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A Field Demonstration of Energy Conservation Using Occupancy Sensor Lighting Control in Equipment Rooms

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SUMMARY

The occupancy sensor lighting control study was sponsored by the Hanford Energy Management Committee (HEMC), which is chaired by U.S. Department of Energy, Richland Field Office staff. The Pacific Northwest Laboratory identified energy savings potential of automatic equipment-room lighting controls, which was demonstrated by the field experiment described in this report.

Occupancy sensor applications have gained popularity in recent years due to improved technology that enhances reliability and reduces cost. Automatic lighting control using occupancy sensors has been accepted as an energy-conservation measure because it reduces wasted lighting. This study focused on lighting control for equipment rooms, which have inherent conditions ideal for automatic lighting control, i.e., an area which is seldom occupied, multiple users of the area who would not know if others are in the room when they leave, and high lighting energy intensity in the area.

Two rooms were selected for this study: a small equipment room in the basement of the 337 Building, and a large equipment area in the upper level of the 329 Building. The rooms were selected to demonstrate the various degrees of complexity which may be encountered in equipment rooms throughout the Hanford Site.

The 337 Building equipment-room test case demonstrated a 97% reduction in lighting energy consumption, with an annual energy savings of $184. Including lamp-replacement savings, a total savings of $306 per year is offset by an initial installation cost of $1,100. The installation demonstrates a positive net present value of $2,858 when the lamp-replacement costs are included in a life-cycle analysis. This also corresponds to a 4.0-year payback period.

The 329 Building equipment-room installation resulted in a 92% reduction in lighting energy consumption. This corresponds to annual energy savings of $1,372, and a total annual savings of $2,104 per year including lamp-replacement savings. The life-cycle cost analysis shows a net present value of $15,855, with a 5.8-year payback period.

Although the results demonstrate that occupancy sensor lighting control in equipment rooms is a cost-effective energy-conservation measure, the installation can be labor intensive. A sensitivity analysis reveals that minor changes in labor assumptions can change the economic outlook drastically. Therefore, a follow-up study to investigate other, less complicated means of effective lighting control should be pursued, and the follow-up study has been proposed.

ACKNOWLEDGMENTS

The author would like to thank many people who have helped with the project. Darrel Hatley's contributions, particularly in site identification and installation coordination, were invaluable additions to the project. The author thanks members of the Hanford Energy Management Committee for their support and encouragement throughout the project. Steve Weakley, as the liaison between the research staff and the energy management committee, was very supportive and helpful throughout the study. And finally, many thanks to Steve Merrick, who was instrumental in starting the project, and was responsible for the original implementation plan and project scope. With guidance and mentoring, Steve helped me get started in the project and I am grateful for his contributions in that regard.

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1.0 INTRODUCTION

Building equipment rooms, in which heating, ventilation, air conditioning, and other machinery are located, must have acceptable lighting in order for maintenance personnel to carry out their work. However, although these equipment rooms are seldom occupied, the lights are generally left on continuously. Although the natural solution would seem to be to have the workers turn off the lights when not in use, several compounding factors eliminate this simple solution. In addition to many rooms not even equipped with light switches, other factors such as multiple entry points and large rooms where multiple teams may be working independently lead to the conclusion that conventional light switches are not appropriate. Employing automatic lighting control using occupancy sensors is an effective means of reducing the amount of energy consumed for equipment-room lighting.

This report documents the equipment-room lighting evaluation task using motion sensor controls performed for the Hanford Energy Management Committee (HEMC) by Pacific Northwest Laboratory (PNL).[a] The task supports the energy reduction mission mandated by Executive Order 12759, which calls for a 20% reduction in the use of energy in federal buildings and facilities and in federal operations by the year 2000 (DOE 1992).

This study investigates applying lighting control occupancy sensors in two equipment rooms on the Hanford Site. The rooms were chosen to represent differing complexity. In addition to evaluating energy savings, issues such as installation cost, operational characteristics, and user acceptance are also explored. Although the primary objective is determining cost effectiveness, the other issues are important when considering the potential for wide-scale implementation of the technology.

The two rooms selected for the study were an equipment room in the 337 Building and one in the 329 Building. The 337 Building equipment room, located in the basement, is a relatively straight-forward implementation of the technology. Two lighting circuits with a total of 1280 watts of

(a) Operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

fluorescent lighting are controlled by two ultrasonic motion sensors connected in parallel. Before the sensors were installed, the lights were left on continuously because the light switches are on the far end of the room. The size and layout of the room ensures that practically every location in the room is within the range of one of the sensors.

The other room selected for the study was the top floor of the 329 Building. This area is large and rather complex compared to the 337 Building installation. A total of 11 circuits with over 10,000 watts of fluorescent lighting required a total of 11 ultrasonic and infrared motion sensors divided into three independent control zones. Before the motion sensors were installed, the lights were on continuously because most of the circuits were not equipped with light switches. Even with the extensive amount of motion sensor coverage, there are still areas in which maintenance personnel may be working for extended periods of time out of the range of a motion sensor. This problem has been mitigated by installing time-delay bypass relays for those special circumstances. Occupants can specify a time delay during which the lights remain on despite the operation of the motion sensors.

The complexity of the 329 Building installation, determined to be beyond that of a typical installation for the Hanford Site, is well suited to contrast the relatively simple 337 Building installation and demonstrate a broad range of installation and operational difficulty. In addition to reporting the results of these two studies, this report will document generic characteristics discovered with motion sensors, and explore issues associated with wide-scale implementation.

The report contains five sections. In Section 2, the background of occupancy sensors and generic issues of installation are presented. Section 3 details the study approach and specifics of the two installations. The results of the study are presented in Section 4, and Section 5 contains conclusions and recommendations.

2.0 BACKGROUND

The following section discusses motion sensor technology and installation issues which are applicable to the overall technology. Issues relating to the field demonstration installations are discussed in later sections.

2.1 MOTION SENSOR TECHNOLOGY

Motion sensor lighting control has gained acceptance in recent years through technological advances that improved the reliability and reduced the cost of the sensors. Motion sensors are used to detect the presence of people in a specified area by detecting movements associated with personnel activity.

Traditionally used for security purposes, motion detection is now widely used for lighting control. Many national, regional, and local energy efficiency standards now incorporate specific allowances for occupancy sensors, another term for motion sensors, recognizing their efficient means of reducing wasteful energy consumption (WSEO 1991).

The two most widely available types of motion sensors are ultrasonic and infrared. Ultrasonic sensors work on the principle of the Doppler Shift. The sensor emits a high-frequency inaudible sound and measures the rate of the return of the reflected signal from objects in the room, thus enabling the sensor to detect motion (Novitas, Inc. 1988). Infrared sensors detect a moving heat source by continuously monitoring the ambient thermal environment (Cable Electric Products 1989). Because these sensors operate by very different principles, there are advantages and disadvantages with each of them.

Generally, ultrasonic detectors are better suited for applications such as storage areas, hallways, restrooms, and large open areas. They are poorly suited for areas which have high ceilings, high air movements, or are not enclosed. Infrared sensors are good for applications which are enclosed and have no obstructions, have high air movements, high ceilings, are a wall switch replacement, and hallways. However, they are poorly suited for restrooms, storage areas, and large spaces (Lane 1992).

The characteristics of equipment rooms must be considered when determining a preferred type of detector. A large enclosed area that contains obstructions would indicate the use of ultrasonic sensors. However, equipment rooms also have high air movement and often have high ceilings. Therefore, one aspect of the study is to determine the best type of detector for equipment-room lighting control.

To effectively utilize the best of both sensor characteristics, vendors recently introduced hybrid motion sensors that use both ultrasonic and infrared detectors. One concept requires that both of the sensors detect motion before the lights will be turned on, while only one of the sensors detecting motion is adequate to keep the lights on. Although hybrid motion sensors may be the preferred technology alternative, they were not available at the time the study began, and were not included in the demonstration project.

2.2 INSTALLATION ISSUES

It is impractical to design a system in which any occupant of the room is within range of a motion sensor at all times. Also, the motion detector may not continuously detect the presence of occupants. To compensate for these factors, there is a time delay included between the last detected motion and switching the lights off in order to avoid interfering with normal work activities. The time delay must be kept short to minimize the amount of unnecessary lighting after the occupants exit the area, about 5 to 12 minutes. To properly detect the presence of occupants, it is necessary to have enough sensors in areas where they are expected to spend considerable time.

Setting the correct sensitivity of the sensors is a critical factor during installation. The motion detectors should detect motions such as people walking and performing work activities. However, if the sensitivity is too extreme, normal ambient noise or other interference may trigger the device to switch improperly. Ensuring that the lights do not turn on unnecessarily is the most difficult aspect of setting the proper sensitivity.

Ultrasonic sensors are generally more accurate for detecting little motion and are more susceptible to false tripping. This is especially true in equipment rooms, where the room may have considerable vibration or air movement. Therefore, infrared sensors should be used when the ambient noise and interference prevents ultrasonic sensors from operating correctly.

3.0 STUDY APPROACH

This section discusses the approach taken, and documents the implementation of the demonstration project. The analysis methodology and assumptions are included in this section. The operational experience, installation performance, and analysis results are given in Section 4.

3.1 OCCUPANCY SENSOR INSTALLATION

Ultrasonic occupancy sensors were initially selected, although infrared sensors were eventually required in the 329 Building installation due to high ambient noise and interference. Because the frequency of occupation is expected to be low in the area throughout the day, the maximum allowed time delay setting is used. This reduces the likelihood of the lights turning off when someone is in the room. Because the frequency of occupation is low, the amount of unnecessary lighting from the time delay after occupants exit is not a significant factor. The installation is designed as a permanent fixture, conforming to appropriate codes and standards and installed by craft services personnel. This approach yielded installation cost data, which is necessary in order to estimate the potential for eventual wide-scale implementation.

The 337 Building room arrangement requires two sensors to provide coverage over most of the room. The occupancy sensors used are Novitas, Inc. Light-O-Matic™ ultrasonic occupancy sensors. In addition to the sensors, relays are installed to switch the lighting circuits using 15 volt direct-current control wiring. Because two lighting circuits were present, two switching relays are installed, with both sets of relays and sensors connected together at the 15 volt control wiring. Therefore, both lighting circuits are energized when either sensor detects motion.

The 329 Building installation is far more complex. The area was divided into three control zones, with all of the lights in each zone controlled by all of the sensors within that control zone. This allows a segmented approach to lighting control. Only the zone with occupants present will be lit. The zones are divided as follows:

- North Room - At the north end of the building, this room contains large air filters and other air handling equipment and has a high ceiling. There are two lighting circuits in this room.
- Center Area - A large open area, this zone is roughly square with a lot of duct work along the floor and pieces of machinery throughout. There are five lighting circuits.
- South Area - In addition to a switchgear room, there are large pieces of air handling equipment and a long corridor. This area is expected to have the most routine short-duration traffic. There are three lighting circuits in this zone.

Different occupancy sensors are used depending on the location and characteristics of the various scanning areas. The original design called for 8 ultrasonic occupancy sensors and 11 switching relays. Four of the sensors were to be one-way room sensors, three two-way sensors, and one warehouse/corridor sensor. However, during the installation there were problems encountered with the sensors and the design was modified. Infrared sensors are used in certain cases, which are described in more detail in Section 4.

3.2 ELECTRICAL METERING EQUIPMENT

Electrical consumption data was collected using a portable Field Data Acquisition System (FDAS). The FDAS collected time-series power consumption data, which are stored and transferred periodically via a telephone modem. For this study, a portable FDAS was available and used for both installations. The 329 Building, due to the large area encompassed by the installation, required the additional use of unused channels on an existing FDAS. This FDAS is used by the Hanford Utilities Group for internal billing data. It is possible to have multiple users query a single FDAS to obtain specific information without affecting the other user's data.

The loggers are called automatically on a daily basis, and store the data on a central computer for eventual analysis. The data storage and manipulation package used is standard PNL software, developed for various energy metering projects.

Figure 3.1 shows the installation configuration and a phasor diagram of the voltages. The two 337 Building lighting circuits are fed from two different phases in a 120/208 volt panel. In addition, the outlet providing

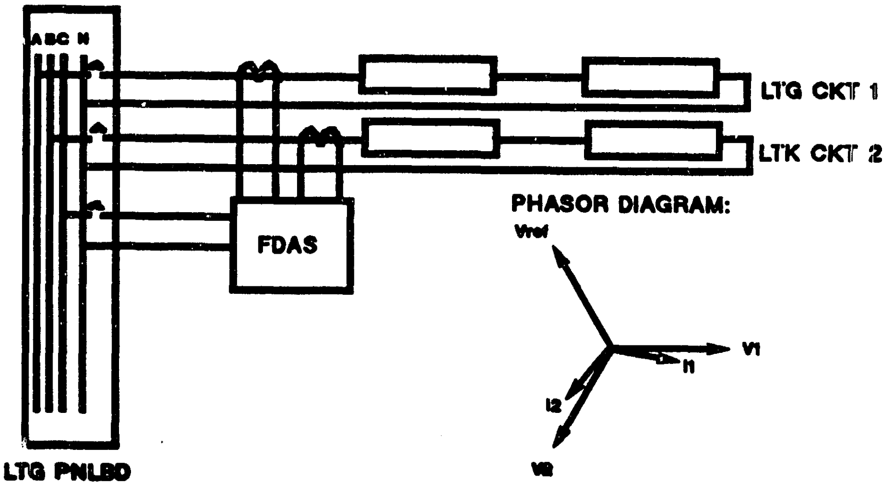


FIGURE 3.1. 337 Building Installation Configuration

power to the portable logger is on a separate phase from the lighting circuits, which involves a total of three phases.

In order for the FDAS to properly record the actual power consumed by the lighting circuits, the reference voltage must be shifted by 120° to correspond with the actual load voltage. The procedure is to deliberately connect the current transformer with reverse polarity, i.e., a 180° phase shift. This results in a 60° phase shift remaining in the measurement, which has a power factor of 0.5. Therefore, to obtain the actual power consumed, the resulting measurement is multiplied by two to correct for the phase shift introduced by configuring the measurements for 240 volts when the actual voltage is 120 volts.

The 329 Building installation plan is considerably more complex. A floor plan display of the design is given in Figure 3.2. The portable data logger, located in the north room, meters lighting consumption data for the north and center zones, lighting panels "V" and "J" respectively. The south area zone is measured from lighting panel "F," located in the switchgear room. Each of the loggers uses three-phase reference voltage from the respective lighting panels. The portable logger is modified to allow two separate voltage signal inputs because it is measuring lighting circuits from two separate panels.

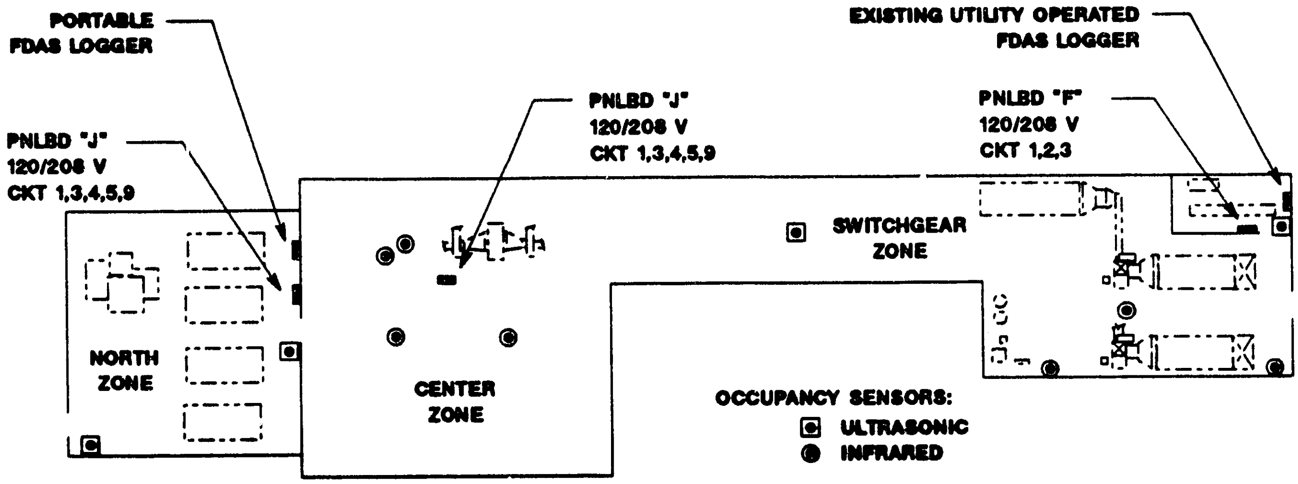


FIGURE 3.2. 329 Building Installation Plan

3.3 ECONOMIC EVALUATION

The economic analysis, in accordance with Title 10 of the Code of Federal Regulations, Part 436 Subpart A (10 CFR 436-A), uses a 25 year life-cycle cost approach (Ruegg 1987). A net present value for each of the installations is calculated by estimating the cost of installation and operation over 25 years, offset by expected energy cost over that same period.

The following approach is used to calculate the net present value:

- The first-time installation cost is determined for the case study.
- Replacement costs are determined, and converted to a present worth.
- Base-year energy savings are determined, and calculated as a present worth over the analysis period.
- Lamp replacement savings are calculated for a typical year, and calculated as a present worth over the analysis period.
- The net present value is determined by subtracting the present worth of all costs from the present worth of all savings.

Real constant dollars are used in the analysis, which represents cash flow in future years unchanged with respect to inflation. Removing inflation from the analysis eliminates the burden of estimating it for future years. It is assumed to be included in all costs and benefits equally, and thus cancels out in the analysis. All future costs and benefits in a real dollar analysis do not escalate in future years unless a specific justification can be made. A discount rate of 4.6% and appropriate energy escalation factors are used in accordance with 1992 Federal Energy Management Program guidelines as mandated for all federal energy conservation projects (Lippiatt 1991).

If the project has a positive net present value, it is economically viable and should be pursued. As with all types of engineering and economic analysis, however, there is some uncertainty in the data and assumptions used in the analysis. Therefore, sensitivity cases are analyzed to quantify the financial risk associated with the decision to pursue the project.

Although the net present value alone is enough to determine the economic viability of the project, the payback period is often useful to augment the net present value. Typically, a short payback period indicates less importance on future year assumptions, reducing the financial risk associated with the project. Additionally, a short payback period can provide better intuition for determining the cost advantage of implementing the project. Therefore, a payback period analysis is included in the economic analysis. The payback period in this report represents the actual payback period which includes the time-cost of money or the discount rate as compared with simple payback which does not.

3.3.1 Installation Cost

The installed cost of the motion sensor equipment is based on actual cost incurred during the demonstration project. Since the focus of this analysis is determining the viability of wide-scale implementation, only the cost associated with installing the motion sensors and related switching equipment is estimated. Other installation costs incurred during the demonstration project, such as installing the current transformers and the FDAS equipment, is excluded from the installation cost estimate for the analysis. A formula for estimating this cost is given in Equation (3.1), which is based on information provided by installation personnel.

$$\text{Estimated Installation} = 120\%\ \text{Actual Hardware} + 50\%\ \text{Actual Labor} \quad (3.1)$$

The 20% increase in hardware cost is due to Hanford procurement and receiving practices, which include an additional charge on all purchases based on a percentage of the purchase order. The demonstration project labor cost, as mentioned above, includes allocation for time solving problems associated with first-of-kind activities as well as installing the electrical metering apparatus. Additional installations in a wide-scale implementation would not require these additional costs.

3.3.2 Replacement Cost

Installed as a permanent fixture, the lighting control system is intended to operate reliably for an extended period of time. Recognizing the increased complexity of the lighting system, additional maintenance cost is included in the analysis. The motion sensors have an assumed 10-year replacement cycle. Although they are expected to last longer, this requirement is chosen to represent a conservative performance estimate. Although failed components are replaced only when necessary, in keeping with standard economic practices, this analysis assumes complete replacement of all hardware in 10-year intervals.

The replacement hardware cost is the same as that in the initial installation in constant dollars. The replacement labor cost is assumed to be half of the initial installation labor cost. This reduction accounts for costs associated with site preparation, conduit and wire run placement, and fabrication of mounting brackets, all of which are unique to first-time installations.

Using a 10-year replacement schedule for a 25-year life-cycle analysis period results in a salvage value of remaining equipment life at the end of the analysis period. An in-service salvage with linear depreciation is assumed. At the end of year 25, 5 of the 10 years of useful life of the equipment remain, available for continued operation beyond the analysis period. Therefore, half of the replacement cost in constant dollars is a salvage value credit at year 25 in the life-cycle analysis.

3.3.3 Annual Savings

Reductions in cost associated with operating the lighting controllers are calculated as annual benefits, which consist of the annual energy savings and the annual cost savings associated with lamp-life extension. These benefits offset the life-cycle cost in determining the present value of the project.

The energy savings are determined by extrapolating the measured difference in energy consumption during the project to a representative annual amount. In both demonstration cases, the baseline energy consumption is 100% of the connected load. The savings potential is determined by subtracting the measured consumption from the baseline.

Lamp-replacement cost is a significant maintenance activity. In addition to the labor cost associated with replacing lamps, the purchase and disposal costs can be significant. Fluorescent lights contain mercury, and require disposal as hazardous waste.[a] In addition to environmental considerations, there is a substantial disposal cost involved. By operating the lights for fewer hours, the mean time between failures will increase thereby reducing lamp-replacement cost.

(a) Personal communication with D. D. Hatley, Facility Operations supervisor, April 1990.

4.0 RESULTS

This section discusses the specific installation issues of the demonstration project, details the results of the energy consumption measurements, and provides life-cycle cost and savings calculations for net present worth and payback period.

4.1 INSTALLATION EXPERIENCE

The 337 Building occupancy sensors worked extremely well during the demonstration project. A minor sensitivity adjustment was required shortly after installation upon preliminary review of the collected energy consumption data. In addition to demonstrating proper performance, the sensors were well received by workers accessing the area.[a] In addition to not creating disruptions to work performance, the impression of energy conservation creates a positive attitude.

Significant difficulties were encountered during the installation of the 329 Building occupancy sensors. The difficulties were primarily a result of unanticipated problems with the ultrasonic sensors which were replaced with infrared sensors, and impossible-to-predict problems such as receptacle and non-lighting loads improperly fed from the lighting circuits that required correction.

Approximately half-way into the installation it was discovered that some of the ultrasonic sensors would not work properly. Regardless of the sensitivity setting, the sensors would be continually activated by the "noisy" ambient environment, primarily associated with equipment vibration and high air flow. Infrared sensors were used in these locations, which resulted in proper lighting control operation. However, the control voltages for the two types of sensors used are not compatible, and additional relay circuit modifications were necessary.

Additional sensors were installed to more adequately cover the complicated floorplan arrangement. Since the infrared sensors used have a

(a) Personal communication with D. D. Hatley, Facility Operations supervisor, April 1990.

relatively narrow field of view compared to the ultrasonic sensors specified in the design, up to four infrared sensors are required in place of a single two-way ultrasonic sensor.

It was discovered that non-lighting electrical loads had been connected to the lighting circuits, contrary to Hanford standards. In addition to receptacles, it was discovered that a water heater had been connected to the lighting circuit. These loads should not be switched off when there are no occupants in the room, and had to be moved to other circuits.

After the installation was completed and sensitivity adjustments performed on the basis of metered consumption data, the system demonstrated satisfactory operation and substantial energy savings.

Although the occupancy sensors are intended to detect occupancy throughout most of the room, it is unavoidable that workers will at times occupy areas beyond the view of a sensor, especially given the complex configuration of the 329 Building equipment-room floorplan. Time-delay bypass relays were installed in all three control zones because it was not acceptable to have the lights turn off because occupants were beyond the view of a sensor. Using these timers, maintenance personnel can select any time up to 60 minutes in which the lights are to stay on regardless of occupancy sensor detection.

Both the 337 and 329 Building installations have normal and emergency lighting circuits which are fed from separate panels. The emergency lighting circuits consist of fewer lights in a given area than normal lighting circuits, but provide enough light for mobility and exiting if necessary. None of these circuits are affected by the occupancy sensors in the demonstration project.

4.2 MEASURED ENERGY SAVINGS

The annual energy savings is determined for each of the sites by comparing the average energy consumed during the test period from the estimated baseline energy consumption. The data are summarized in Table 4.1. The 337 Building equipment-room case demonstrated nearly 97% reduction in energy consumption, while the energy consumption for the 329 Building equipment room was reduced by about 92%.

TABLE 4.1. Measured Energy Consumption Savings

Building	Baseline Consumption (Watts)	Occupancy Sensor Consumption (Watts)	Annual Energy Savings (kWh/year)
337	1,280	41	10,850
329	10,035	821	80,700

The average daily consumption of the 337 Building occupancy sensor controlled lighting is given in Figure 4.1. The average value of the daily consumption was 41 watts. The analysis period is between April 27, 1990, and January 14, 1991. This represents the time that the sensors were operating correctly after the initial break-in period where the sensitivity was adjusted and when the FDAS was removed for the 329 Building demonstration measurements. Missing data, which occasionally occurs due to errors in the FDAS operation, are removed from the figure.

The average daily consumption for the 337 Building over the same time period aggregated by time of use is shown in Figure 4.2. It is clear from this graph that the sensors are operating as expected with good correlation between consumption and anticipated work schedules.

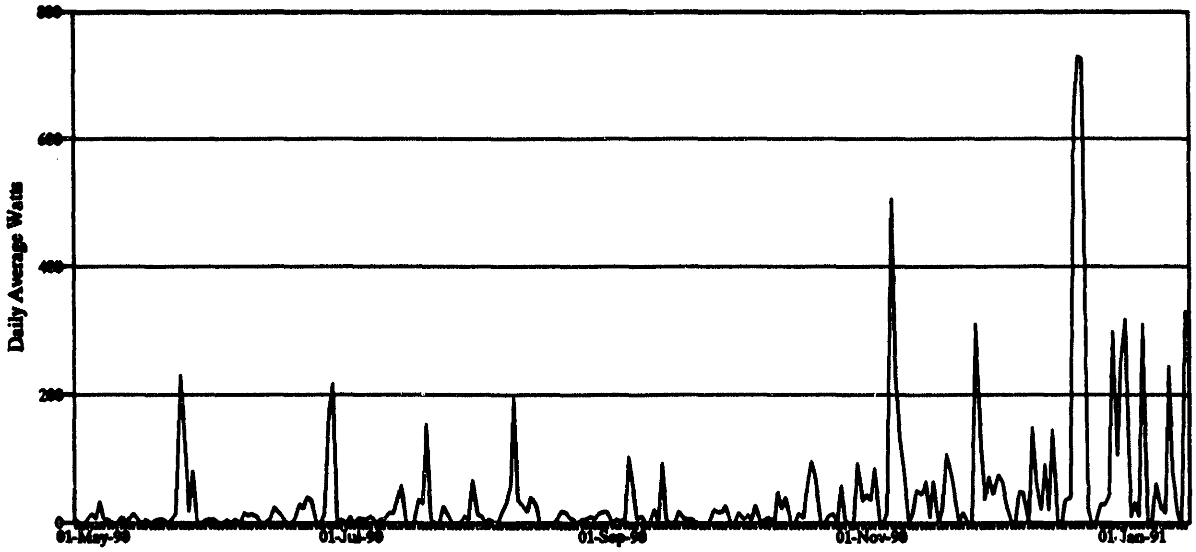


FIGURE 4.1. 337 Building Lighting Consumption with Occupancy Sensors

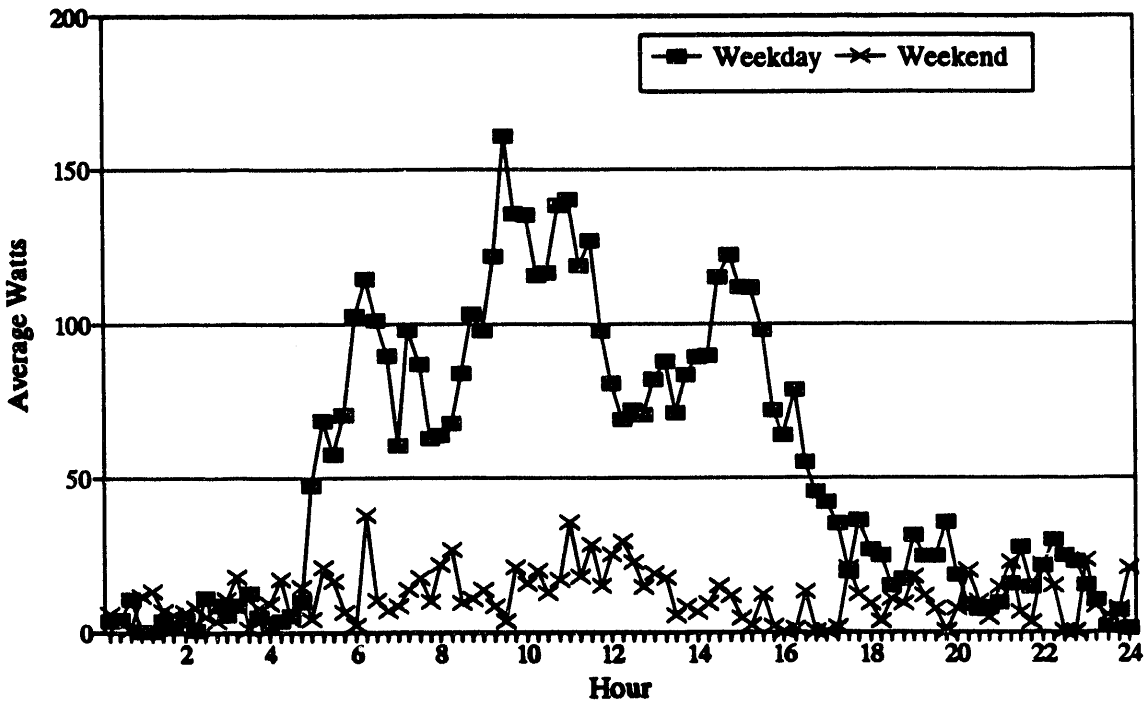


FIGURE 4.2. 337 Building Average Daily Consumption by Time-of-Day

The average daily consumption for the 329 Building case is given in Figure 4.3. The average value of the daily consumption was 821 watts. The analysis period is August 1, 1991, through March 31, 1992, after the initial calibration was completed and just prior to a failure in one of the infrared sensor relays that brought the system off-line. The relay was subsequently replaced, but the data collection has been discontinued. This graph shows fairly consistent consumption over the analysis period.

Figures 4.4, 4.5, and 4.6 illustrate the average consumption by time-of-use for each of the three control zones. Of the three, the north room appears to present the poorest correlation between electrical consumption and expected occupancy, indicating the sensors may still not be calibrated properly. This is manifest by the fairly flat load profile, with no real difference between weekday and weekend consumption. Such characteristics as the peak at 2:00 a.m. in all three load profiles, indicating a fairly regular but brief

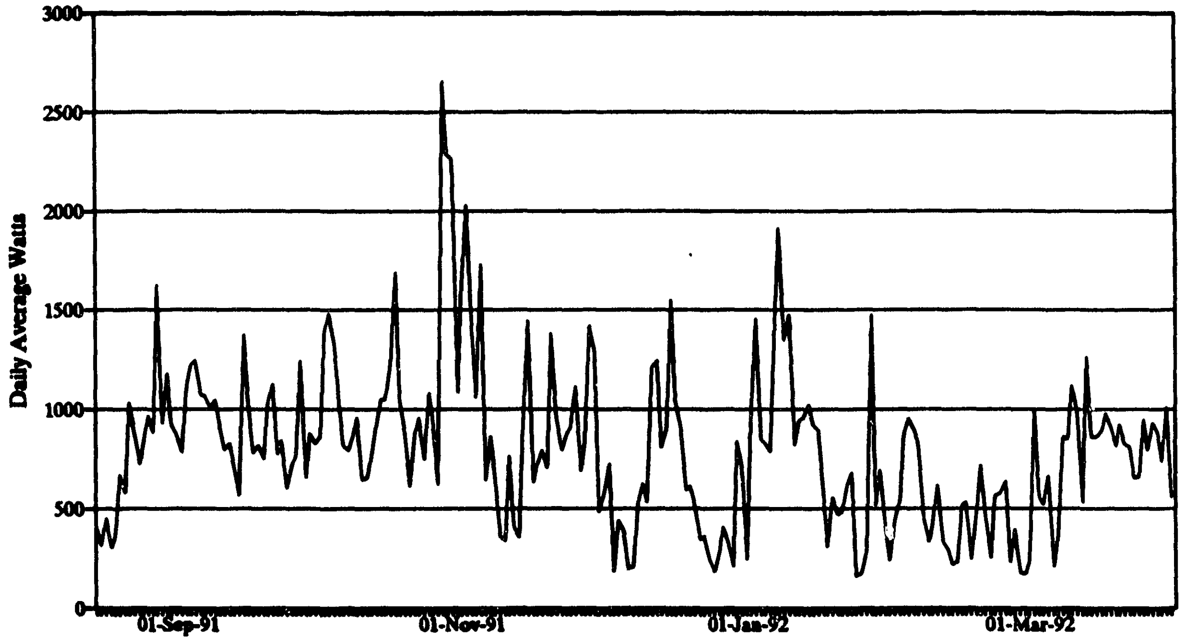


FIGURE 4.3. 329 Building Lighting Consumption with Occupancy Sensors

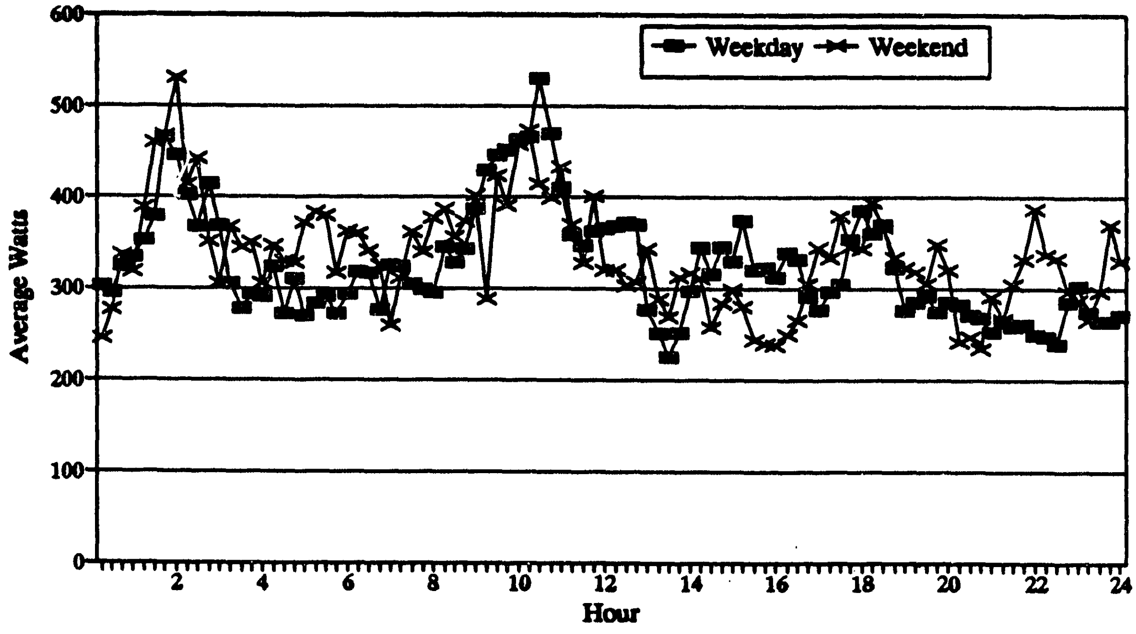


FIGURE 4.4. 329 Building North Zone Average Daily Consumption by Time-of-Day

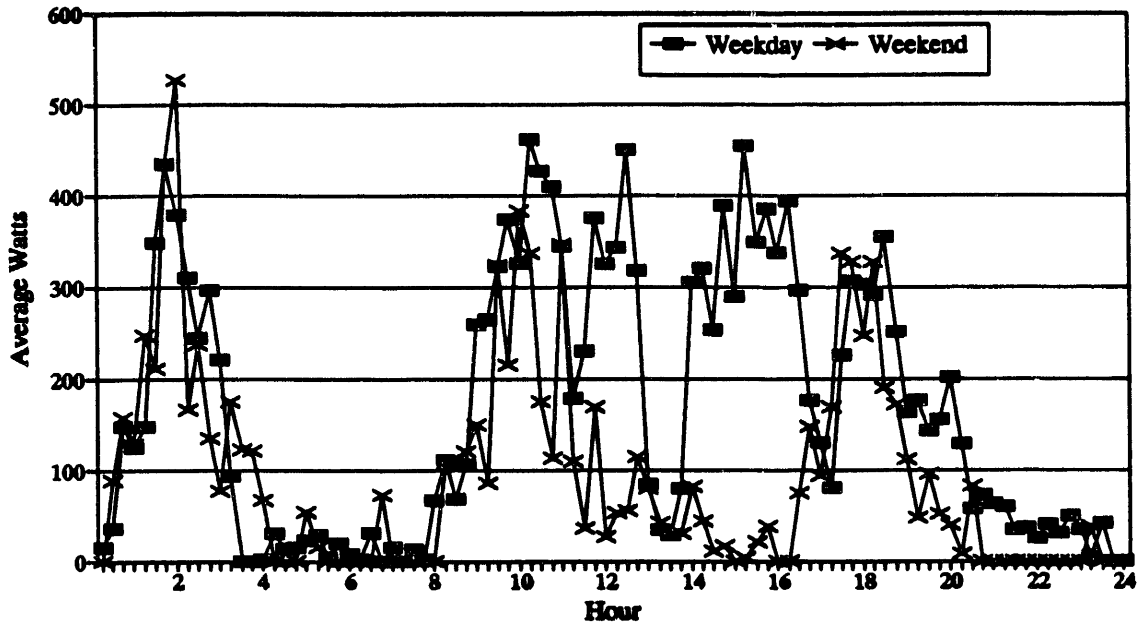


FIGURE 4.5. 329 Building Center Zone Average Daily Consumption by Time-of-Day

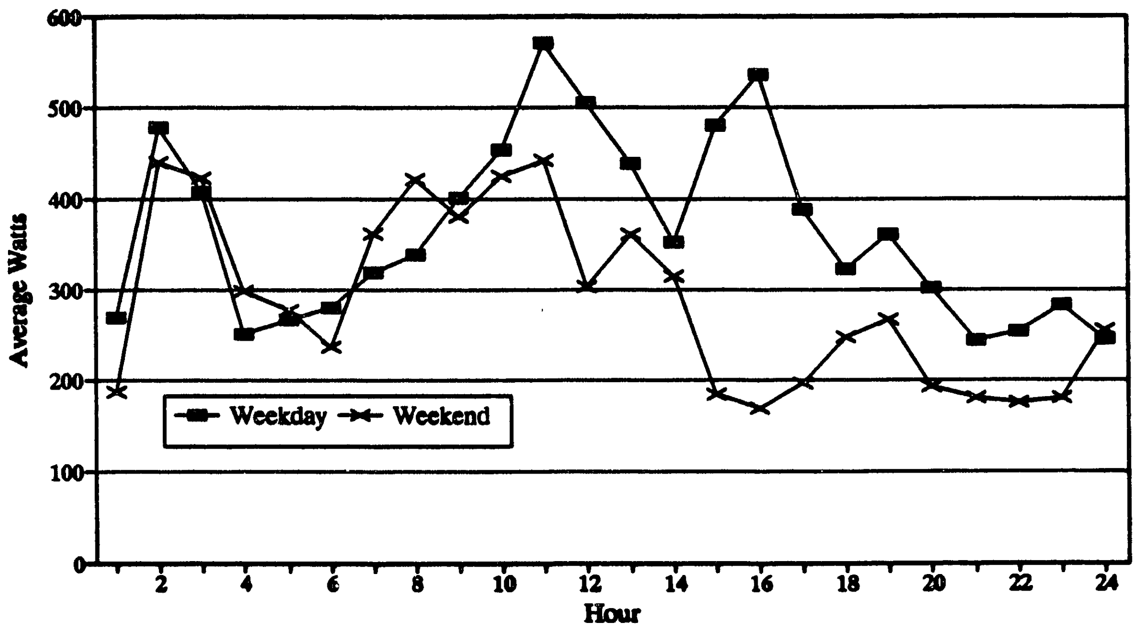


FIGURE 4.6. 329 Building South Zone Average Daily Consumption by Time-of-Day

occupancy at this time, is consistent with a walk-through during the night shift at about the same time each day. Other characteristics such as reduced activity during the lunch hour also indicate that the sensors are operating fairly well. The center zone appears to have the best correlation between energy consumption and anticipated occupancy patterns. This zone also represents the largest reduction in energy use. Graphs such as these that display daily consumption and time of use characteristics are important for ensuring that the sensors are operating correctly with proper sensitivity calibration.

4.3 ECONOMIC EVALUATION

The economic evaluation described in Section 3 is given in this section for both the 337 and 329 Building installations.

4.3.1 Installation Cost

The installation cost breakdown is provided in Table 4.2. The hardware cost is obtained by adding 20% to the sum of purchase requisitions for the sensors, relays, and other materials such as conduit and miscellaneous supplies. The 20% charge is the approximate overhead charge applied to all Hanford purchases to cover the procurement and receiving costs associated with the cost of buying equipment.

The labor costs shown in the table is 50% of the total installation labor actually charged to the project. This 50% is the approximate ratio between the actual occupancy sensor system installation time and that associated with other aspects of the demonstration project as explained in Section 3.3.1.

TABLE 4.2. Installation Cost Breakdown (1991 dollars)

Description	337 Building	329 Building
Total Hardware Cost	350	1550
Installation Labor Cost[a]	750	8900
Total Installation Cost	1100	10450

(a) Does not include cost associated with FDAS installation and configuration, or special labor requirements associated with demonstration project.

4.3.2 Replacement Cost

As discussed in Section 3.3.2, an estimate of the replacement cost which occurs every 10 years is simply the hardware cost and half of the initial installation labor cost. Therefore, the replacement cost for the 337 Building is $725, and $6000 for the 329 Building. This represents both hardware and labor cost of installing new equipment and removing the old equipment.

4.3.3 Energy Savings

The energy consumption reduction of operating the lighting controller is converted into annual savings by using the appropriate electrical rate. Hanford purchases its electricity directly from the Bonneville Power Administration (BPA) at transmission voltage. These rates are provided in Table 4.3. A weighted annual average used for the economic analysis is $0.0170/kWh. The demand charge is not included in this average because the maximum lighting load has not been reduced, thereby not affecting the monthly peak demand. The annual energy savings associated with the 337 Building occupancy sensor lighting control demonstration project is $306, and is $2104 for the 329 Building demonstration project.

4.3.4 Lamp Replacement

By reducing the number of hours that the lights are on, the time between lamp replacement can be extended significantly. Fluorescent lights which remain lit continuously have a life of about 40,000 hours (Lane 1992). Frequent switching can shorten the lamp life. It is generally recognized that switching times shorter than a couple of minutes should be avoided in order to minimize the reduction of lamp life.

TABLE 4.3. Hanford Electrical Rates[a]

Description	Period Rate Applies	Rate
Winter Energy	September through March	$ 0.0187/kWh
Summer Energy	April through August	$ 0.0147/kWh
Monthly Demand	All Year	$ 3.60/kW

(a) Personal communication with J. E. Uecker, July 1992.

Recognizing some lamp-life degradation will occur through frequent switching, a new lifetime of 10,000 hours is assumed for fluorescent lighting which is controlled by the occupancy sensors. However, since the lights are on fewer hours, the time between replacement in increased. Table 4.4 gives the lamp replacements avoided per year using the occupancy sensors compared to the baseline case of running the lights continuously.

Assuming a cost of $20 per lamp replacement, which includes the lamp cost, installation labor, and disposal cost, this amounts to $122 per year for the 337 Building and $732 per year for the 329 Building.

4.3.5 Net Present Value

The net present value is the total life-cycle cost subtracted from the expected savings over the analysis period, shown in Equation (4.1).

$$NPV=AES*UPW_{FUEL}+LRS*UPW-\sum_{0}^{25} COST(n)*SPW(n) \tag{4.1}$$

where NPV = Net Present Value

AES = Annual Energy Savings

UPW_{FUEL} = 25 year Uniform Present Worth factor including fuel escalation

LRS = Annual Lamp Replacement Savings

UPW = 25 year nonfuel Uniform Present Worth factor

COST(n) = nth year cost

SPW(n) = nth year Single Present Worth factor

TABLE 4.4. Lamp Replacement Savings

Building/ Zone	Number Lamps	BASELINE Average Fail/Year	OCCUPANCY SENSOR Hours per Year	OCCUPANCY SENSOR Average Fail/Year	Replacements per Year Avoided
337	32	0.219	281	0.0281	6.109
329 North	60	0.219	1187	0.1187	6.018
329 Center	140	0.219	231	0.0231	27.426
329 South	48	0.219	1529	0.1529	3.173

The Uniform Present Worth and Single Present Worth factors are based on a discount rate of 4.6% obtained from 1992 Federal Energy Management Program guidelines (Lippiatt 1991).

The net present values are provided in Tables 4.5 and 4.6 for the 337 and 329 Building cases, respectively. Also included is the actual payback period which includes the time-value of money or discount rate.

Both installations demonstrate a positive net present value, and hence both represent a cost-effective means of energy conservation. Further, the payback period is within guidelines recommended for energy conservation projects, which is typically 7 to 10 years. Also, energy savings alone are enough to offset the life-cycle cost without including lamp-replacement savings. Figure 4.7 displays the present value of the expected energy savings and life-cycle costs for both installations.

TABLE 4.5. 337 Building Life-Cycle Cost Summary

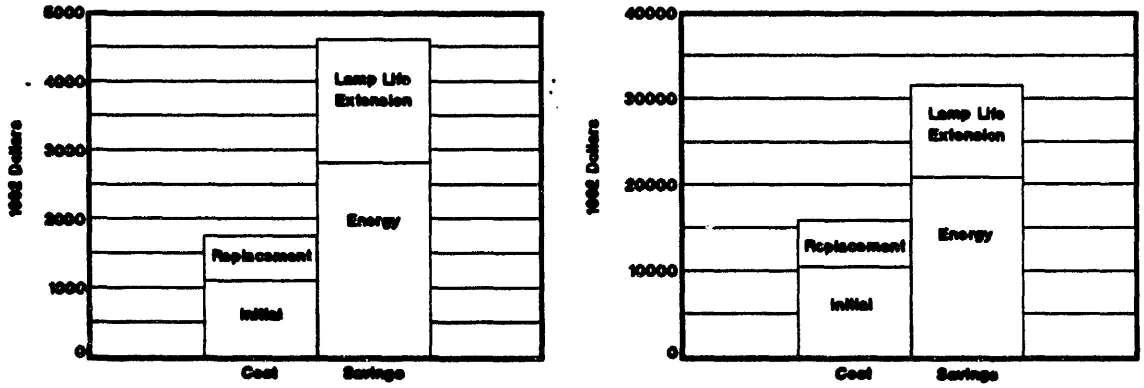
Item	Year	Real Dollars Amount	Real Dollars Present Value
Cost			
Installation	0	1100	1100
Replacement	10	725	464
Replacement	20	725	297
Salvage Value	25	(362)	(116)
Total Life Cycle Cost			1745
Savings			
Energy	Base	184	2809
Lamp Replacement	Base	122	1794
Total Life Cycle Savings			4603
Net Present Value			2858
Payback Period (Years)			4.0

TABLE 4.6. 329 Building Life-Cycle Cost Summary

Item	Year	Real Dollars Amount	Real Dollars Present Value
Cost			
Installation	0	10,405	10,450
Replacement	10	6,000	3,840
Replacement	20	6,000	2,460
Salvage Value	25	(3,000)	(960)
Total Life Cycle Cost			15,790
Savings			
Energy	Base	1,372	20,894
Lamp Replacement	Base	732	10,751
Total Life Cycle Savings			31,645
Net Present Value			15,855
Payback Period (Years)			5.8

4.3.6 Sensitivity Cases

Two sensitivity cases are included to demonstrate the robustness of the economic decision with respect to key assumptions. The first sensitivity analysis explores the occupancy sensor replacement cost assumptions, determining the break-even annual operating cost. The difference between the present value of annual savings and the first-time installation cost is $3,503 for the 337 Building, and $21,195 for the 329 Building. An equivalent annual



(a) 337 Building (b) 329 Building

FIGURE 4.7. Occupancy Sensor Demonstration Project Net Present Values

expense for these two cases is $239 and $1,444 respectively. At a charge-out rate of $65/hr, this corresponds to 4 labor hours to maintain the 337 Building installation and 22 labor hours to maintain the 329 Building installation each year to break even. Additional labor spent would cause a negative net present value.

Although the sensors are not intended to require any regular maintenance, this small allowance of annual labor hours for break-even is cause for concern regarding the financial security of the investment decision. A mishap in the installation that would require maintenance labor to mitigate and correct could jeopardize the savings potential of the project.

The second sensitivity case deals with the lamp-life reduction assumption for estimating annual replacement cost savings. In this sensitivity case, the break-even lamp-life reduction is calculated which would not change the baseline lamp-replacement expense. The average time of lamp illumination is 7.6%, or 667 hours per year. Therefore, if the baseline bulb life is 40,000 hours with no switching, the bulb life would have to degrade to about 3,047 hours in order for there not to be any lamp replacement savings. Since this number is much less than the original assumption of 10,000 hours, there is a high degree of certainty that there will not be any increase in lamp replacement expenses. Since the annual energy savings present worth exceeds the life-cycle cost present worth, this sensitivity case reaffirms the economic viability of the occupancy sensor installation.

Since the remaining parameters in the economic analysis are based on the demonstration project results, no additional sensitivity cases are warranted.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This section gives the conclusions drawn from the occupancy sensor demonstration project, discusses wide-scale implementation of occupancy sensor based control, and recommends further activities in the area of equipment-room lighting control.

5.1 MAJOR FINDINGS

Both the 337 Building and 329 Building demonstration projects indicate that occupancy sensor lighting control is a cost-effective means of conserving energy for equipment-room lighting. In accordance with federal economic analysis guidelines, both projects have a positive net present value, with savings exceeding costs for a 25-year analysis period. In addition, both demonstrated reasonable payback time well within established guidelines for energy-conservation projects.

However, both installations indicate sensitivity to labor costs associated with maintaining the equipment. Unforeseen difficulties in the installation and operation of the system could negate the cost advantage of applying motion sensor technology to control equipment-room lighting.

5.2 INSTALLATION CRITERIA

Using criteria obtained from the demonstration project, it is possible to estimate the cost-effectiveness of future installations. This would allow guidance for a case-by-case evaluation of equipment rooms to determine if occupancy sensor installation is cost-effective.

First, an estimate of the energy savings potential is required. By adding the connected lighting load and accounting for an occupancy sensor lighting fraction of about 7 to 8% (based on average lighting duration demonstrated in the test project), determine the expected annual energy savings. Then, calculate a present value by using the electrical billing rate and the uniform present value factor for expected escalation of fuel prices.

Next, calculate the expected installation cost by determining the total number of occupancy sensors required. Including hardware and labor, this can be in the range of $550 to $950 per sensor, depending on the complexity.

The sensor-replacement cost and lamp-replacement savings are small and offset one another, and can be neglected. Comparing the present value of the estimated energy savings with the estimated installation cost will give a benchmark for the viability of installing the motion sensor lighting control.

Using the above analysis and 1992 energy cost information, the break-even point for installing motion sensors is an average of between two and three lighting fixtures (4 lamps, 160 watts each) for each motion sensor installed. This gives general guidance for the application of motion sensors at other sites using data from the demonstration project.

5.3 ADVANCED LIGHTING CONTROLLER

Although the application of occupancy sensors has been demonstrated to be a cost-effective energy-conservation measure, an investigation of ways to reduce the labor-intensive installation cost should be pursued, especially for large and complex equipment rooms which would require extensive occupancy sensor coverage and complexity. Development of an advanced automatic lighting controller, in which a single control unit can control the lights for a large area, may achieve this goal. However, the basic premise of occupancy based lighting with minimal user interaction should be preserved. The success of such a controller must demonstrate a cost advantage over the occupancy-sensor based lighting control. Therefore, a demonstration of such a controller has been proposed, and is planned to be implemented in fiscal year 1993. The 329 Building will be used for this demonstration, useful because of the extensive comparison data already collected for the occupancy sensor demonstration project described in this report.

If occupancy sensor equipment-room lighting, or an alternative advanced lighting controller, are implemented throughout Hanford, there would be extensive energy savings which would be achieved in a cost-effective manner. This should be pursued because it is consistent with both Executive Order 12759 and the goals of the Federal Energy Management Program.

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APPENDIX

SCHEDULE

APPENDIX

SCHEDULE

July 27, 1989	337 Building motion sensor equipment ordered.
April 13, 1990	Installation of sensors complete in the 337 Building basement equipment room. FDAS on-line.
April 26, 1990	Sensors hooked in parallel. Sensitivity adjustment.
August 13, 1990	Walk-down of 329 Building.
August 17, 1990	329 Building motion sensor equipment ordered.
January 15, 1991	FDAS removed from 337 Building. Walk-down of 329 Building.
January 16, 1991	Additional 329 Building motion sensor hardware ordered.
March 14, 1991	329 Building installation begins.
May 28, 1991	Problems with receptacles on lighting circuits. Infrared sensors used: modified to use with existing relays.
June 3, 1991	329 Building motion sensor installation complete.
June 11, 1991	329 Building FDAS units installed and on-line.
July 31, 1991	Sensitivity settings modified.
November 7, 1991	Minor sensitivity adjustment.
April 1, 1992	Relay failed and bypassed. FDAS metering disconnected.
April 13, 1992	Safety concern filed: system will be modified to accommodate long-term occupancy out of sensor view.
April 16, 1992	Walk-down of time-delay bypass relay installation.
June 18, 1992	Inspection: bypass timer installation complete, sensors operating as expected.

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