A MODEL FOR EVALUATION OF LIFE-CYCLE ENERGY SAVINGS OF OCCUPANCY SENSORS FOR CONTROL OF LIGHTING AND VENTILATION IN OFFICE BUILDINGS

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ABSTRACT

Lighting and ventilation represent the majority of the air conditioning loads in office buildings in hot humid climates. Use of motion sensors is one way to minimize the energy used for these loads. This paper describes the methods used for simulating a case study building with motion sensors installed and the monitoring of system on-off statistics related to occupant patterns. It also describes the development of the Monte Carlo model used to predict the on-off status of sensors. The building using the motion sensors is compared to a building that controls the lights and ventilators by a conventional pre-programmed schedule. The conventional methods of simulation were shown to generate misleading information regarding electric demand charges and life-cycle costs of the building. When comparing to actual use patterns, the Monte Carlo process was shown to represent an adequate way to represent the on-off patterns. Computer simulations further demonstrate the potential life cycle cost savings from the use of the motion sensors.

INTRODUCTION

Energy consumption for lighting and ventilation are especially acute in hot humid climates. Energy use by the lighting fixtures themselves represents a large fraction of annual energy use, and in addition the lights add an extra burden to the air conditioning loads. Ventilation air typically has high enthalpy values because of the high outdoor temperatures and humidity, so this represents an extra load for most of the year in what is already a heat-rich environment. Reductions in lighting and ventilation loads would therefore be an asset toward attempts to reduce energy use and utility bills.

The author previously described the computer model calibration difficulties when motion sensors are present to control lights and exhaust fans (Degelman 1999). The previous study reported on a case study building (in Nagoya, Japan) with motion sensors installed to control corridor lights and toilet room lights and exhaust fans. The data from that building were later used in this new study to test the concept in a hot-humid climate.

To describe occupancy and lighting profiles in energy simulation software, we normally use profiles that fix the hourly values to a specific number between 0 and 1 (or 0 to 100%). A profile for typical office lighting is shown in Figure 1. This represents a normalized pattern in which a certain fraction of the lights are presumed to be on for each hour throughout the day. When this curve is used in a simulation model, the electric use for lights follows a rather repetitive and predictable pattern. When motion sensors control the lights, however, a more erratic pattern results with many spikes and valleys. One sample day of measured data from the Nagoya office building is shown in Figure 2. Though the patterns in Figures 1 and 2 resemble each other at a gross level, when viewed from minute to minute, they vary quite significantly. The previous paper demonstrated that when there are high numbers of rooms being controlled by motion sensors, there might be significant reductions in peak power demand because of the randomness of the on-off patterns from room to room. When random on-off patterns for many rooms are summed, they result in a power demand that is much lower than the peak power demand of one room multiplied by the number of rooms. The result of using motion sensors can therefore reduce peak demand charges as well as reducing total energy consumption in the building.

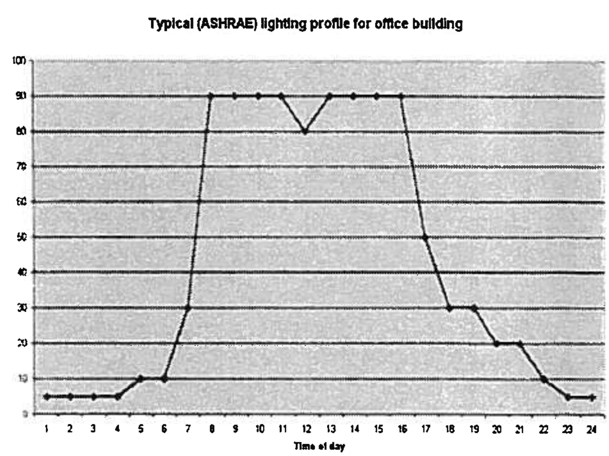

Figure 1. Typical lighting profile for use in computer simulation models

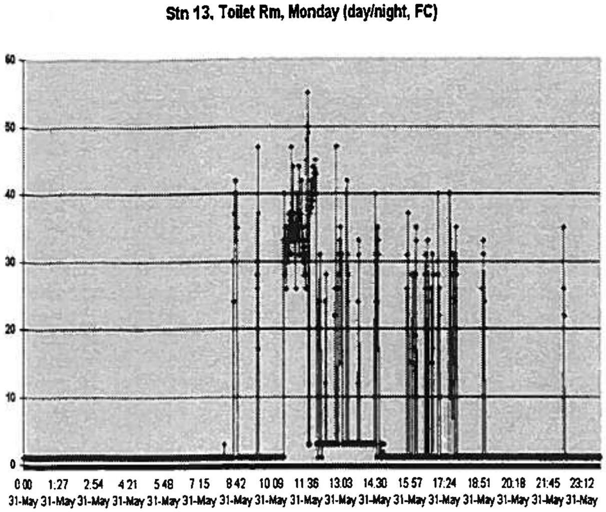

Figure 2. Measured lighting profile when a motion sensor controller is present

CASE-STUDY BUILDING

The case-study building for this project is a U-shaped combination office/laboratory/classroom building on the campus of Nagoya University (See Fig. 3). There are approximately 268 offices on the 10 floors. Occupancy sensors control only the corridor lights and the toilet room lights and exhaust fans.

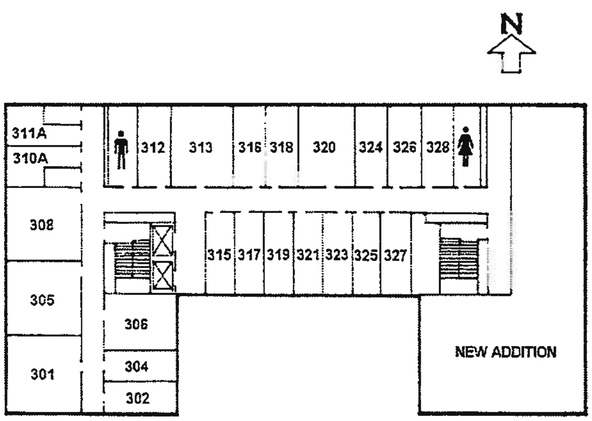

Figure 3. Typical office floor plan in the case study building.

Each office has an individually controlled heating/cooling unit in the ceiling with a wall thermostat in each room. The lighting is provided by six (6) ceiling surface-mounted fluorescent fixtures (2-40w each), totaling 480w for the 26-m^2 room. None of the fixtures have diffuser lenses. There are two light switches – one controls the two fixtures nearest the window, the other controls the four fixtures nearest the corridor side.

Other building characteristics are as follows:

- Size: 10-story, 62m by 30m, U-shaped plan, with entrance on the second floor.
- Gross floor area: 15,980 m^2.
- Wall: 25 cm thick (10 cm brick, 5 cm rigid insulation, 10 cm block); U.F. 0.79 W/m^{2}K, per Table 4, Chap 24 (ASHRAE 1997).
- Windows: Single pane clear glass w/ aperture ratio of 0.82, aluminum frames, and venetian blinds at 45-deg. open; U.F. of 6.47 W/m^{2}K, SHGC of 0.476 and visible transmittance of 0.437, per Tables 11 and 25, Chap. 29 (ASHRAE 1997).
- Lighting power densities: 18.2 W/m^2 in offices, labs and classrooms; 1.8 W/m^2 in corridors; 6.2 W/m^2 in elevator lobbies; 12.1 W/m^2 in toilet rooms; 4 W/m^2 in the entry lobby; and 3.3 W/m^2 in stairwells.
- Typical office: 3.57m by 7.4 m, or 26 m^2.

Motion sensors control lights (ON/OFF control) in the entrance lobby and in all corridors and restrooms. Corridors have three zones on separate motion sensors. A typical ceiling-mounted motion sensor in the corridor is shown in Figure 4.

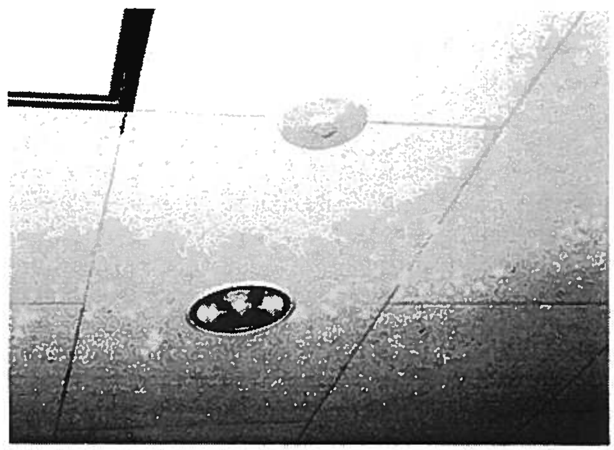

Figure 4. Typical ceiling-mounted motion sensor and recessed compact fluorescent light.

For simulating this building relocated to the U.S., mostly all building physical characteristics were maintained. The lighting power density, at 18.2 W/m^2, in the office spaces represents the predominant lighting load in the building. This is just slightly higher than the Standard 90.1 value of 16 W/m^2 for enclosed offices (ASHRAE/IESNA 1999). The toilet rooms were left at 12 W/m^2. The corridors lighting level at 1.8 W/m^2, however, was far below what would be common in the U.S., so this was reset to the Standard 90.1 value 7.5 W/m^2.

COLLECTING USE STATISTICS

The building use statistics were collected by using Hobo® data loggers. The loggers were set to sense light levels and were fastened to corridor walls in the different lighting zones on each floor and to the toilet room walls so as to avoid daylight from the window but to sense light from the ceiling fixtures. The loggers' time interval was set to one minute. Loggers were left in place for 5.5 days (capturing 7943 data points). Loggers were all set to begin logging at precisely the same instant. Lights switch on instantaneously when motion is sensed and turn off after motion has ceased for 4 minutes and 20 seconds. By analyzing the logged data, it was determined that during working hours the corridor lights remained on around 68% of the time and restroom lights were on around 40% of the time. During non-working hours and nighttime, the corridor lights were on for 28% of the time and the toilet room lights were on for 10% of the time. One of the data loggers is shown attached to a hallway door in Figure 5.

Figure 5. Wall-mounted Hobo data logger.

Samples of the logged data are shown in Figures 6 through 8. The lowest value from the loggers is shown as 1 (off), rather than a zero value.

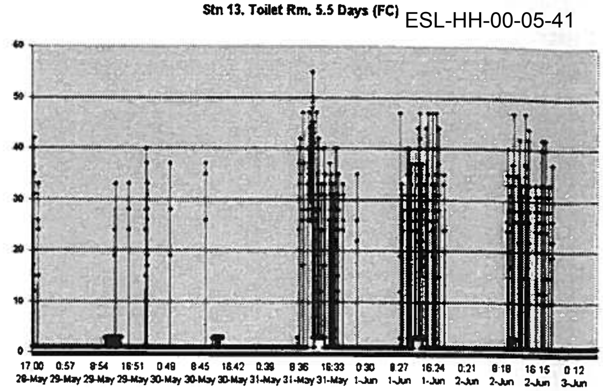

Figure 6. Measured lighting profile for 5.5 day period.

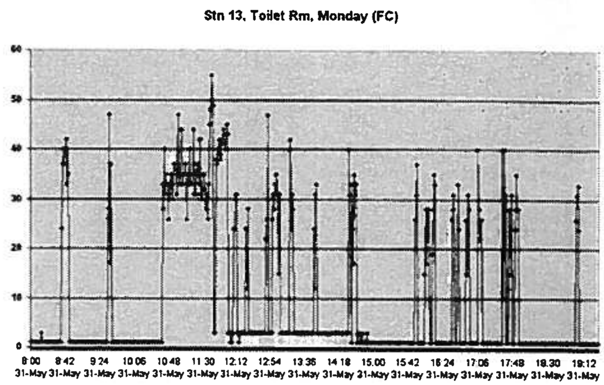

Figure 7. Logged toilet room data for Monday daytime.

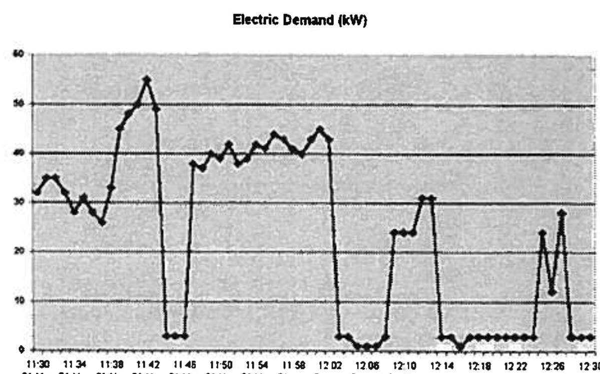

Figure 8. Logged toilet room data for one hour.