How the Use of Lighting Controls Affects Energy Use – A Case Study

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Energy use in buildings is closely linked to operational and space utilization characteristics as well as the behavior of the occupants. Occupants can affect the building energy consumption due to their presence and activities in the building. This can lead to an energy consumption difference between the values estimated in design and the values obtained during the occupied phases of a building's life cycle. This paper focuses on the analysis of energy used in a building lighting system and how the occupant's use of the system can affect the amount of energy consumed. Analysis found that occupant failure to properly use manual controls led to considerable energy waste. Two systems to increase energy efficiency using automation were examined and evaluated based on equipment cost and the value of the anticipated savings.

Key Words: Energy Performance, Lighting Control, Occupancy Sensor, Time of Day Control

Introduction

During the 1970's architects and engineers gathered to talk about ways of improving the performance of buildings, yet still energy consumption and the production of greenhouse gas in the United States continued to rise at an alarming rate (Wagner & Mellblom, 2008). As a result, building regulations such as the European Buildings Directive in Europe, Minergie in Switzerland, or programs such as LEED (Leadership in Energy and Environmental Design) in the U.S. have been established (Schlueter & Thesseling, 2009).

Many buildings designed under these programs have now been occupied, but it hasn't been determined if these buildings are living up to expectations. Building performance needs to be measured by means of post occupancy evaluations (POEs). A sustainable design effort is not the only important parameter for green building certification, the building should also have a sustainable performance after construction has been completed (Newsham, Mancini, Birt, 2009).

The importance of energy performance in building design is considered more today due to the growing awareness of climate change and new building regulations around the world (Schlueter & Thesseling, 2009). In the United States, buildings use approximately 40% of total energy, release 30% of greenhouse gases, consume 70% of electricity, 40% of raw materials and 12% of fresh water supplies. Architects, planners, and constructors are enforced by organizations such as the U.S. General Services Administration (GSA) to respect the energy codes in the design of federally owned buildings. They are starting to consider more environmentally-friendly features in their projects, creating greener buildings (Azhar & Brown, 2009).

The European Union's Energy Performance of Buildings Directive emphasizes that lessening energy consumption is not only a technological problem but also a social one. In other words, reducing energy consumption is affected by not just how buildings are designed, but how they are built, commissioned, and used. Consequently, factors like occupant behavior are as important as the design and construction of buildings for lower energy usage (Janda, 2009).

Occupant behavior is one of the most important input parameters influencing the results of building performance simulations (Hoes, Hensen, Loomans, Vries, Bourgeois, 2008). Where technology is operated by humans, failure of the human component to control the environment can derail the whole mission. Leaving lights and equipment on at the end of the day or during the day, poor zoning and controls are behavioral reasons for wasteful energy consumption (Masoso & Grobler, 2008). Energy education should be more comprehensive, integrated, hands-on, and iterative if the aim is to make people take more responsibility for their role in the built environment (Janda, 2009).

This study explores how occupants affect the energy use in a LEED building. It focuses on energy consumption related to lighting use in classrooms and labs and looks at the relationship between LEED expectations and the real world. The Gorrie Center at Auburn University which houses the School of Building Science has a LEED Gold certification and was examined to provide answers to the questions:

- What is the relationship between expected energy consumption using LEED guidelines and actual consumption measured after the building is occupied?
- What are the energy usage details for lighting use (On/Off + Occupied/Vacant)?
- Can provisions be made to reduce unnecessary energy use in the building?

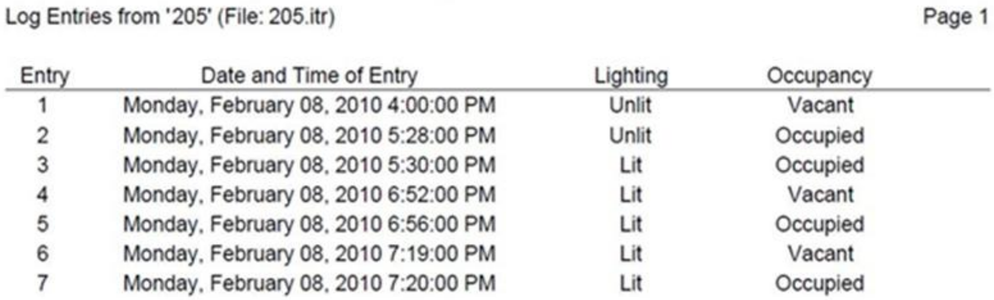
As Clark Kerr explains, “Universities are the most long-lived organizations in the world”. Universities have the longevity and stability to realize the lifecycle cost savings necessary to make green buildings economically practical (M’Gonigle & Starke, 2006). McGraw Hill also reports that high-performance lighting controls, a sustainable technology, can result in 6.7% enhanced productivity among students and faculty (U.S. Green Building Council, 2008). As building occupants become increasingly aware of the unique, sustainable nature of their facilities, they will take more pride in maintaining them (Martin, 2006).

Methodology

The classrooms, computer lab and thesis lab in the Gorrie Center were found appropriate for monitoring occupancy and lighting loads. The lighting in these rooms is controlled by manual light switches. Since this involves occupant interaction, analysis of the energy use related to the lighting system was meaningful for the study objectives.

Lighting and occupancy was monitored in each room for a one month period. A combination motion sensor/photocell was used for monitoring each room. The units were supplied by Watt-Stopper, Inc. model #IT-200. These devices log both occupancy and lighting on/off state simultaneously. The units are clipped to the ceiling grid and a small arm extends into the cell of a lighting fixture to sense whether the fixture is on or off. Placement was tested to ensure ambient light from room windows did not interfere with the data collected. A built in motion detector along with an adjustable time delay logged the present of people in the room. The placement and sensitivity was also tested to ensure an accurate depiction of occupancy in the space. Three sensors were used to monitor a total of 6 rooms between February 8th and March 5th 2010, and between March 5th and April 2nd 2010.

The sensor log data indicates the lit/unlit status of the fixture and the vacant/occupied condition of the space along with the time either status changed. An example of the log file created by the sensors and downloaded to computer is shown below in Figure 1.



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Log Entries from '205' (File: 205.itr)                                    Page 1

Entry        Date and Time of Entry                 Lighting       Occupancy
  1     Monday, February 08, 2010 4:00:00 PM         Unlit          Vacant
  2     Monday, February 08, 2010 5:28:00 PM         Unlit          Occupied
  3     Monday, February 08, 2010 5:30:00 PM         Lit            Occupied
  4     Monday, February 08, 2010 6:52:00 PM         Lit            Vacant
  5     Monday, February 08, 2010 6:56:00 PM         Lit            Occupied
  6     Monday, February 08, 2010 7:19:00 PM         Lit            Vacant
  7     Monday, February 08, 2010 7:20:00 PM         Lit            Occupied
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Figure 1: Snapshot From Log Data Sheet (Created by the Sensors)

The figure above indicates at 4 pm room 205 was unlit and vacant. It remained that way until 5:28 when someone entered the room. Shortly thereafter the lights were turned on at 5:30 and the room was both lit and occupied until 6:52. In addition to the logs, additional programing furnished by Watt-Stopper provided compilation of the log data into graphs and reports which are used below. Graphs include Average Use and Lighting/Occupancy Summary.

Expected Occupancy assumptions were created for each classroom based on the daily schedule for that class obtained from school records of classroom use. This was used to establish occupancy that would have been expected at design to forecast building energy use. It was assumed that occupants come to the classroom an hour before the first class or scheduled activity and that they stay an hour afterward.

Another assumption was made when very short periods of unoccupied status appeared in the logs as in Figure 1 above, entries 6 & 7. When the room went vacant at 7:19 then occupied a minute later at 7:20, that this was most likely attributable to a failure of the motion sensor to sense activity in the room due to lack of complete coverage. As the data was thoroughly analyzed, these small errors became obvious and the data was corrected to eliminate them. Using available sensor data, the calculated motion sensor coverage for the rooms ranged from 48% of the floor area to 95% of the floor area. Where more floor area was covered these errors were, as expected, greatly reduced. It is assumed that these corrections had no effect on the data analysis.

One method of eliminating the negative impact of occupant failure to turn off lights would be to install motion sensors to detect occupancy and automatically turn off lights when the room is unoccupied. Using this approach, the wasted energy would yield a savings for each room. This value was calculated using the number of hours the room was lit but unoccupied, assuming this wasted energy for the room lighting would be saved during these hours.

Another, slightly less effective method of reducing the negative impact of occupant behavior is to control the room lighting with a time of day timer. A time schedule was established to allow local manual control of lights in the rooms between the hours of 6 am and midnight on weekdays and noon until midnight on weekends. After midnight the lights would be automatically turned off until the established "on" time the next day. To implement this approach, the gathered data was modified to simulate lights were turned off during the designated hours and the calculations for energy cost were repeated using the remaining data as collected.

The data reported for each room includes three different components. The first describes and graphs the data collected from the sensors in three categories: On+Occupied, On+Vacant, and Off+Vacant. The cost of energy wasted to light rooms while vacant is calculated. This energy could be recovered with an automatic motion sensor system. The second component compares the expected occupancy and the occupancy actually observed with the sensors. This data shows the difference in energy projections that would be made at design and energy actually used once occupied. The third component incorporates the application of a time of day system and calculates energy savings that could be recovered with that type of system.

Data

The following considerations were used for calculating the results:

- Each light fixture in the rooms consumes 96 watts of electricity.
- The energy cost is $0.11 per kW hour.
- The calculation of potential savings is based on an annual (365 day) period

Room 205 was monitored from February 8, 2010 to March 5, 2010. It is a 35 seat classroom with desktop computers and twenty 3-lamp fluorescent fixtures utilizing a total of 1920 watts of electrical input. Of the total elapsed time (564 hours), the lighting remained on with the room vacant 44% of the time. The estimated annual cost of energy wasted to power the lights while the space was unoccupied is approximately $735. Figure 2 below shows the breakdown of the three basic conditions: on and occupied, on and vacant, off and vacant.

The Expected Occupancy based on class schedules for the 26 day monitoring period was 197 hours. Occupants actually used 16 additional hours adding an annual cost of $47 above expected projections. The result is this room's actual annual energy consumption for lighting is $782 higher than design models would indicate - this increase being directly attributable to occupancy and occupant behavior.

A time of day system would have reduced the On+Vacant time by 39 hours during the monitoring period resulting in $115 annual savings.

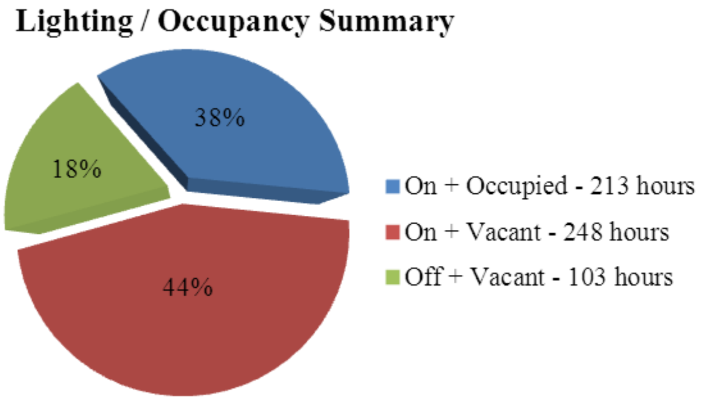

Figure 2: Room 205

Room 227 is a 60 seat classroom with tables and chairs only – no computers. It utilizes twenty four fluorescent lighting fixtures consuming 2304 watts. It was monitored from February 8, 2010 to March 5, 2010. Of the total elapsed time (593 hours), the lighting remained on with the room vacant 60% of the time as shown in Figure 3 below. The estimated annual cost of energy wasted to power the lights while the space was unoccupied is approximately $1,260.

The Expected Occupancy based on class schedules was 164 hours for the 26 day monitoring period. Occupants used an additional 37 hours representing $132 additional cost for lighting. Total lighting energy cost is $1392 more than design estimates.

A time of day system would have reduced the On+Vacant time by 111 hours during the monitoring period resulting in $395 annual savings.

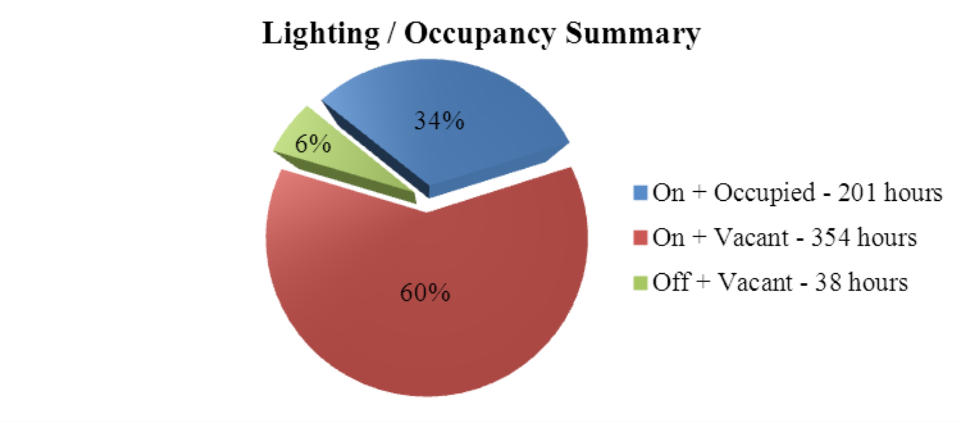

Figure 3: Room 227

Room 303 is a 30 seat classroom with tables and chairs only – no computers installed. It utilizes sixteen fluorescent lighting fixtures consuming 1536 watts. It was monitored from March 5, 2010 to April 2, 2010. Of the total elapsed time (643 hours), the lighting remained on with the room vacant 43% of the time as indicated in Figure 4 below. The estimated annual cost of energy wasted to power the lights while the space was unoccupied is approximately $593.

The Expected Occupancy based on class schedules for the 29 day monitoring period was 83 hours. Occupants used 18 additional hours representing $38 additional cost for lighting. Total lighting energy cost is $631 more than design estimates.

A time of day system would have reduced the On+Vacant time by 85 hours during the monitoring period resulting in $181 annual savings.

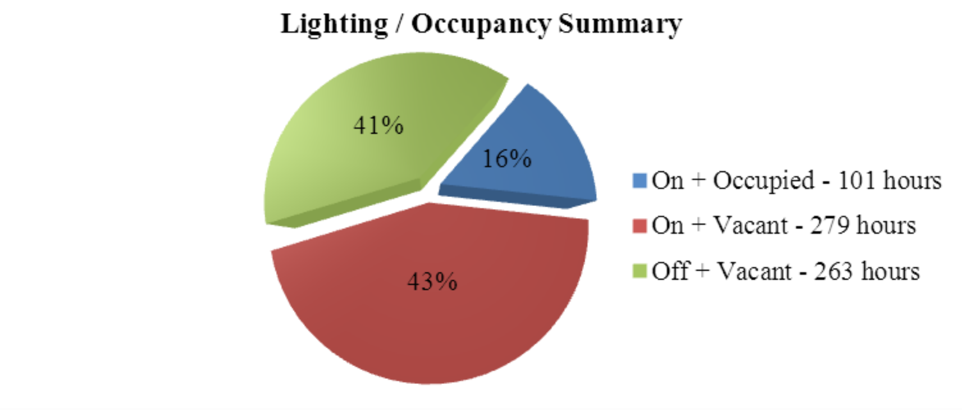

Figure 4: Room 303

Room 307 is a 20 seat classroom with desktop computers. It utilizes twelve fluorescent lighting fixtures consuming 1152 watts. It was monitored from March 5, 2010 to April 2, 2010. Of the total elapsed time (662 hours), the lighting remained on with the room vacant 61% of the time as shown in Figure 5 below. The estimated annual cost of energy wasted to power the lights while the space was unoccupied is approximately $649.

The Expected Occupancy based on class schedules for the 29 day monitoring period was 168 hours. Occupants used 8 additional hours representing $13 additional cost for lighting. Total lighting energy cost is $662 more than design estimates.

A time of day system would have reduced the On+Vacant time by 112 hours during the monitoring period resulting in $179 annual savings.

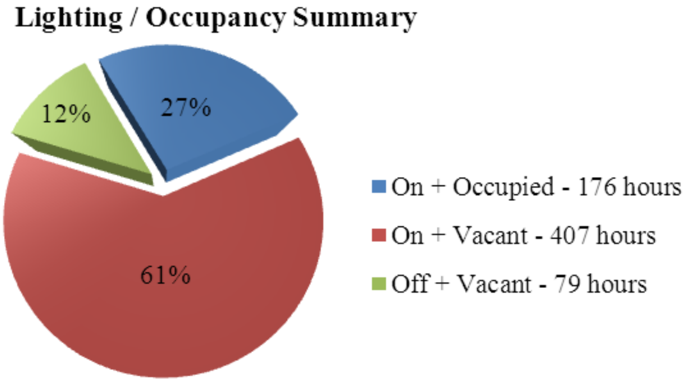

Figure 5: Room 307

Room 325 is an 8 seat computer peripheral room with desktop computers, printers, plotters and scanners. It utilizes four fluorescent lighting fixtures consuming 384 watts. It was monitored from March 5, 2010 to April 2, 2010. Of the total elapsed time (670 hours), the lighting remained on with the room vacant 69% of the time as shown in Figure 6 below. The estimated annual cost of energy wasted to power the lights while the space was unoccupied is approximately $244.

The Expected Occupancy based on class schedules for the 29 day monitoring period was 163 hours. Occupants used 6 additional hours representing $3 additional cost for lighting. Total lighting energy cost is $247 more than design estimates.

A time of day system would have reduced the On+Vacant time by 156 hours during the monitoring period resulting in $83 annual savings.

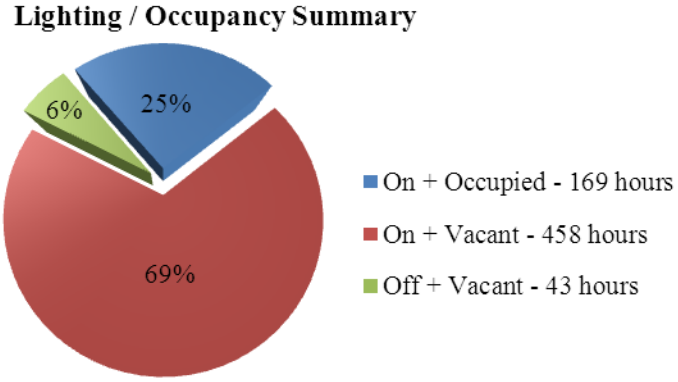

Figure 6: Room 325

Room 327 is a 25 seat senior thesis work room with desktop computers and larger work areas. It utilizes twenty five fluorescent lighting fixtures consuming 2400 watts. It was monitored from February 8, 2010 to March 5, 2010. Of the total elapsed time (597 hours), the lighting remained on with the room vacant 64% of the time as shown in Figure 7 below. The estimated annual cost of energy wasted to power the lights while the space was unoccupied is approximately $1,423. Since this room is the largest room and is often partially occupied, its data is more prone to error due to insufficient occupancy coverage. Where this was evident, appropriate corrections were made to the data.

The Expected Occupancy based on class schedules for the 26 day monitoring period was 209 hours. Occupants used 2 additional hours representing $7 additional cost for lighting. Total lighting energy cost is $1,430 more than design estimates.

A time of day system would have reduced the On+Vacant time by 176 hours during the monitoring period resulting in $652 annual savings.

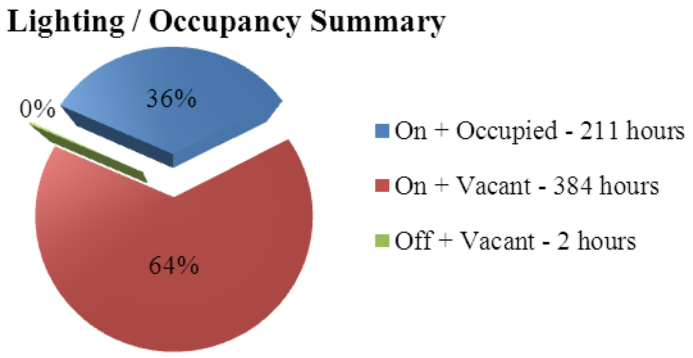

Figure 7: Room 327

Results and Conclusions

The data revealed how effectively the occupants used the manually controlled lighting switches in the monitored rooms. The expected occupancy was also less than the observed occupancy creating an even larger difference between the design expectations and actual energy used after occupation.

The investigation revealed that for the Gorrie Center, occupant behavior can significantly affect energy costs or savings. The failure of occupants to turn off lights when the monitored rooms were vacant resulted in significant additional energy cost. For the 6 monitored rooms, 43% of the energy used for lighting was wasted representing $2,907 per year.

As summarized in Figure 8, energy projections made during design, based on expected use of the rooms, fell short of the actual energy used after occupancy. Accounting for occupant behavior and increased occupant use, the actual energy cost per year was 208% higher than expected. Use of an automatic lighting control system to reduce the impact of occupant behavior can result in significant energy savings. Use of a motion sensor system could save $4,904 per year or 64%. Use of a time of day control system could reduce energy costs by $1,459 or 19% annually.

Estimated cost for implementing a motion sensor system for the classrooms is $2,400 (Tatum, 2010). With annual energy savings indicated above, the system would pay for itself in 6 months. A time of day system with an estimated cost of $1600, would have a payback period of 14 months.

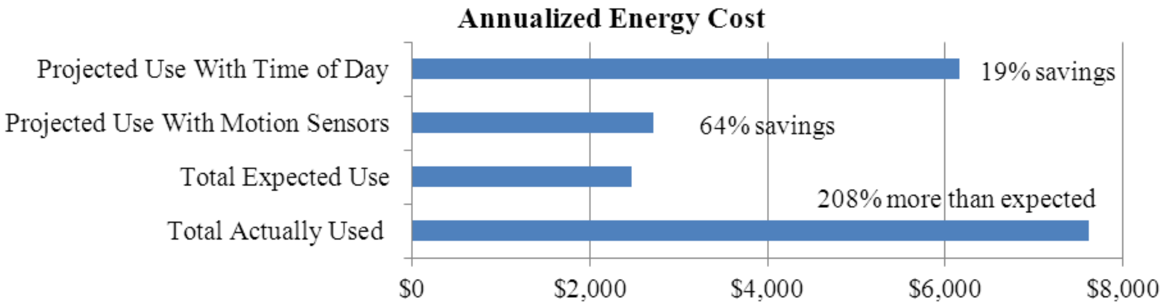

Figure 8: Combined Summary for All Six Rooms Monitored

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