PNL-10135
UC-~~350~~ 1600

Field Analysis of Occupancy Sensor Operation: Parameters Affecting Lighting Energy Savings

E. E. Richman
A. L. Dittmer
J. M. Keller

September 1994

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

DISCLAIMER

Summary

This study is part of the ongoing energy efficiency work sponsored by the Hanford Energy Management Committee (HEMC) for the effective application of energy projects on the U.S. Department of Energy (DOE) Hanford Site in Richland, Washington. The study was performed by Pacific Northwest Laboratory (PNL)[a] in three phases between October 1991 and July 1994. This study was designed to assess the potential energy savings from the use of lighting occupancy sensor control in Hanford Site facilities. The final results of the study provide useful information for assessing the cost-effective use of occupancy sensor lighting control. The results also include an assessment of the total potential savings from the application of sensors across the entire site.

The study involved placing sensor test equipment in multiple office spaces in eight buildings that are part of the Hanford contractor facilities. A total of 154 sample data periods, comprising over 54,700 test hours from various spaces in office and laboratory buildings, were collected and analyzed. The initial analysis of these data assessed wasted-light hours related to various characteristics of the building spaces, occupants, and operated lighting wattage. Further testing was conducted to assess the effects of timer sensitivity adjustments on potential lighting energy savings. Timer sensitivity of occupancy sensor equipment is used to set a reasonable length of time after no motion (no occupancy) is sensed in a space before lights are turned off. The results of this test indicated that up to 100% additional wasted-light energy can be saved by using timer sensitivity settings as low as 2.5 min, which is less than standard factory settings of usually 10 to 20 min.

The analysis indicates that savings from lighting operations are affected by the work function and number of occupants in occupied spaces. For unoccupied spaces (copy rooms, conference rooms, lunchrooms, etc.), the function(s) performed in the space, as well as attitudes by users about the purpose of the space, affect the capacity of these savings. In all spaces, the total wattage of lighting being controlled in the space and the applicable utility rate have a large effect on potential savings.

The availability of daylight in a building space does not appear to have any noticeable aggregate effect on the quantity of wasted-light hours in occupied or unoccupied spaces. An important factor in the level of wasted-light hours in unoccupied spaces (e.g., conference rooms, copy rooms) is the perceived ownership of the building space. Conference, training, library, and storage spaces tend to be *temporarily* owned by an individual or organization and lights are generally turned off when the occupants leave the space. Copy rooms, lunchrooms, unoccupied labs, and restrooms are generally owned by everyone and therefore lights are more likely to be left on for the next occupant. More than one permanent occupant in an occupied space tends to decrease the wasted-light hours (approximately 13% fewer for technical staff and 10% fewer for administrative staff). This decrease is attributed to the staggered use of a space associated with multiple occupancy.

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

The time delay tests indicate that a simple adjustment of installed sensors can have a very large effect on energy savings at a minimal cost. Setting the timer control on a sensor device below the normal factory setting of 10+ minutes can have a significant effect on the number of wasted-light hours saved (up to 39% more if set to 3 min). These tests also indicate a large, untapped source of energy savings associated with the development of better sensor technology. The results of the study cover a majority of the building spaces considered potentially applicable to occupancy sensor technology.

An assessment of the total potential savings for the entire Hanford Site included life-cycle costing that followed the federally accepted methodology. The life-cycle cost analysis was performed for a set of possible lighting wattages across the building spaces and occupant types identified from the initial analysis. A list of room characteristics for buildings on the Hanford Site was used to assess the total potential for lighting energy savings from the use of occupancy sensors for lighting control. Under current conditions, the potential savings is estimated to be $525,812/yr at an initial cost of $976,824. The total Net Present Value for the site is estimated at $3,539,926 with a simple payback period of 1.85 years.

Contents

Figures

Tables

1.0 Introduction and Objective

Sensors that detect occupancy have been used for many years to monitor or control various mechanical and energy-related functions, including lighting operation. As energy-saving devices, occupancy sensors are well suited to reduce lighting use whenever spaces are unoccupied. The potential energy savings from occupancy lighting control depends on several factors related to the building space, occupants, and equipment used in the space. Two of the major factors are 1) potential "wasted" hours associated with occupant characteristics and job functions, and 2) specific lighting control equipment settings and sensitivities. In all occupancy lighting control situations, the operation of the lighting by occupants is the most dominant factor in determining actual lighting energy savings. This factor is also the most variable and hardest to assess. The operating characteristics of specific lighting control equipment are also a major and often unknown factor in potential lighting savings. Each piece of control equipment has slightly different operating adjustments with variable ranges. The actual lighting energy savings attributable to these factors is not well known. Historically, the effects have been estimated by manufacturers, installers, and equipment users. New emerging test equipment provides the capability to perform individual space testing on a case-by-case basis. However, when many installations are planned, a general indication of effectiveness in applicable space types is needed.

This study is part of the ongoing energy efficiency work sponsored by the Hanford Energy Management Committee for the effective application of energy projects on the U.S. Department of Energy (DOE) Hanford Site in Richland, Washington. The study was performed by Pacific Northwest Laboratory (PNL) in three phases between October 1991 and July 1994. The objective of the study was to assess and effectively quantify the potential wasted-light hours associated with spaces in office and laboratory type facilities. These quantities are the primary factor in determining actual lighting energy savings associated with occupancy lighting control. The results of this study can be applied to any federal or commercial building. The assessment will provide needed data to facilities and energy management personnel to help determine cost-effective sensor placement. In addition to identifying the parameters affecting sensor lighting savings, the study also explores potential additional savings from a more effective sensor equipment adjustment. This information provides quantitative insight into the presently unattainable energy savings associated with the limitations of current sensing equipment.

Section 2.0 of this report describes the data collection methodology for this study. Section 3.0 presents the analysis process and additional sensitivity testing performed on the test equipment. The results of the data analysis and economic evaluation are provided in Section 4.0 and conclusions are presented in Section 5.0.

2.0 Field Data Collection

This section describes the equipment and methods used to collect the occupancy data and the criteria used to select test spaces. Detail is also presented on the characteristics data collected for each sample space.

2.1 Sample Spaces and Characteristics

The spaces that made up the study sample represented a nearly complete cross section of the space types found in office and laboratory type facilities. The spaces were selected from Hanford Site facilities.

These facilities represent, in form and function, the range of lighted, occupied facility spaces in most buildings. Spaces were also selected where the operation was considered to be fairly stable. Spaces with odd configurations or mixed uses were usually not selected. Although these space types do exist in all buildings, their numbers are relatively few compared to standard spaces.

Testing was completed in eight buildings that are part of Hanford contractor operations. A total of 154 sample test periods comprising over 54,700 hours of test time were completed for potential use in the study. A small percentage of these sample test periods were removed from the analysis because conditions adversely affected the individual test results, including failed lighting sources and inappropriate sensitivity adjustments. The remaining 141 samples with over 50,400 test hours were used in the analysis. Descriptions and quantities of the spaces and occupant types making up these 141 samples are shown in Table 2.1. The total test hours associated with each space or occupant type is also shown.

Table 2.1. Building Space and Occupant Type Descriptions

Space or Occupant Code	Description	Quantity	Hours
Conference	Conference Room	13	5,383
Copy	Photocopy and/or Mail Room	9	3,186
Lab	Laboratory Without Office Area	12	3,909
Library	Library (small) Typically not Manned	4	1,349
Lunchroom	Lunchroom or Break Room	13	5,711
Restroom	Restroom or Restroom/Locker	10	3,616
Storage	Storage Room	3	980
Training	Training Room/Classroom	1	333
Administrative	Administrator - Program or Finance	22	7,345
Clerical	Clerk - Financial or Technical	3	955
Technical	Engineer/Scientist/Economist/Architect	36	11,988
Managerial	Manager/Group Leader	8	3,339
Secretarial	Secretary/Receptionist	7	2,343

For each sample space, a complete set of space and occupant characteristics data was recorded for use in determining any relational effects on potential lighting savings. These data were collected at the time the sensor equipment was installed. Characteristics that may have an affect on lighting operation and savings potential, such as occupant type and number, function of space, window area, lighting count, and occupant number and type, were entered in spreadsheets with the data collected from the sensor equipment.

2.2 Sensor Equipment and Setup

2.2.1 Occupant Behavior Effects Test

The occupant behavior effects test was designed to assess the parameters affecting wasted-light hours. The tests were conducted using a lighting logger with interactive circuitry for use with a sensor, a companion ultrasonic motion sensor, and a stand-alone lighting logger. A total of 11 sets of similar equipment were utilized during data collection.

The lighting logger and companion ultrasonic sensor used in the analysis are a product of Mytech Corporation.[b] The sensor units included an early version Model OA-1000 test kit containing a Model EM-300 lighting logger with companion sensor and a later Model EAK-101 analyzer kit containing a Model EM-301 lighting logger and companion sensor. Both models are functionally the same and have similar operating characteristics. The sensor units are designed to hang from the grid members of any grid ceiling system using a special clip provided with the unit. Concerns over possible asbestos in the ceiling area of one of the test facilities prohibited any movement of the panels to install the clip. For these installations, a bracket attaching to the very bottom of the grid support was fashioned for each of the units. In other building spaces, a variety of ceiling grid mount and magnetic cabinet and wall mount configurations were used.

The earlier sensor unit model provides for attachment of the companion logger to the sensor unit. In our study, it was sometimes imperative that the logger be installed inside a fixture. The sensor units were modified with an adapter cord from the sensor to companion logger. The later model was designed for remote logger placement and no adjustment was required. A 24-V power supply plugged into a standard 120-V socket provided power to the sensor unit and completed this setup.

In the operating mode, the lighting logger counts time increments in tenths of an hour whenever the photocell reads sufficient light levels, **AND** the sensor reads no motion (open-closed contact signal to the logger) for a specified delay period. This delay period is used to ensure lights are not turned off when occupants are making small or infrequent movements. The resulting time values are considered to be wasted-light hours, indicating the potential savings from improved lighting control. The time delay for these tests was set between 5 and 8 min, which can be considered a reasonable

(b) References to specific manufacturers and models are not to be construed as an endorsement as compared to equivalent instrumentation available from other manufacturers.

effective energy saving setting. Half of the companion loggers were supplied with a sensitivity adjustment used to capture appropriate light-on levels. The sensors were equipped with a signal sensitivity setting, allowing for motion-sensing signal adjustments in case of traffic in nearby areas that may cause false occupancy readings. Each sensor was also equipped with a timer sensitivity adjustment used to set the length of time the unit waited before starting to count wasted-light hours after sensing no motion. This adjustment ensures that lights do not go off when occupants are infrequently making large motions (e.g., reading).

The stand-alone lighting logger used in the analysis was a Model 100 lighting logger produced by Pacific Science and Technology.[(a)] While in operation, the logger records tenths-of-an-hour increments based on photocell indication of light. These units were supplied with sensitivity adjustments to provide effective light-on time readings. To verify proper equipment operation, this logger was attached in or near a subject lighting fixture to record total light-on time to compare with the other logger readings.

2.2.2 Time Delay Adjustment Effects Test

The test equipment used to assess the effects of equipment adjustments consisted of an ultrasonic sensor test unit and a voltage datalogger. Two sets of identical equipment were used for this test.

The sensor unit came from the newer Model EAK-101 analyzer kit from Mytech.[(a)] The datalogger was a Model XT-107 Voltage/Current/Temperature unit produced by ACR Systems Incorporated (ACR).[(a)] This datalogger can read a variety of inputs, including 0-V to 10-V input. Because the sensor unit only outputs an open-close signal, an interim voltage supply was needed to provide a measure of occupancy based on the open-close signal from the sensor. For these tests, a 9-V battery was placed in a circuit between the sensor and datalogger. The datalogger stores time-series voltage and outputs the data to ACR software or other types of spreadsheets.

For this test, the timer setting on the sensor unit was set to the minimum value of approximately 5 seconds to identify exact occupancy periods without the effects of timer delay. The unit was located and adjusted so very small movements by occupants would be detected to ensure the most accurate occupancy data was collected with no false readings. The sensor unit was placed close to the occupant's normal sitting position and/or the sensitivity was raised to maximum and the doors to the space were kept closed during the test period.

2.3 Test Space Sampling Procedure

Initial contacts were made with building operators or owners to present the study and request access to building spaces. The room occupants were also contacted to approve the installations. In

(a) References to specific manufacturers and models are not to be construed as an endorsement as compared to equivalent instrumentation available from other manufacturers.

each space, the characteristics described in Section 2.1 were collected and the equipment installed. An operational check was completed as a part of each installation. This check involved equipment testing and adjustment to ensure no false readings. Careful adjustment was needed in some situations, such as rooms with oscillating fans, bare walls causing high reflectance of sensor waves, high partitions, and multiple-lighting controls.

For the occupant behavior effects test, each sample space was monitored for a 2- to 4-week period. At the end of each period, the time readings on the two loggers were recorded and reset, and a posttest check of each unit's operation was made to ensure the appropriateness of the data. The recorded data were also compared with expected values to verify accuracy. For example, the stand-alone logger reading was always expected to be higher than the sensor companion logger reading and was usually close to the number of work hours for a 2- to 4-week period. In a few cases, the equipment was left installed for another 2-week period if the current data were considered incorrect. Examples of conditions that produced incorrect data included failed lighting fixtures used as the logger light source, posttesting that indicated one or more loggers were reading daylight, and oscillating fans that triggered the sensor when occupants were out.

The equipment settings tests used a subset of the spaces used in the occupant behavior effects tests. Each test was conducted over a 24- to 72-hour period to capture typical operating characteristics. Each set of data was compared to known schedules to verify accuracy. Because of existing equipment limits and the need for nearly exact occupancy start and stop times, the setup was more difficult than for the behavior tests.

3.0 Analysis Process

The analysis used in this study had two primary objectives. First, the analysis aimed at identifying and quantifying the effects of occupant behavior within building spaces that determine energy savings associated with occupancy sensor lighting control. Second, the analysis involved an assessment of the potential increased energy savings associated with improved control equipment adjustment. This section describes the methods used to interpret and assess potential lighting savings from the collected data to meet these objectives.

3.1 Occupant Behavior and Space Characteristics

The first step in the analysis of occupant behavior effects and other space characteristics on lighting use was to estimate the potential yearly wasted-light hours associated with each sampled space. For each 2- to 4-week sample, the hours of wasted light (as recorded by the sensor/logger setup) were extrapolated to a full year using Equation (3.1).

$$YWHours_{Light} = WHours_{Light} * [\frac{8760}{Hours_{Equip}}] \qquad (3.1)$$

where
- $YWHours_{Light}$ = total yearly wasted-light hours
- $WHours_{Light}$ = wasted-light hours identified in the field test
- 8760 = available hours in a year
- $Hours_{Equip}$ = total hours the equipment is installed during the field test.

Because all sets of sensor equipment were set up and removed on the same day of the week and within several hours of each other, any skewing based on nonexact 2- to 4-week periods was considered negligible. Similarly, sample periods with holidays were identified but not adjusted for working/nonworking hours.

Another primary factor in the overall savings analysis is the capacity of available lighting energy in each space that can be controlled. The total lighting wattage was estimated in each sample space based on a lamp/fixture count and an estimate of ballast losses. In each sample space, only operating fixtures were included in the lighting wattage count.

To identify factors affecting energy usage, the differences in wasted-light hours for each space characteristic were compared. The following characteristics are considered to have possible effects on lighting operation and were included in the analysis:

- availability of daylight
- space type (e.g., small office, large office, copy room, conference room)

- occupant type/function (e.g., engineering, administration)

- number of occupants.

The applicable data for each of these characteristics was compared and/or plotted where appropriate to visually determine any apparent trends. Those characteristics that exhibited trends were further explored to assign wasted-light hour values to appropriate space configurations and characteristics. The result of this analysis was a set of wasted-light hour values associated with various occupant and/or space conditions that will form the basis for the assessment of cost-effective lighting control projects.

3.2 Time Delay Adjustment

Currently available lighting occupancy sensor equipment can set the strength of the motion-sensing signal and the length of the time delay function tied to switching off lights. This time delay feature is useful when the strength of the motion-sensing signal must be set lower to avoid detection of occupants outside the desired building space (ultrasonic) or nonoccupant heat sources within the building space (infrared). In many of these situations, more time will elapse between the kind of occupant actions required to trigger the sensor (at its lower setting). The time delay can be set longer to avoid turning lights off on occupants in these situations.

The time delay feature can also have an effect on the quantity of lighting hours saved by the equipment. Whenever the space is vacant, the time allowed before turning the lights off affects the total amount of saved lighting hours. The difference in savings depends on the difference in the timer setting as well as the number of stops or light-off cycles made by the equipment. The number of cycles are directly dependent on the occupant's work function and style and are not affected by the time delay setting.

To assess these effects, a set of tests was conducted to quantify the differences in potential lighting savings associated only with timer setting adjustment. Each test was conducted with identical equipment and setup arrangement. The data collected in each test was a time-series stream of voltage readings taken at 8-second sampling periods and averaged over 56-second periods by a datalogger. The accompanying sensor read occupancy every 5 to 8 seconds and provided an open-close contact signal that produced a voltage input to the datalogger. This stream of data was in voltages from 0- to 9-V, indicating (to a few seconds) the length and frequency of occupied and unoccupied periods. A set of time filters that calculate potential wasted-light hours based on the length and frequency of collected data was applied to each data set to quantify the potential savings associated with various time delay settings in each situation. The results of this test indicate the potential variability in lighting savings based on timer setting.

4.0 Analysis and Results

This section describes the data analysis and development of wasted-light hour values for various building space/occupant categories and the effects of equipment adjustment on potential savings. The results are presented in a manner that can be applied to all commercial and federal building spaces.

4.1 Occupant Behavior and Space Characteristics

The initial step in determining factors affecting potential savings from the use of lighting controls was to compare and plot the data based on the characteristics identified as having potential effects on lighting operation (i.e., room type, occupant type, daylight, and number of occupants). A total of 141 sample periods representing over 50,400 test hours were considered to be without any bias or error and were used in this analysis.

Lighting needs are determined by human occupancy and activity. Human behavior is therefore considered a primary characteristic, having an effect on potential lighting energy savings associated with lighting control. This characteristic was the first one explored in this analysis. Data points corresponding to spaces with permanent occupants were used and are shown in Figure 4.1.

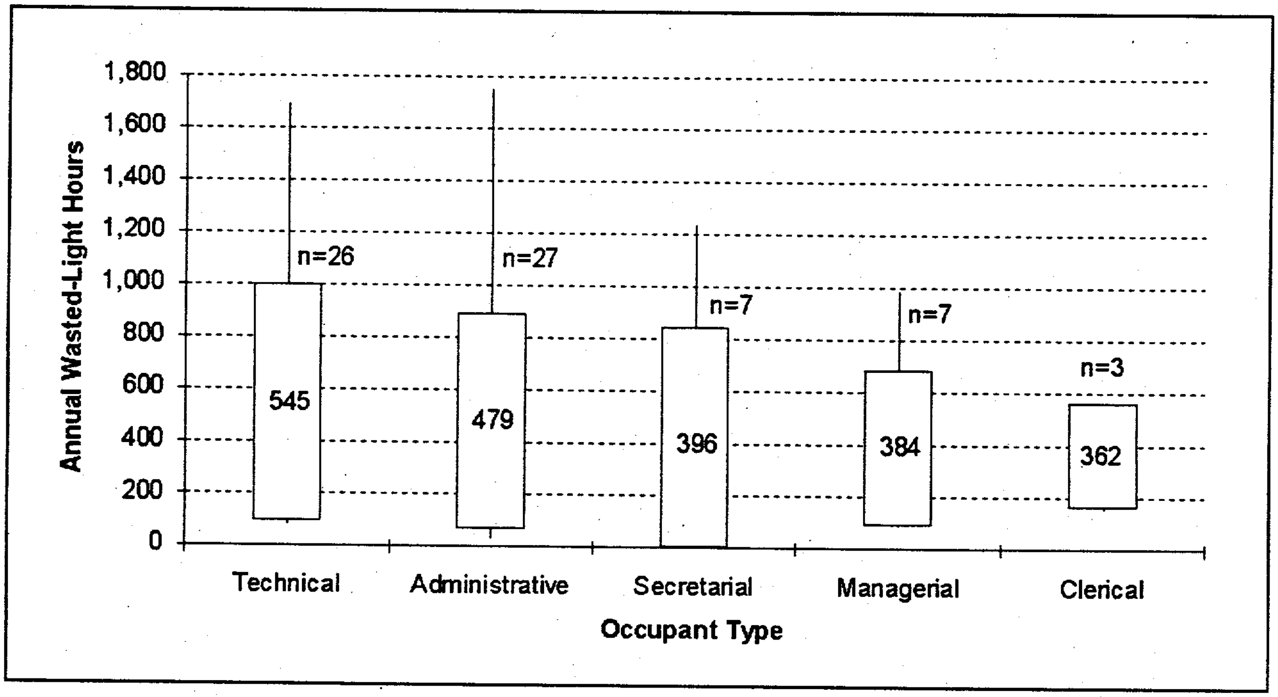

Figure 4.1. Annual Wasted-Light Hours by Occupant Type

A "box and whisker" plot is used to show the mean wasted-light value for each occupant type group, as well as the minimum and maximum points at the end of each whisker, and plus or minus one standard deviation values at the top and bottom sides of the box. The mean values are printed in each box at the mean point in the plot to help visualize any trends. These plots indicate the form and magnitude of variability or scatter associated with potential energy savings within each group. Also included on each plot are "n" values, indicating the available number of data points used to produce each plot. This plot indicates that technical and administrative staff exhibit higher potential lighting savings than secretarial, managerial, and clerical staff. The plot also shows a very slight increase (mostly high values) in the variability of actual potential savings associated with technical and administrative staff. Although the differences in the mean potential savings between staff appear small on the plot, they represent potentially significant values. The potential savings difference between clerical and technical staff mean values is equivalent to an approximately 50% increase over the clerical staff value. Variability indicates true-life conditions and each space will exhibit different savings potential. The mean values can be considered useful only when multiple installations are planned or considered.

The second primary characteristic considered in this analysis was the possible effect of daylighting availability on potential energy savings. To assess potential savings associated only with daylighting, companion sets of data were used from the two largest occupant type categories. The other categories had sample numbers considered too small to produce useable results. If a similar trend was evident between the groups, then an effect could be implied. Figure 4.2 shows the box and whisker plots for these occupant types. The plots show no clear trend that can be attributed to daylighting, although effects resulting from daylighting availability exist.

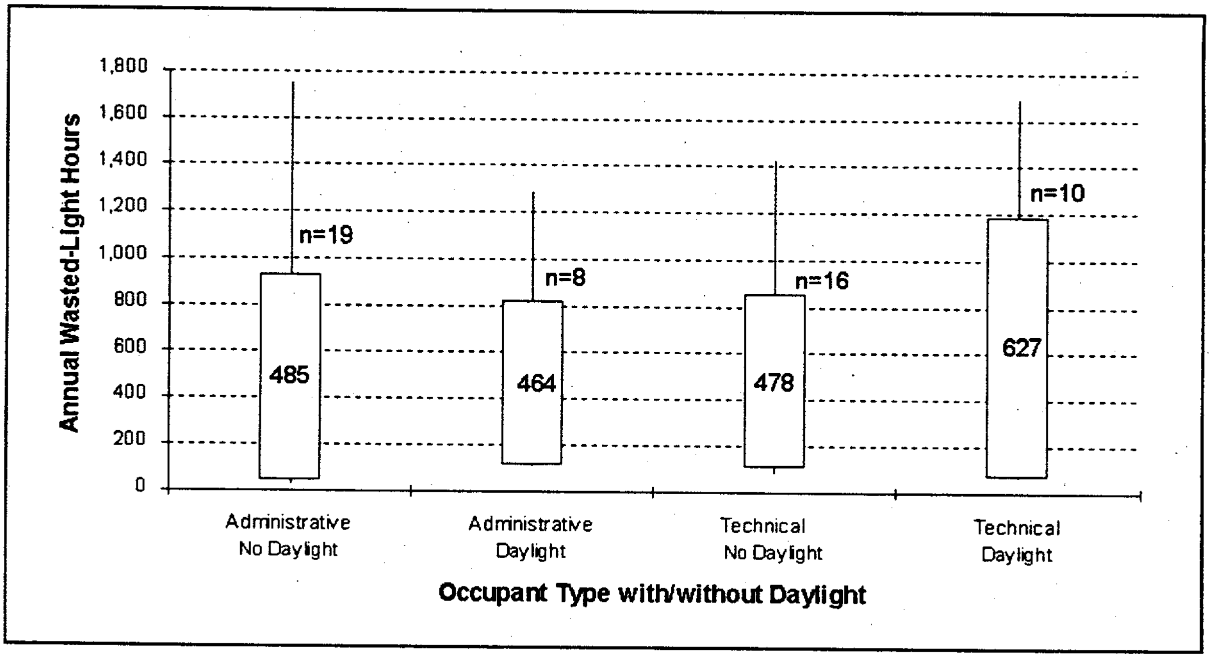

Figure 4.2. Annual Wasted-Light Hours by Occupant Type With/Without Daylight

A third characteristic explored in this analysis was the number of occupants in a particular lighted space. The fact that more than one occupant uses a space may affect lighting operation or the number of opportunities to save energy because of increased occupancy time. To avoid including other effects from multiple occupant types that may mask the effect of occupant count alone, the two largest data sets were split into single and multiple groupings. Figure 4.3 shows a decrease in potential lighting savings when multiple technical occupants are in one space. The difference appears small on the plot, but results in a 14% increase in savings potential with one occupant. The mean values can only be considered useful when dealing with multiple spaces. Similar data for administrative occupants is shown in Figure 4.4, showing a smaller effect in savings potential with only an 11% increase.

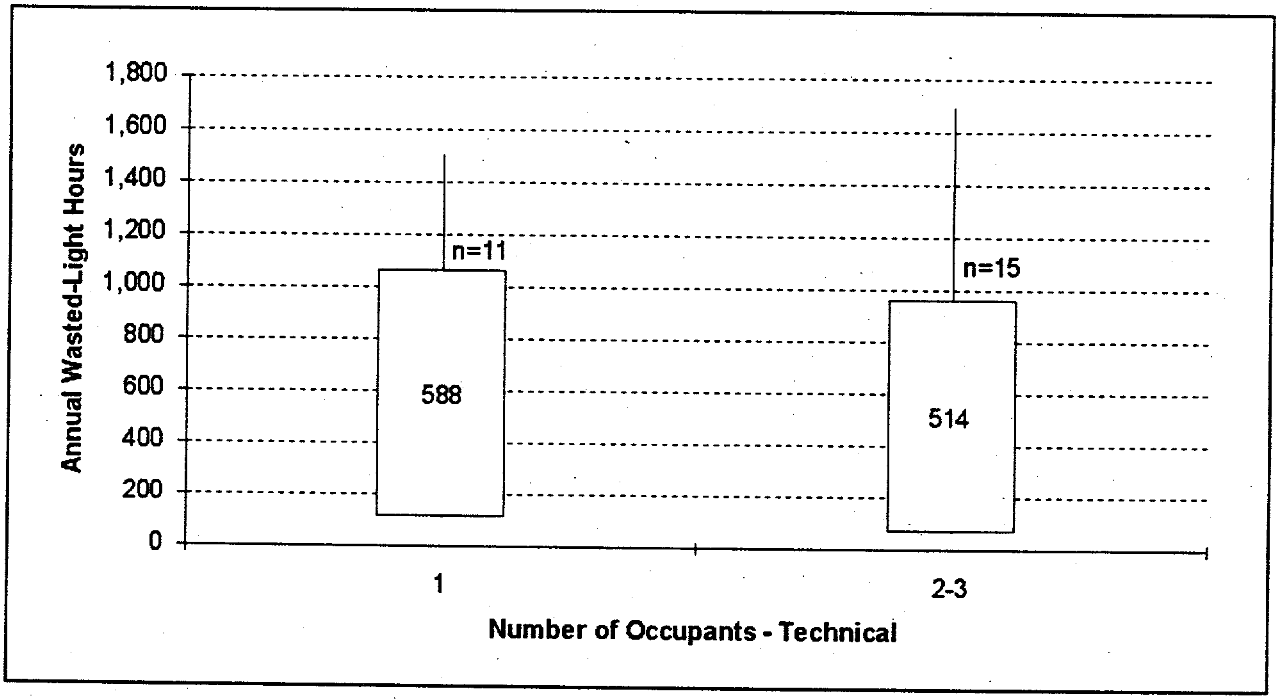

Figure 4.3. Annual Wasted-Light Hours by Number of Technical Occupants

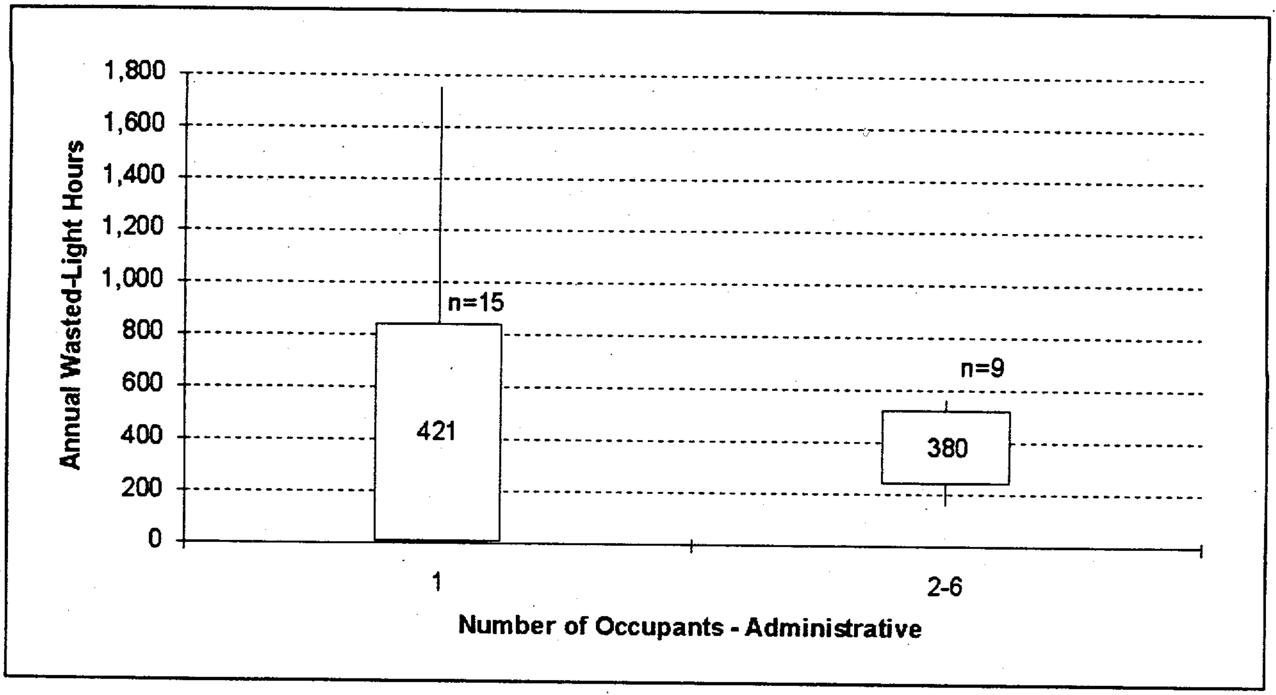

Figure 4.4. Annual Wasted-Light Hours by Number of Administrative Occupants

The final characteristic explored in this analysis was the difference in room type and function. Lighting control in permanently occupied spaces is affected by the occupants. Spaces that do not have *permanent* occupants experience lighting control based on *temporary* occupant motivation. Figure 4.5 shows box and whisker plots for each of the space types that generally have no permanent occupants. Conference and training spaces have little savings potential. These spaces are actually *temporarily* owned by the occupants; thus, the lights are more likely to be controlled. The library spaces in the sample are generally small -- specific reference storage areas not occupied by a materials custodian. Thus, these spaces are operated similar to storage areas where materials are retrieved on a case-by-case basis. These spaces are also temporarily owned and the potential savings is relatively low. A final space type group is at the high end of potential savings, which includes copy rooms, lunchrooms, unoccupied laboratory spaces, and restrooms. These spaces are all characterized as being generally unowned by any one person at any time. They are considered *public* spaces and the lighting is usually not controlled by most users. As with the effects of the other characteristics, the wide variability of the individual data points in the groupings must be considered.

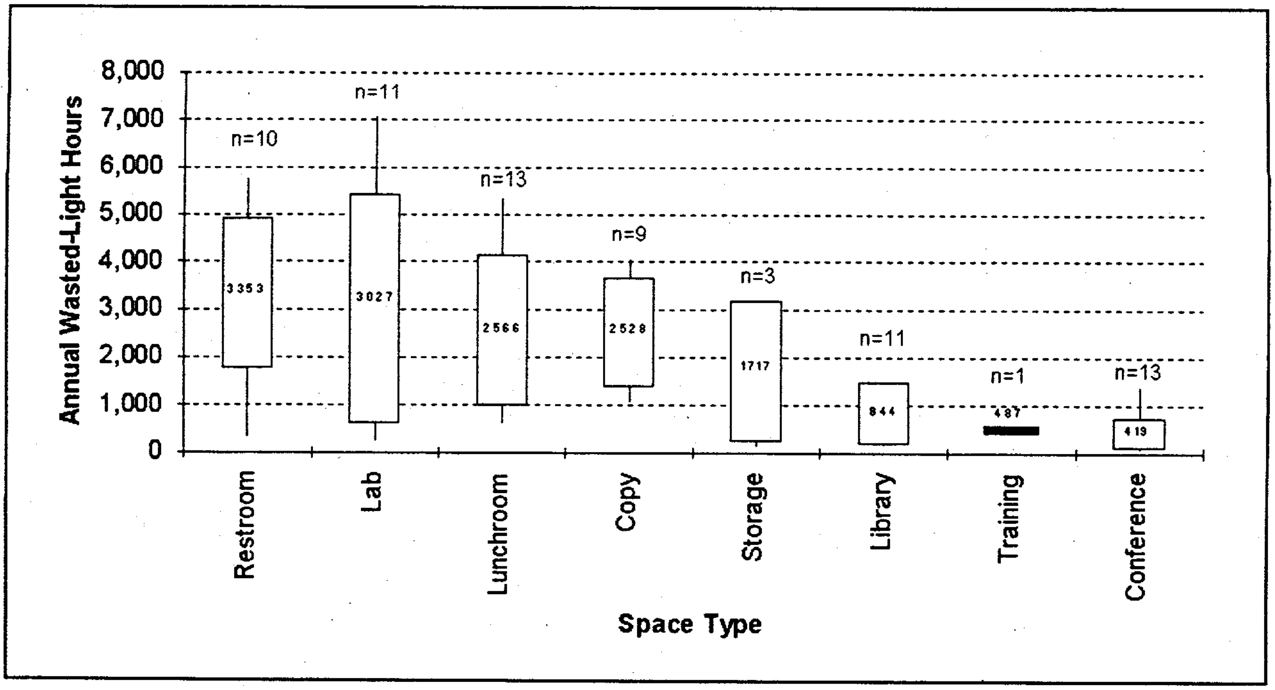

Figure 4.5. Annual Wasted-Light Hours by Space Type

The results of this analysis are the set of mean wasted-light hours shown in Table 4.1. The value

Table 4.1. Wasted-Light Hours for Occupant and Space Types

Space or Occupant Type	Wasted-Light Hours	+ or - Standard Deviation
Restroom	3353	1580
Lab	3027	2408
Lunchroom	2566	1579
Copy	2528	1132
Storage	1717	1476
Library	844	648
Training	487	0
Conference	419	323
Technical (2+ occup)	514	446
Technical (1 occup)	588	477
Administrative (2+ occup)	380	140
Administrative (1 occup)	421	417
Secretarial	396	447
Managerial	384	295
Clerical	362	197

of + or - one standard deviation from the mean is included to present a range of values associated with each mean. If a single space or only a few spaces are being considered, these ranges can be useful in understanding the possible variance in actual savings potential. Because the test equipment was set at a timer delay of between 5- and 8-minutes (less than the 10- to 20-minute factory setting), these values are considered somewhat conservative. The results in Section 4.2 provide some insight into the potential difference in savings associated with other timer setting values.

4.2 Time Delay Adjustment

The testing and analysis performed on the time delay adjustment of the sensor equipment provides insight into the importance of equipment adjustment at installation and during use. Most occupancy sensor equipment has both a signal strength/direction and timer adjustment. The signal strength/direction adjustment must be used to set the unit for the space within which it is installed. This adjustment sets how far and where the unit reads, which is critical for correct operation. Once this adjustment is set, the timer adjustment can be used to temper the effects of the strength/direction setting or other occupant behavior characteristics. The timer adjustment determines how long the unit will wait after sensing no motion before turning lights off. This feature helps avoid inadvertently turning lights off when occupants are making movements too small for the sensor to read.

The analysis of this equipment feature is based on very precise occupancy data used to assess exact occupancy and no-occupancy periods. Several offices and other rooms were initially monitored, but some were found to be difficult spaces in which to acquire good data. Because very exact occupancy data was needed and currently available test equipment does not possess the needed level of accuracy, accurate data collection was difficult in real world settings. The six test spaces that produced accurate data represented spaces used by technical (2 offices) and managerial occupants (2 offices), a restroom, and a copy/mail room.

The data from these six tests were recorded as time series voltage readings that indicate occupancy periods (see Sections 2.2.2 and 3.2 for test equipment and operation descriptions). Each set of raw voltage data was converted to occupancy period information. All of the weekend days were removed from the data to create data sets that represent only occupied periods. The data were divided into 24-hour periods to insure consistency between rooms. Complete days were chosen because two of the monitored spaces are shared by all building occupants. The lighting in these areas is typically left on all the time.

For office spaces, a person popping their head into a space to see if the occupant was present is not considered an occupied situation for these tests. If the sensor was actually controlling the lights, the lights would be off and it would be unnecessary to enter the space to determine if the occupant was present. For each incidence of this nature, the datalogger records 5 to 8 seconds of occupancy and may show a positive voltage reading for one 8-second sampling period. These readings cause average recorded values of less than 1.5 V in the 56-second datalogger time interval. For this study, these intervals were not considered occupancy. Any activation of the sensor in the restroom or copy/mail room was considered occupancy because it is common for people to quickly move in and out of these spaces This is especially true in the copy/mail room where a person can easily enter, retrieve mail from a box, and exit in 8 seconds.

When occupants remain still for periods greater than the 56-second reading time, a recorded 0 voltage reading may occur indicating false unoccupancy. Given the accuracy of the test setup for this analysis, a false unoccupancy is unlikely. It is even more unlikely that these periods will last as long as 2 minutes, which can be considered a minimum setting in real applications of today's technology. Some short-term informal field testing was conducted on office spaces having occupancy sensor lighting control. In all cases where the timers were set at 2 minutes, the occupants experienced lights going off while in the space. Therefore, periods of apparent unoccupancy for less than 2 minutes will ultimately be considered not useful as potential lighting reduction time and possible false, unoccupied readings less than 2 minutes will not affect data quality. After these modifications were complete, the data was processed using a database and spreadsheet. The result was a list, by space, of the length of the unoccupied period and the number of times that particular length of unoccupied period had occurred. Table 4.2 presents this calculated data for one of the office spaces.

Table 4.2. Sample Calculations of Percent Potential Savings From Different Time Delay Settings

		Cumulative Minutes Saved at:				
No. of Minutes	No. of Occurrences	20-Min Setting	15-Min Setting	10-Min Setting	5-Min Setting	2-Min Setting
1	7	-	-	-	-	-
2	4	-	-	-	-	0
3	5	-	-	-	-	5
4	3	-	-	-	-	11
5	5	-	-	-	0	26
6	3	-	-	-	3	38
7	2	-	-	-	7	48
8	2	-	-	-	13	60
9	3	-	-	-	25	81
10	1	-	-	0	30	89
12	1	-	-	2	37	99
13	2	-	-	8	53	121
14	2	-	-	16	71	145
15	4	-	0	36	111	197
16	1	0	1	42	122	211
21	1	1	7	53	138	230
22	2	5	21	77	172	270
25	1	10	31	92	192	293
Percent Savings:		<3%	8%	24%	50%	76%

To calculate the savings at a specific time setting, the length of the sensor time delay was subtracted from the length of each unoccupied period. For example, a space with a 15-minute unoccupied period equipped with a sensor set at a 10-minute time delay will result in 5 minutes of light savings. These savings were calculated for 2-, 5-, 10-, 15-, and 20-minute time delay settings, with the amount of savings being summed for each time setting. Blank cells in the table are periods when the space was not occupied long enough for the lights to turn off. The percentages at the bottom of the table are the percent of potential savings if the lights were turned off as soon as the occupant left the space (i.e., if a 0-minute delay were possible, there would be 100% savings).

To graphically see the differences between samples, a set of histograms was developed to present the percentage of lighted unoccupied time in various time bins for each space. Figures 4.6 through 4.11 show the binned unoccupied periods for each space.

The two technical staff samples (Figures 4.6 and 4.7) show that most of the unoccupied periods are of short duration. In these cases, the standard timer setting (usually factory set at 10 to 20 minutes) represents a large portion of each period. Therefore, the percentage of additional savings from reducing this delay is high. The unoccupied periods for managerial occupants are more varied, but are heavily represented by longer periods. In these cases, the standard timer settings represent a smaller portion of total unoccupied time and therefore savings percentages are smaller.

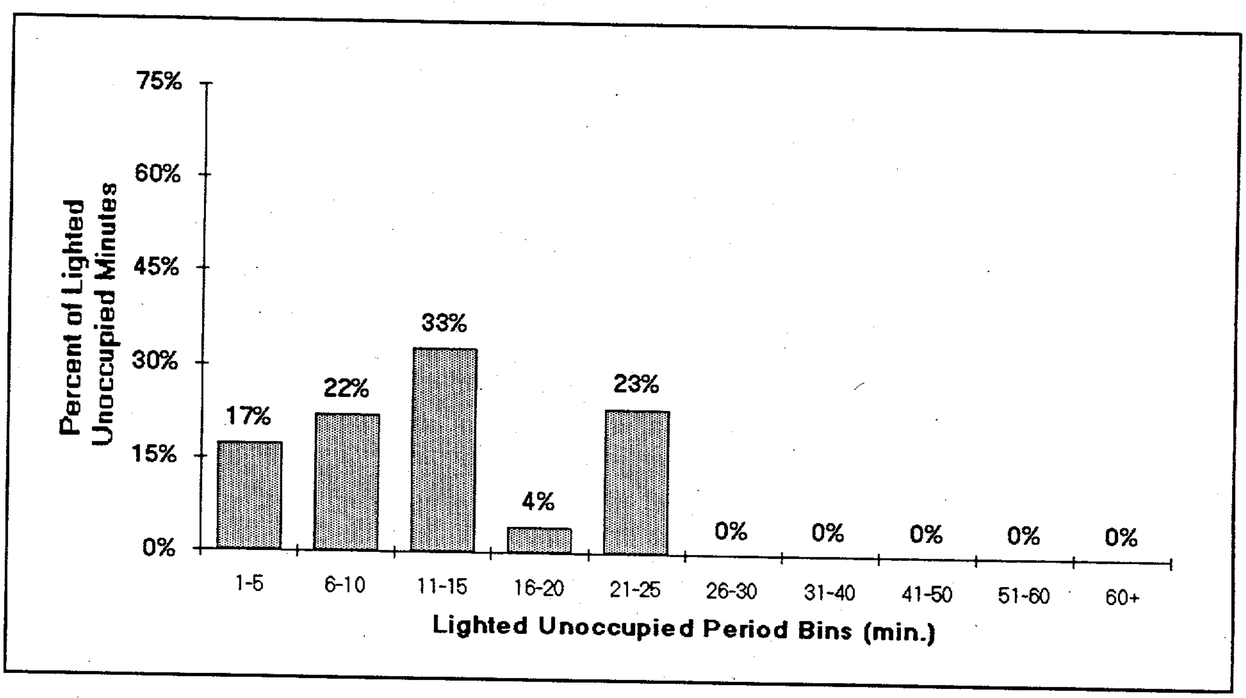

Figure 4.6. Percent of Lighted Unoccupied Minutes for Technical Staff No. 1

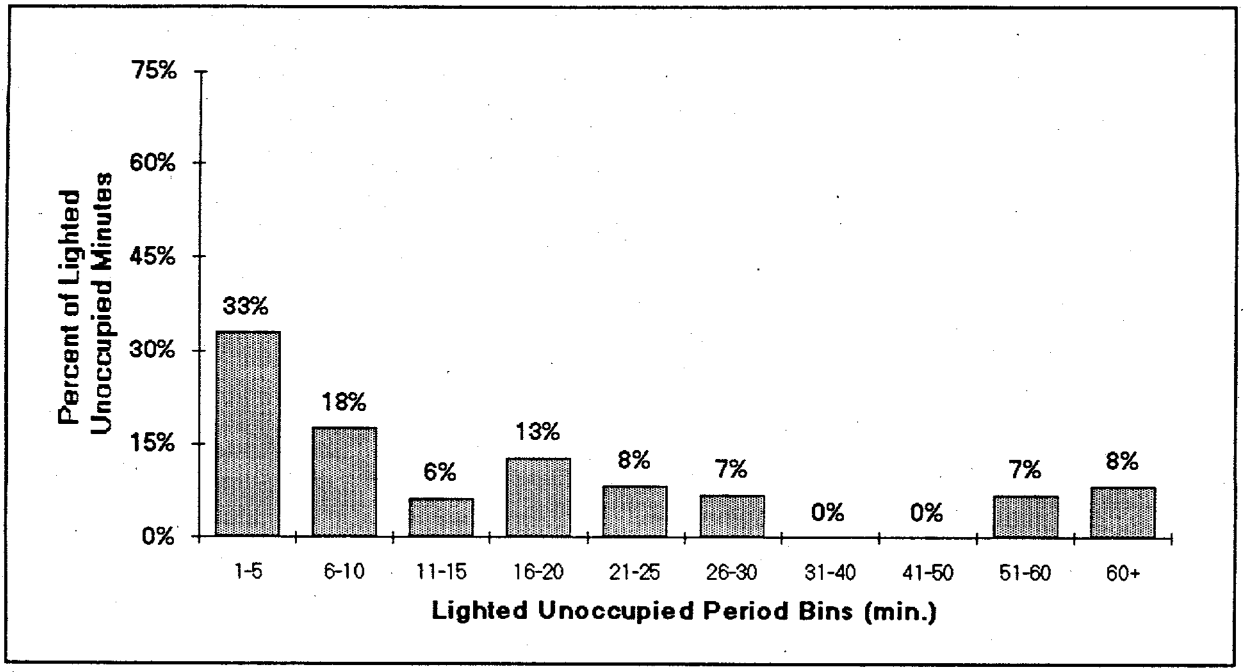

Figure 4.7. Percent of Lighted Unoccupied Minutes for Technical Staff No. 2

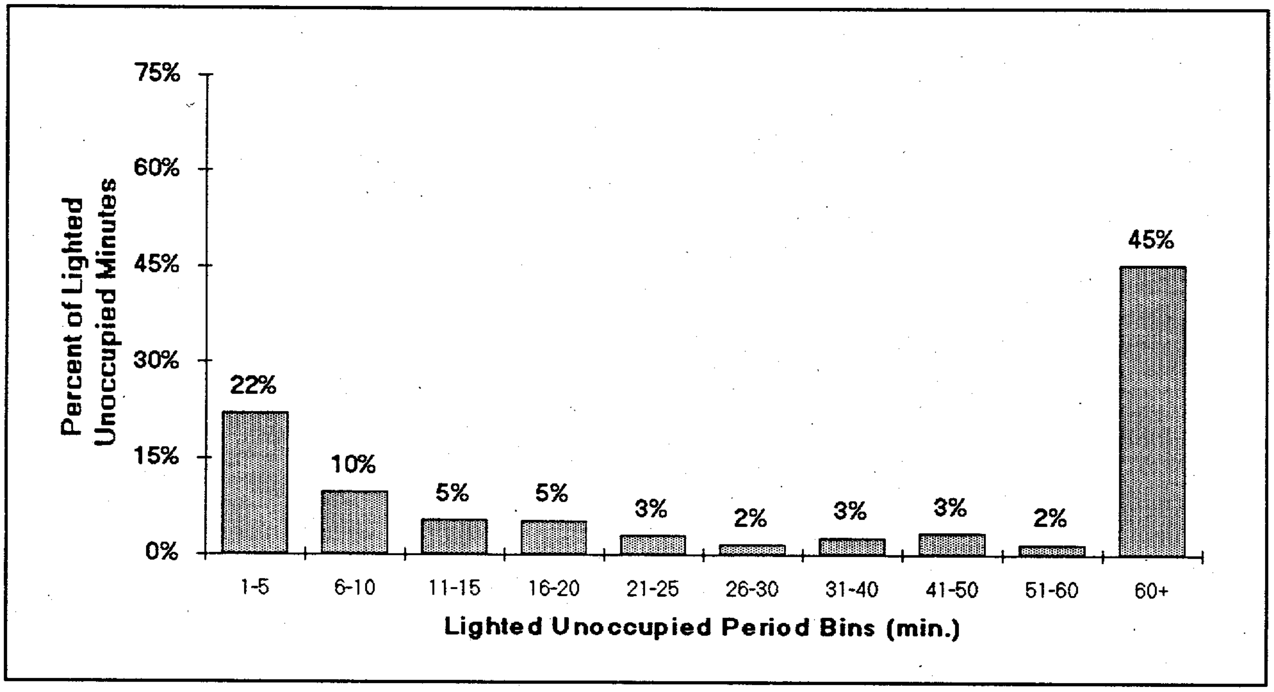

Figure 4.8. Percent of Lighted Unoccupied Minutes for Manager No. 1

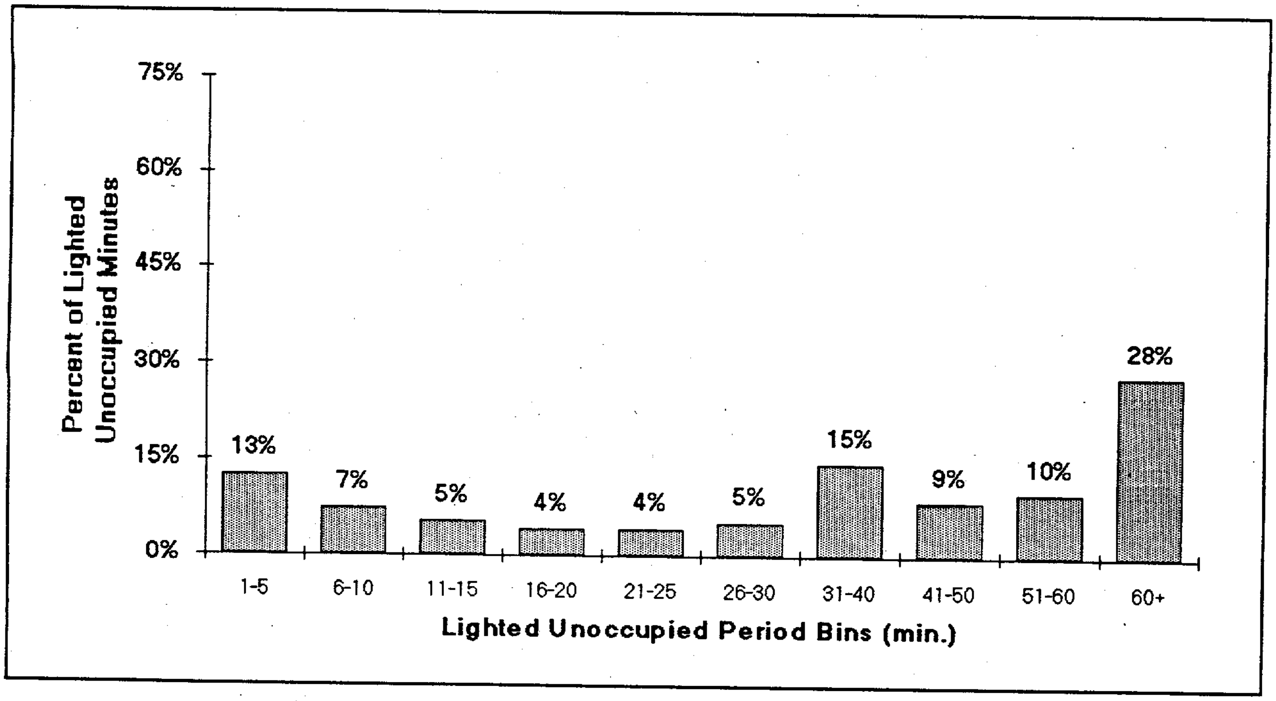

Figure 4.9. Percent of Lighted Unoccupied Minutes for Manager No. 2

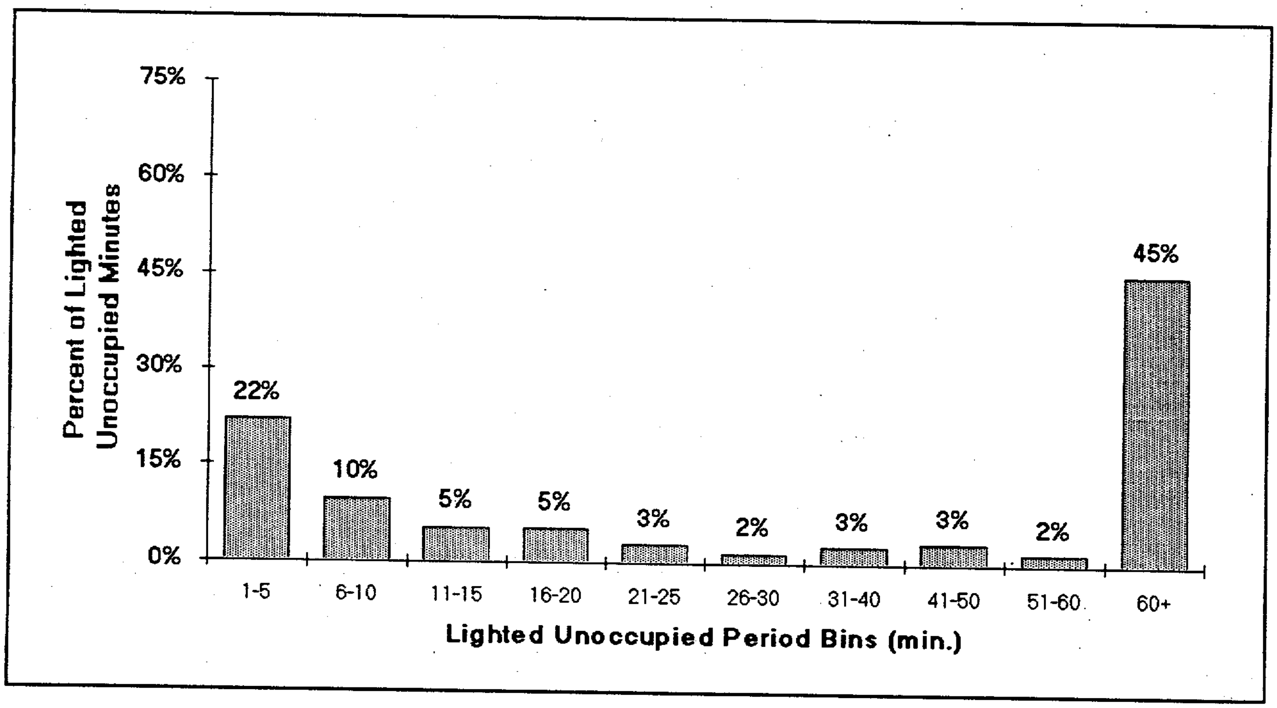

Figure 4.10. Percent of Lighted Unoccupied Minutes for Copy/Mail Room

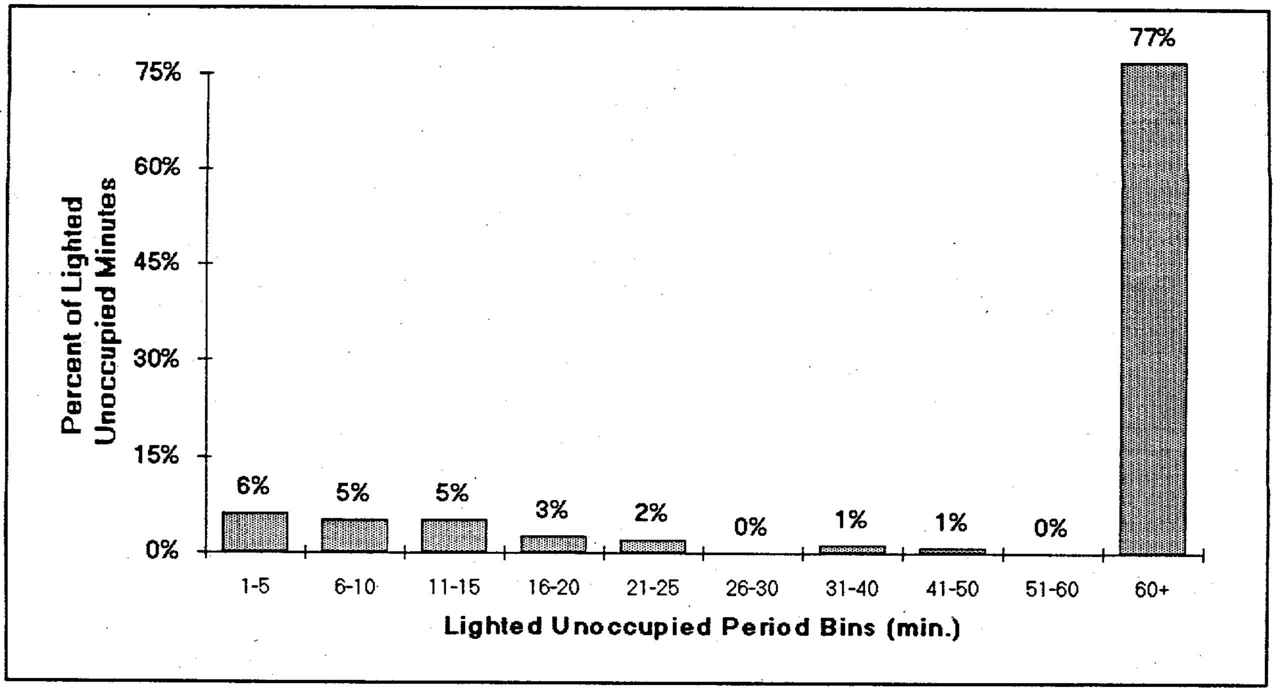

Figure 4.11. Percent of Lighted Unoccupied Minutes for Restroom

The copy/mail room distribution is different than the managerial staff distribution but ultimately has the same effect on savings. Copy/mail room spaces naturally experience long and short periods of unoccupancy while restrooms are dominated by very large periods of unoccupancy. These large periods of unoccupancy mean that little additional savings results from better timer adjustment for this space type.

The longer the unoccupied period, the less effect the length of the time delay has on the potential savings. Typically, when an occupancy sensor is installed, the time delay is left at the factory setting of 10 to 20 minutes. Resetting the time delay as low as possible when the occupancy sensor is installed is worthwhile, especially for technical staff offices. However, caution should be used to avoid setting the timer so low that lights are turned off on occupants. This situation can result in poor technology acceptance and no savings. The percent of potential savings associated with the five different time delay settings for all six of the monitored spaces are shown in Table 4.3. Figure 4.12 presents the same information graphically and includes a theoretical 0-minute setting, where the potential savings would be 100% for all six spaces.

Table 4.3. Percent of Potential Savings at Various Time Delay Settings

Space or Occupant	2- Min Setting	5-Min Setting	10-Min Setting	15-Min Setting	20-Min Setting
Technical Staff No. 1	76%	50%	24%	8%	3%
Technical Staff No. 2	64%	45%	29%	20%	13%
Manager No. 1	80%	67%	53%	44%	36%
Manager No. 2	84%	72%	59%	49%	41%
Copy/Mail Room	78%	65%	55%	50%	46%
Restroom	93%	86%	79%	75%	73%

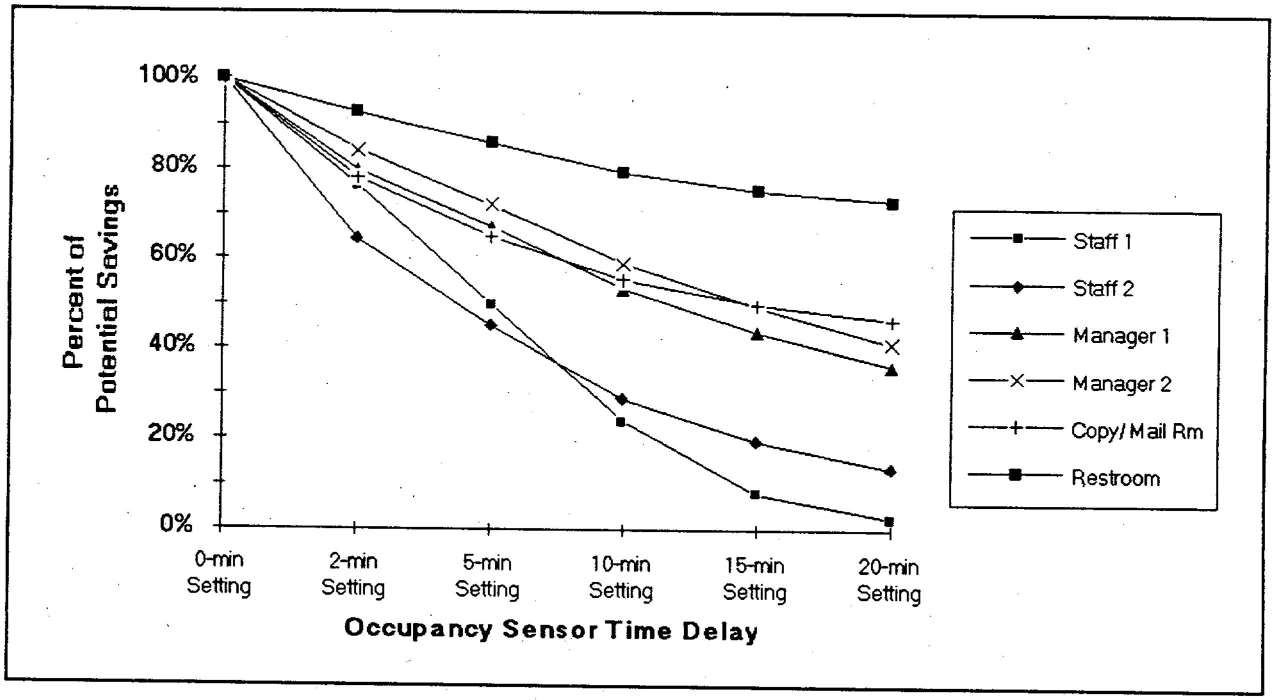

Figure 4.12. Percent of Potential Savings for Spaces at Various Time Delay Settings

The six datasets shown in Figure 4.13 are three groupings representing different savings potential depending on the space or occupant type. The highest potential percentage increase of savings is available by adjusting timers in technical staff offices followed by managerial staff offices and copy/mail rooms. The least increased savings from timer adjustment is found in restrooms.

It is important to note that this analysis is based on very small samples. The effects shown closely follow generally expected effects and are considered representative. However, more testing is needed to obtain more accurate values. Because monitoring was done in only six spaces in one building, it is problematic to extrapolate these results to all office building spaces. Additional monitoring at several other locations would result in a better understanding of the effect of the time delay on different spaces and occupant types.

4.3 Application of Results at the DOE Hanford Site

Applying the basic results of this study at the DOE Hanford Site will provide information necessary to effectively implement occupancy sensor technology as part of the federally mandated energy reduction plan. This application involves the following: 1) identify an economic method of cost-effective assessment, 2) assess current market products, costs, and equipment applicability, 3) identify the space types and conditions that will make application of sensors cost-effective at the Hanford Site, and 4) apply this information across all Hanford Site spaces to determine total savings capacities and costs.

4.3.1 Economic Analysis Methodology

The economic analysis method should provide federally accepted metrics of cost effectiveness, as well as information useful to site personnel in preparing project plans. A life-cycle cost (LCC) analysis is considered to be the best method for assessing overall cost effectiveness of energy retrofit options and is the mandated method of the federal government. For this study, the LCC methodology in the *Life-Cycle Costing Manual for the Federal Energy Management Program* (NBS 1987) was used. The result of the LCC analysis is a net present value (NPV) that is *the present dollar value of the net savings of the action over the period of analysis (10 years).* When it is not known how long a building space will be occupied, the life portion of the LCC analysis may be much less than normally considered. Therefore, some measure other than LCC effectiveness may be useful. Because energy savings and material/installation costs are the major items in this analysis, a payback year metric (which should be a relatively stable indicator of cost effectiveness) was also presented. The payback year is *the number of years required to pay back the first cost of the retrofit from the present value of yearly energy savings*. The factors considered to have an effect on the cost effectiveness of occupancy lighting control were:

- available wasted-light hours
- operated lighting capacity (watts)
- sensor equipment and installation cost
- electricity rate structure
- sensor equipment longevity
- maintenance costs associated with new sensor/lighting systems

- maintenance and lamp savings because of decreased replacement needs

- stability of present building space function/operation.

The available wasted-light hours factor is addressed in Section 4.1. The capacity of installed/operated lighting is a variable that has a large effect on cost effectiveness. For this study, the lighting wattage was recorded for each space type and size and was found to range between 1 and 4 W/ft^2 for a conservative average of approximately 3 W/ft^2. These values depend on the size of the space and other space characteristics. The approach chosen for this analysis was to identify the space sizes corresponding to an average wattage value that would be LCC-effective places for sensor control given all other considerations.

The equipment and installation cost factor in this analysis is another major factor in LCC-effectiveness. Many products are available on the market at varying costs. For the applications represented by this study, two classes of sensor equipment covered nearly all applications. In all but a few of the study cases, a wall-mounted sensor located in place of existing switch(es) provided appropriate control. This switch control type is the most common type of sensor control and is available in capacity ratings to meet the needs of most room sizes. For this study, units with capacities of up to 1000 W and up to 2000+ W were considered. Average vendor costs for the units were approximately $48.00 and $59.00, respectively. Personnel at the Hanford Site estimated the labor rate for electricians at approximately $65.00/hour. Labor hours for tasks similar to installing a switch-mounted sensor, including all training, were estimated to be approximately 0.4 hour. Based on this information, the estimated cost for installing either unit was $26.00. For the LCC analysis, the cost of the larger unit ($85.00 total) was used for any capacity greater than 1000 W uses. For all other analyses, the smaller unit cost ($74.00 total) was used.

Electricity costs also have a major impact on an LCC analysis. For the Hanford Site, two primary electricity sources provide over 99% of the total site-consumed energy. These sources are the City of Richland utility and the Hanford Site utility system. The yearly rates were calculated at approximately $0.055/kWh for the Hanford Site service (includes demand and many support costs) and approximately $0.043/kWh for the City of Richland service (includes demand). The City of Richland value was derived from a typical office building yearly consumption value applied to the current seasonal rates. The actual seasonal use of each facility determines the actual energy saved. For this study a conservative blended rate of $0.045/kWh was used.

Equipment longevity was ignored in this LCC analysis because the sensor equipment is considered to last as long as the lighting fixtures. Maintenance costs associated with the sensor equipment were also ignored. There is no additional maintenance associated with the sensors that replace wall switches. If small maintenance work is needed, it does not likely affect the stable maintenance budgets associated with Hanford Site facilities. The need to replace burned-out lamps will be decreased with occupancy sensor control because each lamp will have a longer effective life. This decrease may lead to potential maintenance and lamp purchase savings. However, these potential savings are generally considered small and may not materialize, depending on the lamp replacement system used by maintenance staff (group, spot replacement). These potential savings were conservatively ignored in this analysis.

The stability of current building space function/operation cannot be assessed in most cases. For this analysis, each space was considered to be stable (usable) for the life of the analysis (10 years). The stability of each space function/operation must be considered with each possible retrofit situation.

The analysis must also use standard acceptable monetary discount factors and fuel escalation values to produce consistent results. For this study, the discount rate and uniform present value (UPV) discount factors taken from the *Energy Prices and Discount Factors for Life-Cycle Cost Analysis 1994* (NIST 1993) were used. A discount rate of 3.1% and associated UPV discount factor of 8.59 were used in this analysis to adjust the current yearly energy consumption to a present value of savings over the analysis period of 10 years. The 10-year analysis was chosen because of the many leased facilities on site and the general consensus among Hanford Site facility planners that energy-related projects must be considered on a realistic 10-year basis.

4.3.2 Commercial Occupancy Sensor Equipment

The current market of occupancy sensor control equipment is growing fast and constantly changing with new products and product improvements. However, a standard selection of products and technologies still exists for use in building spaces. The two technologies used for occupancy sensor control are ultrasonic and infrared.

Ultrasonic units rely on the same technology used in exterior security lighting. This technology "bounces" ultrasonic waves throughout a room to detect motion. This technology, as packaged in a lighting control unit, cannot easily detect very slow motion or movement of smaller objects. Therefore, this technology is not 100% accurate in all situations and the use of time delay is required. The time delay allows the unit to "delay" turning off lights until sufficient time has passed for occupants to make a large enough movement to be seen or to be assured no one is in the space. This technology is well suited for enclosed spaces where ultrasonic waves can be contained so movement outside of a space is not read. This technology is particularly useful in spaces with tall partitions and other blockage because the waves will bounce around them and see hidden movement. Because this technology will see movement of any kind (if large enough), items such as fans, large movements of air, and floating balloons may cause false readings. Care must be taken during installation to ensure effective application.

Infrared technology is based on equipment that reads temperature differences over time to determine the movement of warm objects. Like the ultrasonic technology, the infrared technology is not always 100% accurate. Slow movement can be missed and other objects, such as heated moving air, may provide false readings. The infrared technology also cannot read through obstructions and must therefore only be used in relatively partition-free spaces. However, infrared technology is generally easier to adjust in the space because sections of the lens can be masked to avoid reading in unwanted areas. These units are provided with time delay to avoid incorrectly turning off lights.

Currently available equipment comes in a wide variety of configurations in both ultrasonic and infrared technologies. Configurations are generally designed for wall switch or ceiling mount operation. The wall switch types are easiest to install because they simply replace a current wall switch. The ceiling mount varieties require more installation time, but can provide more flexibility in operation and setup. Some ceiling units can operate large numbers of lighting fixtures in large open areas, but require additional relay equipment. Some new advances in occupancy sensor control have, or are being developed, to have dual technology sensing and daylight control. The dual sensor units combine ultrasonic and infrared technologies for a more effective sensor combination. The addition of daylight sensing to standard units can be useful for spaces with windows or skylights where effective daylight is available.

Current equipment prices vary depending on manufacturer, offered features, etc. Table 4.4 provides information on the basic available sensor configurations to determine the appropriate sensor type for a specific application.

Table 4.4. Occupancy Sensor Control Equipment Characteristics

Unit Type	Coverage Range	Cost Range	Application
Ultrasonic Wall Switch Replacement	Up to Approximately 2000 ft^2	\$40 to \$90	generally smaller enclosed spaces such as offices, work rooms, and labs; particularly good in spaces with partitions such as restrooms; cannot easily mask to avoid seeing through openings.
Infrared Wall Switch Replacement	Up to Approximately 2000 ft^2	\$40 to \$90	generally smaller enclosed spaces such as offices, work rooms, and labs; where full room is viewed by switch; not good in spaces with partitions such as restrooms; can easily mask reading in unwanted openings.
Ultrasonic Ceiling Mount	Up to Approximately 4000 ft^2	\$50 to \$140	similar to ultrasonic wall switch unit, but with larger coverage and control capability; can be placed in any ceiling location.
Infrared Ceiling Mount	Up to Approximately 4000 ft^2	\$50 to \$140	similar to infrared wall switch unit, but with larger coverage and control capability; can be placed to read over short partitions.

4.3.3 Cost-Effective Application of Space Types and Conditions at the Hanford Site

This analysis provided information needed to present a more accurate way to identify spaces that will provide cost-effective lighting energy savings from the application of occupancy sensor control. The wasted-hours values and economic analysis parameters presented in Sections 4.1 and 4.3.1 provide this information. Equations (4.1) and (4.2) can be used to determine whether particular types of spaces will provide cost-effective lighting energy savings when retrofitted with occupancy sensor controls.

$$NPV=[YWHours_{Light} * ERate * \frac{W}{1000} * UPV]-Cost \quad (4.1)$$

$$YPayback=\frac{Cost}{[YWHours_{Light} * ERate * \frac{W}{1000}]} \quad (4.2)$$

where	NPV	=	net present value
	ERate	=	applicable blended electricity rate in dollars per kilowatt-hour
	$YWHours_{Light}$	=	total yearly wasted lighting hours
	W	=	wattage controlled by occupancy sensor
	1000	=	watts per kilowatt-hour
	Cost	=	installed cost of equipment
	YPback	=	years of energy savings needed to pay back the installed cost investment
	UPV	=	uniform present value factor as used in federal life-cycle costing. This value depends on the location, discount rate, and analysis period.

If the NPV value is positive, then the retrofit of the space is likely to be a positive financial investment. If the NPV is negative, the space should generally not be retrofitted if cost-effective savings is the goal. The payback year value is derived as an added metric for effective savings. This value roughly estimates the number of years of energy savings needed to pay off the investment.

When applying these equations, remember that the yearly wasted-light hour values are the averages derived in this study. These actual individual values are quite variable within each space or occupant type. Therefore, Equations (4.1) and (4.2) cannot be accurately used to assess the potential savings at one or a few spaces. The equations can, however, provide a good indication of cost effectiveness when many similar spaces are being considered.

Tables 4.5 and 4.6 contain the NPVs and payback periods calculated using Equations (4.1) and (4.2), respectively, with data specific to the Hanford Site. These calculations included an analysis period of 10 years, 1994 UPV of 8.59, and equipment installation cost of $85.00 or $74.00. The values in both tables are only included for those spaces or occupant types where a positive NPV was calculated. A negative NPV indicates that over the analysis period, the action would lose money. Wherever this is the case in Table 4.5, the spaces in both Tables 4.5 and 4.6 are left blank. This data forms the basis for assessing the cost-effective sensor application spaces on the Hanford Site. When reading Tables 4.5 and 4.6, remember that:

- No savings (in terms of dollars) will be specifically seen for a facility unless it is metered or otherwise credited with appropriate savings.
- These values are based on current total rates. Under the Hanford Site system, if a large energy reduction is accomplished, the support cost portion of this rate may be redistributed and savings may be LESS than shown.
- The values for "occupant type" are based on occupants in office spaces ONLY. Similar occupants in nonoffice spaces may not exhibit the same lighting operation characteristics.

Table 4.5. Net Present Values for Hanford Site Spaces and Occupant Types

Building Space or Occupant Type	Wasted-Light Hours	Lighting Capacities (Watts)					
		200	300	400	500	600	700
		Net Present Value					
Technical (2+ occup)	514	-	-	5	25	45	65
Technical (1 occup)	588	-	-	17	40	62	85
Administrative (2+ occup)	380	-	-	-		14	29
Administrative (1 occup)	421	-	-	-	7	24	40
Secretarial	396	-	-	-	3	18	33
Managerial	384	-	-	-	0	15	30
Clerical	362	-	-	-	-	10	24
Conference	419	-	-	-	7	23	39
Training	487	-	-	1	20	39	58
Library	844	-	24	56	89	122	154
Storage	1717	59	125	191	258	324	391
Copy	2528	121	219	317	415	512	610
Lunchroom	2566	124	224	323	422	521	620
Lab	3027	160	277	394	511	628	745
Restroom	3353	185	315	444	574	704	833

Table 4.6. Payback Years for Hanford Site Spaces and Occupant Types

Building Space or Occupant Type	Wasted-Light Hours	Lighting Capacities (Watts)					
		200	300	400	500	600	700
		Payback Years					
Technical (2+ occup)	514	-	-	8.0	6.4	5.3	4.6
Technical (1 occup)	588	-	-	7.0	5.6	4.7	4.0
Administrative (2+ occup)	380	-	-	-	-	7.2	6.2
Administrative (1 occup)	421	-	-	-	7.8	6.5	5.6
Secretarial	396	-	-	-	9.1	7.6	6.5
Managerial	384	-	-	-	8.6	7.1	6.1
Clerical	362	-	-	-	-	7.6	6.5
Conference	419	-	-	-	7.8	6.5	5.6
Training	487	-	-	8.4	6.8	5.6	4.8
Library	844	-	6.5	4.9	3.9	3.2	2.8
Storage	1717	4.8	3.2	2.4	1.9	1.6	1.4
Copy	2528	3.3	2.2	1.6	1.3	1.1	0.9
Lunchroom	2566	3.2	2.1	1.6	1.3	1.1	0.9
Lab	3027	2.7	1.8	1.4	1.1	0.9	0.8
Restroom	3353	2.5	1.6	1.2	1.0	0.8	0.7

4.3.4 Hanford Site Energy Reduction Potential

The assessment of total potential savings on the Hanford Site was estimated using square footage data for site facilities available from various Hanford contractors. An estimate of 8,400,00 ft^2 was used as the total for all facilities on site having potential occupancy sensor applications. Approximately 2,065,000 ft^2 of this data was available on a room-by-room basis.

The room-by-room data contained space type codes and square footage for each space in each facility. Some of the spaces in the room-by-room data were not included in the calculations because they were considered inappropriate for control retrofit. These included attics, docks, hallways, hot cells, security vaults, and other miscellaneous spaces. Shop areas were also not included because no corresponding wasted-light data was available. For each room-by-room data point used in the assessment, space and/or occupant type codes were assigned as well as appropriate wasted-light hour values. Lighting wattage values were also assigned to each space type based on the installed wattages found in the test space data. Spaces smaller than 75 ft^2 or greater than 4000 ft^2 were not included in the assessment. Spaces below 75 ft^2 and above 4000 ft^2 in real-world applications may not be good spaces for standard occupancy control. Other large-scale control methods not included in the scope of this study may be more applicable. In some cases, no control may be possible.

For each space, an NPV was calculated using Equation (4.1) in Section 4.3.2. A total NPV for the representative 2,065,000 ft^2 of facilities was calculated by summing all positive NPV values. A simple payback period was also calculated from those data points where a positive NPV was calculated. A total site NPV was estimated based on the ration of total site square footage to room-by-room square footage. A total site payback period was considered to be the same as the one calculated from the room-by-room data. Table 4.7 presents the important information for both the room-by-room data and corresponding total site estimate.

Table 4.7. Total Estimated Energy Savings Potential at Hanford Site

Item	Room-by-Room Data	Total Site Estimate
Total Facility ft^2	2,065,000	8,400,000
Total ft^2 Controlled Space	945,064	3,844,000
Total Positive NPV	$870,232	$3,539,926
Total Estimated Cost	$240,136	$976,824
Total Yearly Energy Cost Savings	$129,262	$525,812
Estimated Simple Payback Years	1.85	1.85

5.0 Conclusions and Recommendations

The results of this analysis provide useful information for assessing the cost-effective application of occupancy sensor controls in building spaces. The types and quantity of spaces that will benefit from this technology depends primarily on the function of each building space and its occupants, the amount of lighting wattage to be controlled, and the applicable utility rate. Specific conclusions drawn from the analysis are as follows:

- The availability of daylight in a building space does not appear to have any noticeable aggregate effect on the quantity of wasted-light hours in occupied or unoccupied spaces. This conclusion is based on the lack of any noticeable correlation between the daylight and no-daylight levels of wasted-light hours for various occupant types.

- An important factor in the level of wasted-light hours in unoccupied spaces (e.g., conference rooms, copy rooms) is the perceived ownership of the building space. Conference, training, library, and storage spaces tend to be *temporarily* owned by an individual or organization and lights are generally turned off when the occupants leave the space. Copy rooms, lunchrooms, unoccupied labs, and restrooms are generally owned by everyone and therefore lights are more likely to be left on for the next occupant.

- More than one permanent occupant in an occupied space tends to decrease the wasted-light hours (approximately 13% fewer in technical staff and 10% fewer in administrative staff). This decrease is attributed to the staggered use of a space associated with multiple occupancy.

- Setting the timer control on a sensor device below the normal factory setting of 10+ minutes can have a significant effect on the number of wasted-light hours saved (up to 39% more if set to 3 minutes).

Although wasted-light hour values for various building spaces and occupant types were derived from representative real-world data, there is still a lot of variability in how spaces are used. A single application may not achieve the savings presented here because of the many factors that can affect lighting use in a specific space. The data is recommended only for use in determining potential savings for groups of similar building spaces.

The application of this study's findings at the Hanford Site indicate a potential energy cost savings of $525,812/yr because of the use of occupancy sensor lighting control. The cost to achieve this savings level is estimated at $976,824. The total NPV for the site is estimated at $3,539,926 with a simple payback period of 1.85 years. This estimate is based on applying controls only in those spaces where the resulting action is LCC-effective.

Companion issues to occupancy control exist that can have a major effect on lighting energy use. These issues include daylighting control, lighting technology upgrade, and appropriate lighting reduction. These issues are not addressed as part of this analysis, but should be considered for future study and consideration with occupancy lighting control.

6.0 References

National Bureau of Standards (NBS). 1987. *Life-Cycle Costing Manual for the Federal Energy Management Program*. NBS Handbook 135, U.S. Government Printing Office, Washington, D.C.

National Institute of Standards and Technology (NIST). 1993. *Energy Prices and Discount Factors for Life-Cycle Cost Analysis 1994*. NIST Handbook 135, National Technical Information Service, Springfield, Virginia.

Distribution

No. of
Copies

Offsite

12 DOE/Office of Scientific and
Technical Information

2 K. Dean Devine
Federal Energy Management Program
U.S. Department of Energy
EE-44
1000 Independence Avenue SW
Washington, DC 20585

M. Ginsberg
Federal Energy Management Program
U.S. Department of Energy
EE-44
1000 Independence Avenue SW
Washington, DC 20585

L. Harris
Federal Energy Management Program
U.S. Department of Energy
EE-44
1000 Independence Avenue SW
Washington, DC 20585

V. Petrolati
DOE/In-House Energy Management
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

No. of
Copies

Onsite

4 DOE Richland Operations Office

D. D. Green	K8-50
M. B. Hitt	A7-27
T. L. Kehrli	G3-18
W. A. White	G3-18

5 Kaiser Hanford Engineers Company

W. G. Sealock	G3-04
L. H. Smith	B4-40
W. S. Dunnivant	G3-04
D. A. Maez	G3-04
J. E. Uecker	S2-12

36 Pacific Northwest Laboratory

C. A. Anderson	K5-20
D. M. Carroll	K5-08
A. L. Dittmer	K5-08
J. C. Hail	P7-70
M. A. Halverson	K5-08
R. E. Jarnagin	K5-08
J. M. Keller	K5-08
G. B. Parker	K8-54
E. E. Richman (10)	K5-08
W. F. Sandusky	K5-08
R. F. Szydlowski	K5-08
S. A. Weakley (10)	K8-18
Publishing Coordination	
Technical Report Files (5)	