category of religious worship and are non-industrial (EIA 2003). However, the results presented in this paper serve to illustrate the benefit of long-term monitoring in many types of buildings through this specific test case. Each of the buildings is approximately 20,000 ft^2 and consists of multiple classrooms, offices, and several large meeting areas. These buildings experience large usage on Sundays, but relatively infrequent, yet consistent usage throughout the remaining week. The majority of building usage on weekdays typically occurs during evenings or mornings, outside of typical business hours.

Over 100 data loggers were installed throughout the building to measure temperature, relative humidity, light, and occupancy in every room and area. Additionally, the building is conditioned by ten small heating, ventilation and air conditioning (HVAC) units, and loggers were installed to measure the power consumption and supply air conditions of these systems. Finally, a single CO_2 sensor was rotated throughout the building to gather representative CO_2 levels throughout the building. All temperature readings were logged at 30-second intervals, and current loggers on the HVAC systems were logged at intervals between 30 seconds and 1 minute. CO_2 measurements were taken every 10 seconds. The light and occupancy measurements are state dependent, and consequently measurements are recorded whenever there is a change in state. Data were collected in the first building for 6 months and the second building for 12 months. As the purpose of the study was to passively monitor building conditions, the researchers didn’t interfere with building operations and had no influence over building retrofits and building operational changes. More complete building details and the study setup are included in previous work (Terrill 2015).

Outline of Paper

This paper looks at four interesting results of potential opportunities for energy savings or improving health conditions. These results are only revealed through long-term monitoring and would be difficult to identify in a one-day energy assessment. They serve to highlight the benefit of long-term monitoring in industrial facilities as a way to identify additional energy efficiency opportunities.

The following are the four different presented results:

1. Faulty HVAC Sensors
2. Temperature Setbacks
3. Monitoring Health Conditions
4. Occupancy Based Lighting Control in Restrooms

Experimental Result #1: Faulty HVAC Sensors

There are multiple HVAC units that service different areas of the building. Through the course of data collection, a particular system exhibited anomalous use compared to the other systems. Although the operational settings were the same, the system consumed considerably more energy compared to other systems. Figure 1 shows the energy consumption for this and two other systems. These three systems were similar in capacity, and the types of rooms conditioned were similar in size and occupancy. As seen in the figure, this anomalous system consumed an unusually large amount of electricity. This is notable because each system was programmed with the same temperature setpoints, occupancy schedules, and temperature setbacks.

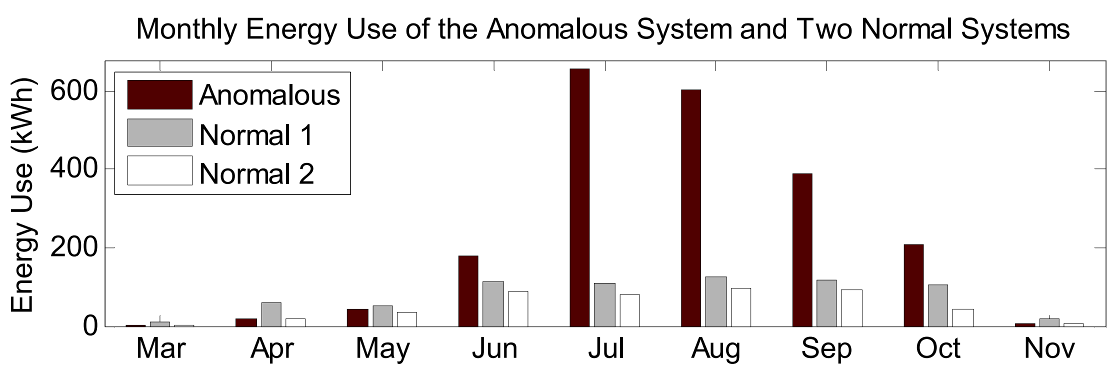

Figure 1. Comparison of energy usage for a system with a faulty sensor with two normal systems. Each of the systems was comparable in capacity and operational settings.

Figure 2 shows additional information for the anomalous system and one of the normal systems for a two week period in July 2014. As can be seen in the figure, the anomalous system remained on for days at a time, with the only fluctuation in power consumption coming from weather loads. The normal system shows the expected sporadic use to condition the space when occupied or to maintain the temperature setbacks. The second subplot verifies that the increased energy consumption doesn't come from a larger heat load in the space. Both rooms have a cooling setpoint during occupancy 74 °F and a cooling temperature setback of 80°F. As seen in the figure, the large energy usage of the anomalous system comes from significant overcooling of the conditioned space.

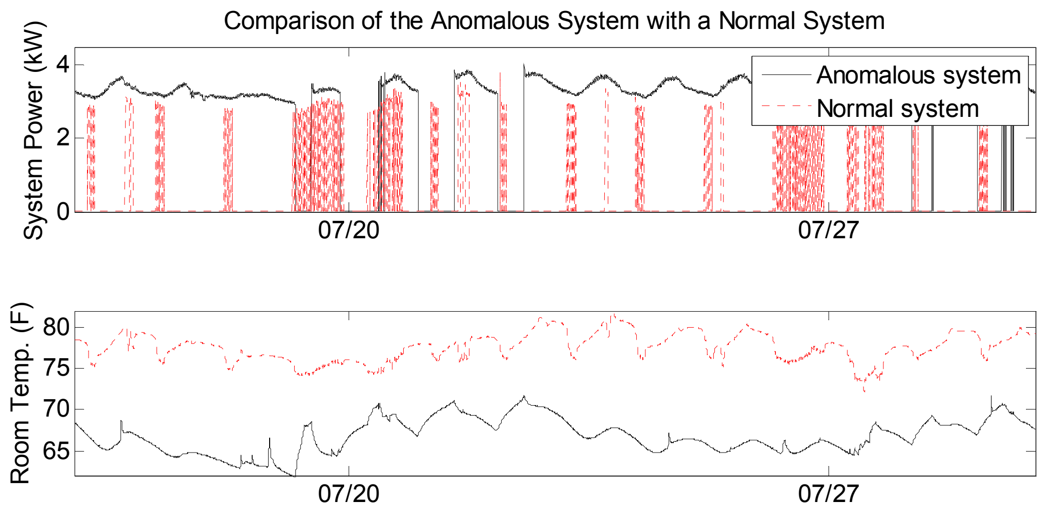

Figure 2. Power consumption and space temperature for the faulty system and a normal system. The faulty system remained on for days, resulting in overcooling of the conditioned space.

The cause for the anomalous operation was a faulty sensor. During a time period when normally unoccupied, the researchers observed that the temperature displayed at the thermostat was above the cooling setpoint, even though the actual temperature of the space was below the setpoint by a significant margin. The system ran continuously in an attempt to lower the room temperature further. As this problem is most evident during periods without occupancy and other heat loads, long-term monitoring enables the diagnosis of the faulty sensor and correction of the faulty condition. Several types of monitoring could catch this problem, including temperature loggers in the space, loggers measuring supply air conditions, and loggers recording power consumption. Many times, likely during periods of occupancy, the temperature of the space is below the setpoint but still within general building temperature setpoints. This faulty condition likely went uncorrected because many times the temperature of the space was within reasonable temperature limits. However, the anomalous condition is quickly identified with long-term monitoring, which can produce significant cost savings from repairing the faulty sensor.

While monitoring of direct manufacturing processes is common to prevent waste in material or productivity, often the support processes aren’t monitored but are repaired or corrected when problems arise. An example of an unmonitored support system is compressed air systems in manufacturing plants. Compressed air constitutes a significant portion of energy use in many plants, and a significant amount of energy is lost in typical manufacturing facilities due to compressed air leaks (DOE 2004). Long-term monitoring of compressor use by plant personnel with a data logger is an easy way to spot obvious problems and areas of waste, which typically occur from leaks and equipment left on. Even with minimal expertise, identification of this waste is readily apparent.

Experimental Result #2: Temperature Setbacks

Temperature setbacks in buildings during unoccupied times is an established energy efficiency measure that is commonly implemented in many buildings. Both of the studied buildings implemented temperature setbacks during unoccupied periods. The default temperature setbacks for every HVAC system in the building includes heating and cooling setpoints during unoccupied times of 68 °F and 80 °F, respectively. There are manual temperature overrides in the building for each system that allows an occupant to temporarily switch the system to "occupied" and allows some control over the temperature setpoint. The HVAC system servicing the main worship area in the building was replaced in early May 2013. After installation of the new system, the thermostat controlling the temperature in the main meeting area was not given the temperature setbacks as typically found throughout the building. This operational change continued for several weeks before it was discovered and corrected to include temperature setbacks.

The problem took so long to discover because temperature setbacks inherently operate when the building is not occupied, thereby increasing the difficulty in diagnosing the lack of temperature setbacks. However, with long-term monitoring of the building conditions, the operational change is immediately obvious and can be quickly corrected. Figure 3 shows the temperature of the main meeting area for one week without temperature setbacks and for two other time periods that had temperature setbacks. The different temperature profile with no temperature setbacks is clear and requires no additional analysis to diagnose. This demonstrates a very simple operational change that can be made because of long-term monitoring that is difficult to diagnose without monitoring and can lead to excess energy loss.

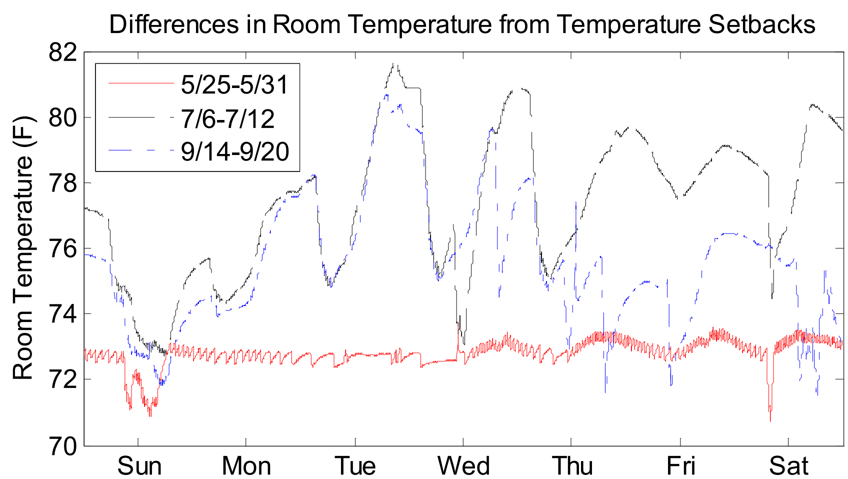

Figure 3. Diagnosis of the lack of temperature setbacks is immediate when monitoring room temperature.

Due to the comprehensive nature of the study, the energy savings from including temperature setbacks can be quantified. To analyze the savings in energy consumption, a 4-week window was taken for time periods with and without temperature setbacks. These time periods are summarized in Table 1. Two different time windows with temperature setbacks were analyzed and compared to the time period without setbacks. The first time period is a 4-week period closely following the 4-week period without temperature setbacks. As this time period occurs later in the summer, the average temperature is several degrees warmer during this time period. However, this provides a comparison with minimal probability for equipment degradation or changes. The second time period for comparison occurs in September and October of that same year. Although several months later, this time period has an overall similar average temperature. The expected use of the HVAC system in this time period is similar to the time period without setbacks.

Table 1. Comparison of energy usage for three time periods, two with temperature setbacks and one without setbacks.

Time Period	Operational Condition	Average Temperature over Time Period	Total Energy Usage
5/18/2014 - 6/14/2014	No temperature setbacks	78.2 °F	631 kWh
6/29/2014 – 7/26/2014	Temperature setbacks	82.6 °F	432 kWh
9/7/2014 – 10/4/2014	Temperature setbacks	77.6 °F	407 kWh

The average energy usage for the different time periods is presented in Figure 4. This figure shows the average use for each day of the week over the 4 week time period. As seen in the figure, the total Sunday usage, when the building is heavily occupied, is similar for all three buildings as there is minimal time with temperature setbacks. However, during other days in the week, especially near the end of the week, the average daily energy use for time periods with temperature setbacks is significantly lower than the time period without the setbacks. Note that although the average outdoor temperatures may be comparable over the entire time period, there are significant fluctuations in daily HVAC use due to normal weather patterns. The average weekly total usage, which represents the sum of each individual daily usage, is also displayed on the figure to summarize the energy savings from temperature setbacks. Over normal operation with temperature setbacks, the increased energy usage without temperature setbacks ranges from **46-55%**. Since this operational change only affects periods without occupancy, these savings represent a significant portion of total energy that can be reduced with minimal impact on thermal comfort for occupants. The identification of this operational change is easily diagnosed through long-term monitoring.

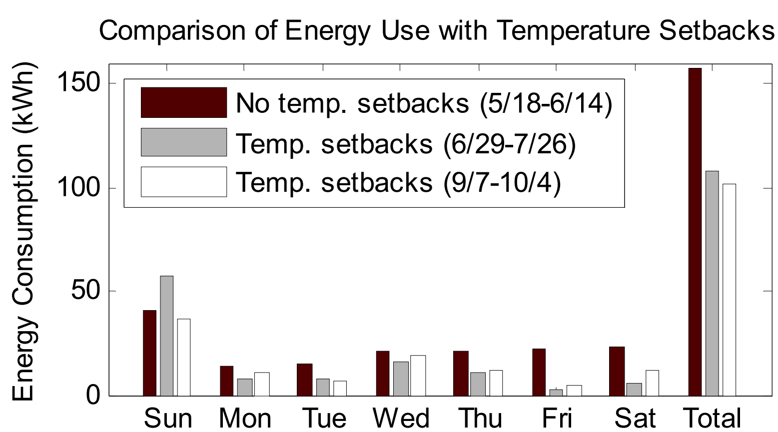

Figure 4. Comparison of average daily use for conditioning the main meeting area with and without temperature setbacks.

Although the quantification of energy savings required additional analysis, the identification of the different operational condition was quickly identified without extensive analysis. Similar opportunities are easily identifiable in industrial settings, such as large equipment or motors being left on or in standby mode when production is off.

Experimental Result #3: Monitoring Health Conditions

One common area of interest in building performance is maintaining acceptable CO_2 levels. The American Society of Heating and Air Conditioning Engineers sets acceptable limits for CO_2 to maintain a comfortable environment for occupants. The recommended limit for CO_2 levels is 700 ppm above normal background levels (ASHRAE 2013). In evaluating CO_2 levels throughout the building, a single CO_2 sensor was rotated to three different areas of interest: 1. the main meeting area, 2. one of the offices, 3. a children's meeting area.

Figure 5 shows the CO_2 levels of one of the offices from mid-May to mid-July in 2014. The background level for CO_2 is approximately 500 ppm, resulting in an acceptable limit of 1,200 ppm. As seen in the figure, the CO_2 levels rise significantly above the recommended 1,200 ppm consistently through the time period. Many of the peaks correspond to Sundays when the building has a high intensity of usage.

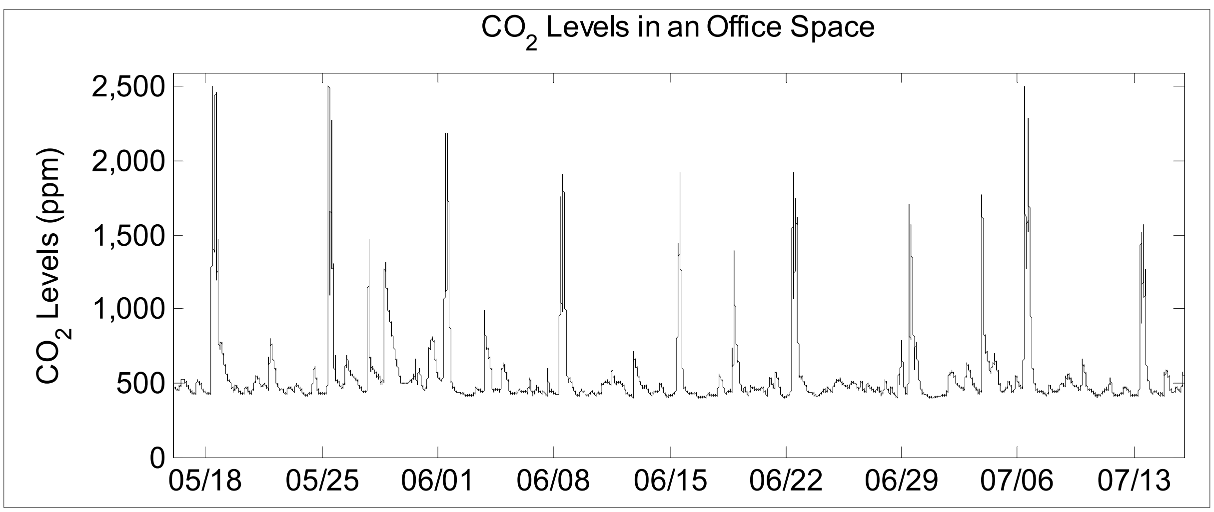

Figure 5. CO_2 levels in an office space over approximately one month of data collection. Large spikes occur during heavy occupancy and exceed the recommended CO_2 levels.

Similar high CO_2 levels were found in the other areas of the building as well. Each area experienced large peaks in CO_2 levels during time periods of heavy occupancy. These levels exceed the recommended limits for CO_2 and present an opportunity for improving building operation. A summary of the CO_2 levels for each Sunday of data collection is given in Table 2. The average maximum CO_2 value was calculated by taking the maximum CO_2 value for each Sunday of data collection and averaging these values over all Sundays. The average CO_2 value was calculated by averaging the CO_2 levels for each Sunday between 8:00 am and 6:00 pm. Of particular interest is the maximum sensor capability of the CO_2 sensor. The sensor limit was 2,500 ppm, and the CO_2 levels in the children's meeting area exceeded this value each week during data collection. Therefore, the actual maximum CO_2 value and average CO_2 value will be larger than those listed in the table.

Table 2. CO_2 values for different areas of the building during data collection.

Area	Average Maximum CO_2 Value	Average CO_2 Value
Main Meeting Area	1,725 ppm	1,120 ppm
Children's Meeting Area	2,500 ppm*	1,540 ppm*
Office	2,080 ppm	1,300 ppm

* Note that 2,500 ppm is the sensor limit, so the actual values will be higher than those listed.

Long term monitoring facilitates the ability to diagnose both that there is an issue with high CO_2 levels and the cause for the issue. Figure 6 shows the CO_2, occupancy, and HVAC data for the main meeting area on a particular Sunday. The CO_2 levels rise above the acceptable limit of 1,200 ppm. In general, many buildings will experience high CO_2 levels when the space is occupied but not conditioned. However, occupancy and HVAC data reveal that the CO_2 levels still rise above acceptable limits, even when the space is conditioned. The time period between 9:00 am and 10:30 am illustrates rising CO_2 levels even when the space is conditioned. This reveals the need to bring in additional outside air when space conditioning to maintain acceptable CO_2 levels. Without long-term monitoring, this condition would be difficult to detect or diagnose. A single CO_2 measurement may reveal the higher CO_2 concentrations, but the underlying cause for these high levels would not be possible with isolated measurements.

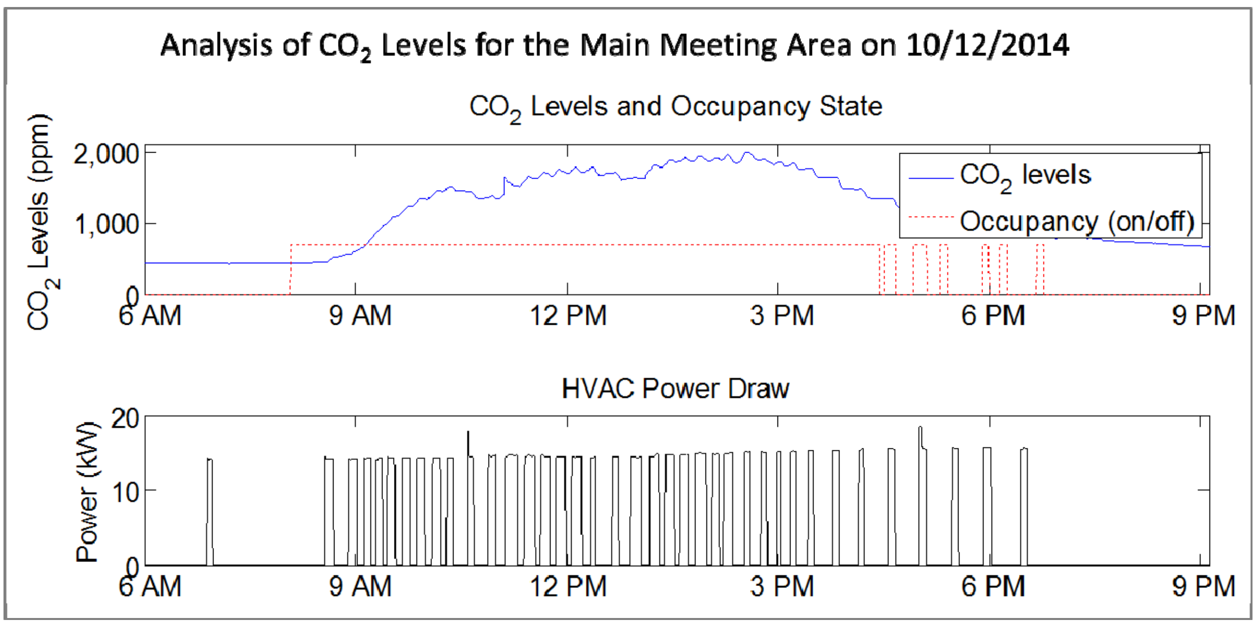

Figure 6. Analysis of CO_2 levels during one Sunday for the main meeting area. Despite conditioning throughout the day, CO_2 levels still exceed recommended limits.

Experimental Results #4: Occupancy Based Lighting Control in Restrooms

In many buildings, occupancy based lighting control in sporadically used areas presents an opportunity to reduce energy consumption by turning off lighting when a space is unoccupied. When comparing the two studied buildings, the first building had standard light switches, while the second was equipped with occupancy based lighting control. As each of the buildings has similar characteristics and occupancy patterns, this difference in lighting controls presents an opportunity to evaluate the effectiveness of occupancy based lighting control.

Figure 7 shows the lighting performance of the first building (without occupancy sensors) and each of the restrooms in the second building (equipped with occupancy sensors). Despite the presence of automatic lighting control in the second building, the lighting usage matches or exceeds the lighting of the first building. Specifically, the lighting usage in the men's restroom is significantly higher than the usage in the first building.

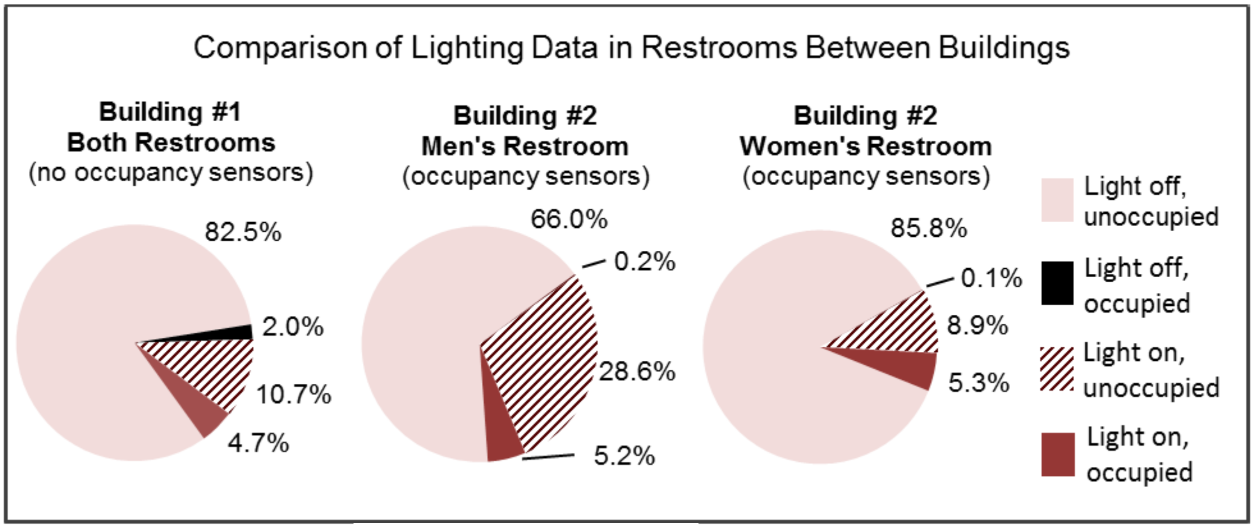

Figure 7. Comparison of lighting for restrooms without occupancy based lighting control in the first building and with occupancy based lighting control in the second building.

The reason for the significant increase of usage for the men's restroom in the second building is an oversensitive occupancy sensor that triggers the lighting. This sensor registered the air movement of the HVAC system, and consequently the lighting is turned on every time the space is being conditioned. This condition is illustrated in Figure 8. The lighting corresponds with the occupancy as expected. However, the lighting is also correlated with instances when the HVAC system is running. This highlights the need to obtain correct sensitivity levels on occupancy sensors and demonstrates the value of long-term monitoring of any building. As occupancy based lighting control is applicable to industrial and commercial facilities, correct sensitivity levels are a critical element in delivering estimated energy savings.

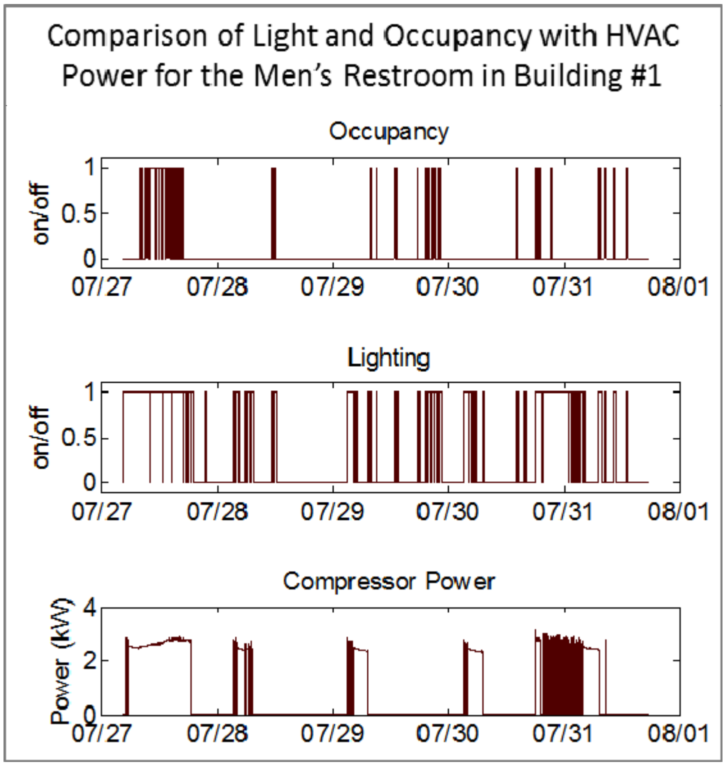

Figure 8. Evaluation of lighting usage compared to occupancy and HVAC usage. The sensitivity of the occupancy sensor on the lighting switch was too high and triggered the lighting whenever the HVAC system was running.

After removing instances of lighting that are correlated to the HVAC system, the corrected lighting usage of the men's restroom is displayed on the left of Figure 9. This usage is comparable to the usage in the women's restroom. The primary reason the energy usage of lighting isn't significantly reduced with occupancy based lighting control is the timer lengths on the occupancy sensors. The timer length for each of the restrooms from the experimental data was determined to be 16 and 18 minutes for the women's and men's restrooms, respectively. Longer timer lengths are desirable to prevent the lighting from automatically turning off while a space is still occupied. However, the total energy use from lighting largely depends on the length of the timers, as illustrated on the right of Figure 9.

In industrial facilities, lighting presents a common, albeit minor, opportunity for energy saving recommendations, either through upgrading lighting or reducing the time lighting is used. To accurately estimate the potential for savings or determine actual savings, long-term monitoring provides detailed data that can't be replaced by estimating occupancy schedules and patterns. As light and occupancy loggers can record data for months between downloads and lighting analysis tools are built into most data logger software programs, the savings can be determined with minimal capital cost and time.

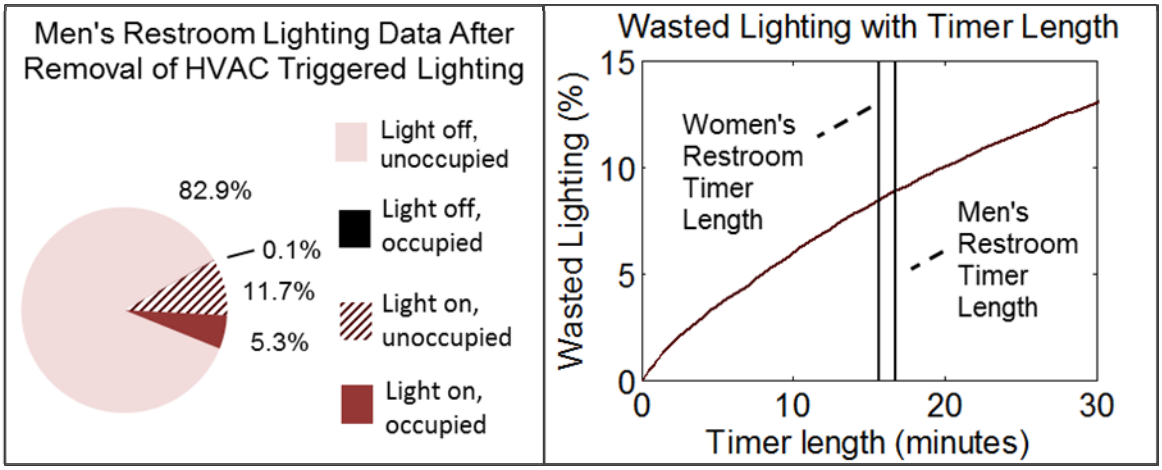

Figure 9. Lighting data in the men's restroom after the removal of lighting triggered by the HVAC system is shown on the left. Evaluation of wasted lighting with varying timer lengths for the restrooms in the building is shown on the right.

Application to Actual Industrial Facilities

Although the experimental results presented in the paper come from a non-industrial building, these results illustrate general advantages that long-term monitoring have over traditional one-day energy assessments. In the following section, potential opportunities that were identified in industrial facilities are discussed. These opportunities were identified during one-day energy assessments through the IAC program, but sufficient time wasn't available during the visit to properly analyze the energy saving opportunities. These additional recommendations could have been made through long-term monitoring of equipment or processes. These opportunities serve to reinforce the benefit of long-term monitoring in industrial facilities by providing specific examples.

- In a certain manufacturing process, the temperature of process equipment had to be maintained to a tight tolerance. In controlling the temperature of the equipment, natural gas was used for heating and water was used for cooling. During the one-day energy assessment, the system was observed to operate frequently both in heating and cooling mode in maintaining the equipment. Because of necessary startup conditions, the controller was set to aggressive performance, which caused significant oscillations during steady state operation. This faulty condition likely resulted in significant energy loss, but insufficient data were available to quantify the potential savings in adjusting the temperature controller parameters. Long-term monitoring would enable both the verification of the oscillatory condition as well as the quantification of potential energy savings and cost reductions.
- In one manufacturing facility, the plant runs one full shift with a complete staff and two reduced shifts with minimal staff. These reduced shifts primarily fulfill custom orders and don't require the full facility. All the lighting and support equipment remain on during these other shifts, even though much of this equipment isn't needed. However, plant personnel weren't aware of what equipment or lighting was necessary for the reduced crews to perform their work. Monitoring of lighting and other equipment would

reveal energy saving opportunities by reducing equipment and lighting runtime to only those times necessary.

- A manufacturing plant used a regenerative thermal oxidizer (RTO) to treat the plant's exhaust air. This RTO expelled a large amount of heat that could be potentially used to preheat the boiler make up water supply. Insufficient information was available to estimate the potential energy and cost savings of this recommendation. However, monitoring of the RTO operating conditions would allow accurate evaluation of the energy efficiency opportunity. As the RTO consumed a significant amount of plant energy, this represented a large potential energy-saving opportunity.

Conclusions

As the cost and difficulty of long-term monitoring with data loggers continues to decrease, additional energy saving opportunities become available to building and plant managers. Many of these opportunities require data collection beyond what can be accomplished in a one-day energy assessment. Plant managers can install data loggers and monitor equipment with minimal cost and effort. The collected data can reveal additional and often significant opportunities to reduce utility usage with minimal effort. This paper presented results from four specific examples on how long-term monitoring revealed additional opportunities to improve building performance. Each of these opportunities was identified with minimal effort and data processing. These test cases serve to illustrate the value in augmenting one-day energy assessments with long-term monitoring. As costs to monitor systems with data loggers continue to decrease, building operators can analyze these additional energy-saving opportunities with minimal investment.

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