Bi-level Office Lighting with Occupancy Sensors – Follow-up Analysis

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A Report of BPA's Energy Efficiency Emerging Technologies Initiative

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The following report was funded by the Bonneville Power Administration (BPA) as an assessment of the state of technology development and the potential for emerging technologies to increase the efficiency of electricity use. BPA is undertaking a multi-year effort to identify, assess and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

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The Washington State University Extension Energy Program (WSU Energy Program) prepared this report for BPA as a contractor under the E3T Program. The Project Manager for this project and author of this report is Mary Matteson Bryan, P.E., under contract to the WSU Energy Program. Jack Zeiger, Doug Koenen, and Cindy Wills of the WSU Energy Program coordinated and performed monitoring and data collection. Cori Jackson and Pedram Arani of the California Lighting Technology Center (CLTC) developed the experimental design and procedure and assisted in implementation of field monitoring. This report was reviewed for technical quality by Rob Penney and Jack Zeiger of the WSU Energy Program. The report was edited and produced by Melinda Spencer and graphics support was provided by Gerry Rasmussen, both of the WSU Energy Program.

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Abstract

This report is a follow-up to the report, "Bi-Level Office Lighting with Occupancy Sensors," issued in January 2011. http://www.e3tnw.org/Documents/Bi-Level%20Office%20Lighting-FinalReport.pdf The WSU Energy Program, under contract to BPA, conducted an assessment of an emerging technology at a project host site, the County-City Building located in Tacoma, Washington. The purpose of this project is to assist BPA with the evaluation of bi-level switching of office lighting with occupancy sensor control in individual offices. The assessment results demonstrate that bi-level switching in individual offices can deliver significant savings compared to single-level switching. Payback periods are fairly short for new construction scenarios, but quite long for retrofit scenarios.

Table of Contents

Tables

Figures

Executive Summary

This report summarizes additional analyses performed for an assessment project conducted to evaluate bi-level switching with occupancy sensors for lighting in individual offices. The original emerging technology assessment study, "Bi-Level Office Lighting with Occupancy Sensors," was designed to investigate the potential energy savings and economic performance of bi-level switching with occupancy sensors as compared to the baseline single-level manual switching.

The facility selected for the assessment is the 11-story County-City building in Tacoma, Washington. The baseline for the study consisted of 30 individual offices with single-level manual switching of recessed T8 fluorescent office lighting. Each of the offices was retrofitted with bi-level switching with occupancy sensor control and bi-level ballasts.

The bi-level switches and occupancy sensors can be configured to provide various operational scenarios, each providing a different way for occupants to control the lights. The assessment investigated the energy-savings potential of each of the following three scenarios:

1. **Auto-on at 50%, auto-off**: Lights are switched on automatically at the low level (50%) upon occupancy, the remaining lights can be switched on manually, all lights can be switched off manually, and lights are turned off automatically after the office is unoccupied for a period of time.
2. **Auto-on at 100%, auto-off**: Lights are switched on automatically at the high level (100%) upon occupancy, lights can be switched to a lower light level (50%) or all off manually, and lights are turned off automatically after the office is unoccupied for a period of time.
3. **Manual-on, auto-off**: Lights can be switched on and off manually at 50% or 100%, and lights are turned off automatically after the office is unoccupied for a period of time.

After monitoring existing lighting usage, including task lighting, for three weeks to establish a baseline, each office was retrofitted with the new lighting systems and monitored for successive three-week periods in each of the three scenarios listed above. Data collected included the time of occupancy and the time the lighting level was on high (100%), low (50%), and off to determine which default setting resulted in the lowest energy usage.

This follow-up report includes the following four analyses:

1. **Perimeter offices and interior offices**: Calculate the savings and economic performance for the perimeter offices as compared to the interior offices.
2. **Baseline of single-level switch with occupancy sensor**: Calculate the savings and economic performance for use of a bi-level switch with occupancy sensor set in the auto-on at 50% setting as compared to a baseline of a single-level switch with occupancy sensor.
3. **Baseline of manual bi-level switching**: Calculate the savings and economic performance of a bi-level switch with occupancy sensor set in the auto-on at 50% setting as compared to a baseline of manual bi-level switching.
4. **Alternate installation strategies**: Calculate the estimated installed cost for the two alternate installation strategies described in the original report and calculate the impact on economic performance of using these alternate strategies.

Results

The assessment results demonstrate that lighting energy savings can be achieved through the use of bi-level switching with occupancy sensors and that the level of savings and cost effectiveness vary, depending on a number of factors, including the baseline assumed, lighting hours of operation, installation labor costs, utility incentives and energy costs.

Additional analysis of the data from the original study show that lighting is operated in the low setting for longer hours in the perimeter offices as compared to the interior offices. Given that the perimeter offices have large windows that allow daylight into the space, occupants are more inclined to operate lights at the low level. As a result, energy savings in perimeter offices are higher than in interior offices and the payback period is shorter.

The economic performance of the hypothetical baseline condition of single-level switching with occupancy sensor is improved slightly from the baseline condition analyzed in the original report, with the payback period reduced by one to two years.

The results were mixed for the second hypothetical baseline investigated: an existing individual office with a manual bi-level switch operating all the lights off, half the lights on or all the lights on. The payback period was shorter for a retrofit scenario but was longer for a new-construction scenario as compared to the results from the original report.

Installing the bi-level switching system using one of the alternate installation methods can have a significant impact on economic performance in a new construction scenario, but less so in a retrofit scenario. For a retrofit scenario, the installed cost for both alternative installation strategies is only slightly lower than the installed cost for the original installation strategy, with minimal impact on the simple payback period. For a new construction scenario, the total cost for the two alternative strategies is reduced to a larger extent and, therefore, the payback period is shortened more significantly to a range of one to four years.

Project Background

Office lighting has typically been controlled through the use of manual switches or occupancy sensors that switch all of the lighting in the office on and off. Incorporating bi-level switching with occupancy sensors would allow occupants to select from multiple levels of lighting (high, low, off), with potential associated energy savings.

Please refer to the original assessment report for a detailed discussion of the project background, including an overview of previous studies, and the current state of the technology and market (http://www.e3tnw.org/Documents/Bi-Level%20Office%20Lighting-FinalReport.pdf).

Methods

Please refer to the original assessment report for a detailed discussion of the project methodology.

Findings

Perimeter Offices and Interior Offices

In the original report, the lighting usage data for all offices, both perimeter and interior, was analyzed to calculate average lighting hours of operation for a typical office in the Pierce County County-City Building in Tacoma, Washington. For this follow-up analysis, lighting usage data is analyzed separately for perimeter offices, where daylighting is available, and for interior offices with no windows and no day lighting. Lighting usage data is analyzed for the scenario where the occupancy sensor is set to operate in the auto-on at 50%, auto-off setting.

As with the original report, economic performance is calculated for both retrofit and new construction scenarios. Also, economic performance is calculated separately for a small office and a large office. This is required because the energy savings will be different between a small and large office due to the different connected lighting loads. Because ceiling-mounted occupancy sensors are required for large offices and wall-mounted sensors are required for small offices, the installation costs are different.

Energy cost savings are calculated using an average electric rate of $0.09/kWh. This rate is the average rate for large commercial customers in Washington State as reported by the U.S. Energy Information Administration, August 2010, and adjusted for taxes and fees. Equipment costs used in the analysis are actual end-user costs paid by the project for the materials used for the office retrofits. Potential energy efficiency rebates are not included in this analysis. Pierce County maintenance staff who performed the installations were surveyed to obtain labor hours for installing and commissioning the equipment. These hours were multiplied by an average labor rate from Means Construction Cost Estimating Guides to determine labor costs.

> *Economic estimates are sensitive to site-specific variables such as lighting hours of operation, installation labor costs, utility incentives and energy costs. Economic calculations presented here are based on variables specific to this field assessment. Readers are advised to use their own cost estimates and assumptions when possible.*

New Construction/Major Remodel Scenario

Under the new construction/major remodel scenario, the economic analysis is based on incremental cost and savings as compared to the baseline lighting control system that would have been installed. The baseline lighting control system for this analysis is the minimum code-compliant lighting system, which consists of a single-level occupancy sensor switch. Conveniently, this is the same as our monitored Scenario 3 from the original report and the baseline hours are reported accordingly. The lighting control system is upgraded to bi-level switching by installing a bi-level switch with occupancy sensors and a bi-level ballast. Savings are calculated as the difference between the baseline condition and the bi-level switching condition.

A summary of lighting hours of operation and incremental electric energy savings for the perimeter offices and for the interior offices is provided in the tables and figures below. Detailed calculations can be found in Appendix A.

Table 1: Average Annual Lighting Hours, New Construction

	Average Annual Hours Lights On	Percent of Lit Hours On at 100%	Percent of Lit Hours On at 50%	Average Annual Hours Lights On at 100%	Average Annual Hours Lights On at 50%
Baseline	1,655	100%	0%	1,655	0
Perimeter	1,655	28%	72%	469	1,186
Interior	1,655	46%	54%	762	893

Figure 1: Bi-level Lighting Operation, New Construction

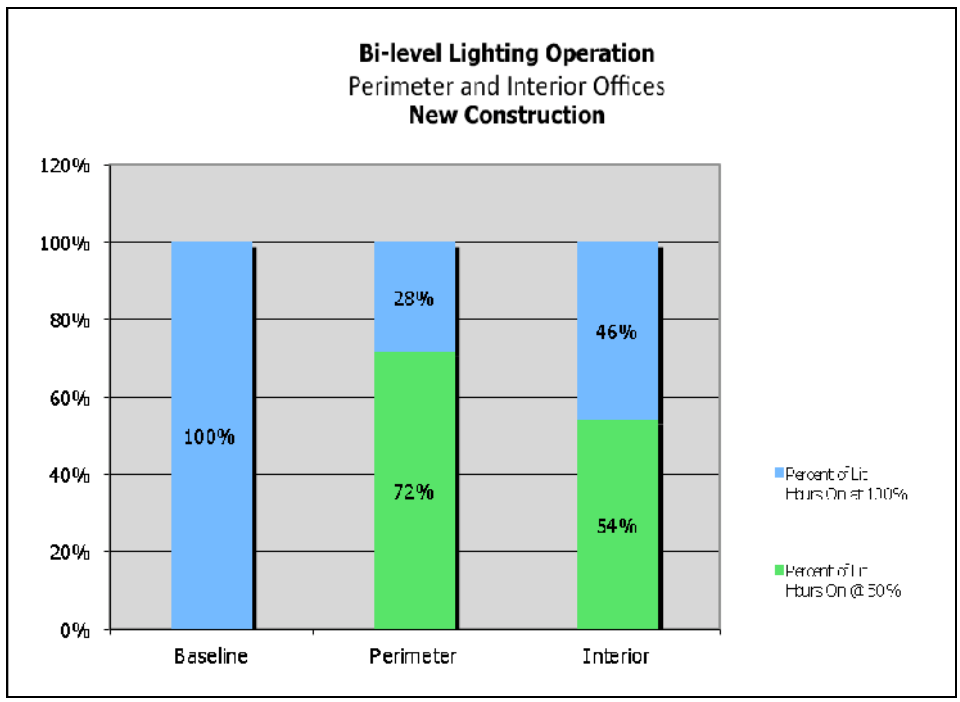


Table 2: Average Annual Electric Energy Savings, New Construction

	Percent Savings	Small Office		Large Office	
		Average kWh/yr	Savings kWh/yr	Average kWh/yr	Savings kWh/yr
Baseline	na	195	na	586	na
Perimeter	36%	125	70	376	210
Interior	27%	143	52	428	158

Table 3: Economic Performance, New Construction

	Energy Savings (kWh/yr)	Energy Cost Savings ($/yr)	Installed Cost ($)	Payback (yrs)
Perimeter, small	70	$6.30	$50	8
Interior, small	52	$4.68	$50	11
Perimeter, large	210	$18.90	$110	6
Interior, large	158	$14.22	$110	8

Retrofit Scenario

For the retrofit scenario, the economic analysis is based on cost and savings of replacing an existing single-level manual switch with a bi-level switch and occupancy sensor. The installed costs used in the retrofit case include the full cost of installing the new bi-level switch and occupancy sensor, and rewiring the existing lighting to bi-level switching.

A summary of lighting hours of operation and the electric energy savings for the perimeter offices and for the interior offices is provided in the tables and figures below. Detailed calculations can be found in Appendix A.

Table 4: Average Annual Lighting Hours, Retrofit

	Average Annual Hours Lights On	Percent of Lit Hours On at 100%	Percent of Lit Hours On at 50%	Average Annual Hours Lights On at 100%	Average Annual Hours Lights On at 50%
Baseline	1,924	100%	0%	1,924	0
Perimeter	1,799	28%	72%	510	1,289
Interior	1,799	46%	54%	828	971

Figure 2: Bi-level Lighting Operation, Retrofit

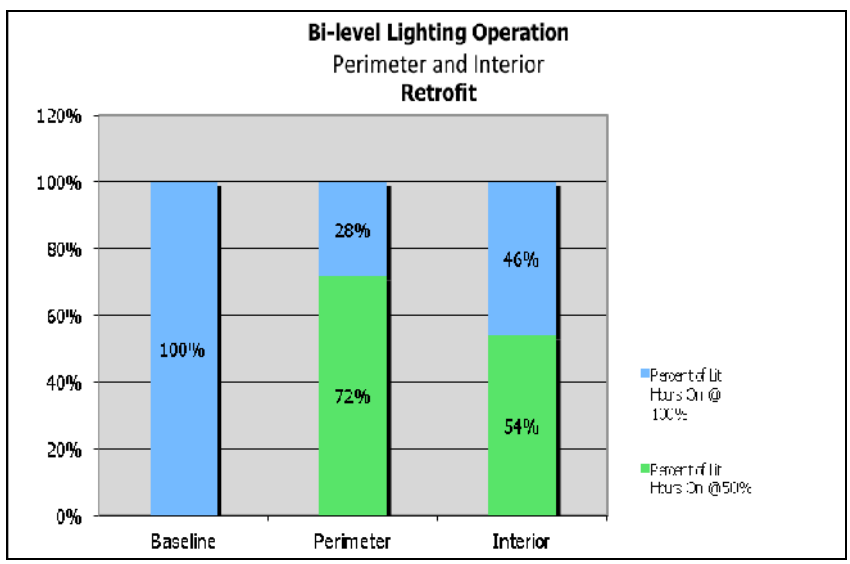


Table 5: Average Annual Electric Energy Savings, Retrofit

	Percent Savings	Small Office		Large Office	
		Average kWh/yr	Savings kWh/yr	Average kWh/yr	Savings kWh/yr
Baseline	na	227	na	681	na
Perimeter	40%	136	91	409	272
Interior	32%	155	72	465	216

Table 6: Economic Performance, Retrofit

	Energy Savings (kWh/yr)	Energy Cost Savings ($/yr)	Installed Cost ($)	Payback (yrs)
Perimeter, Small	91	$8.19	$360	44
Interior, Small	72	$6.48	$360	56
Perimeter, Large	272	$24.48	$870	36
Interior, Large	216	$19.44	$870	45

For both the retrofit and new construction scenarios, lighting is operated in the low setting for longer hours in the perimeter offices than in the interior offices. Given that the perimeter offices have large windows that allow daylight into the space, occupants are more inclined to operate lights at the low level. As a result, energy savings in perimeter offices is higher than in interior offices and the payback period is shorter.

Baseline of Single-Level Switch with Occupancy Sensor

In the original report, the baseline condition is an existing individual office with a single-level manual switch that can be used to turn on or off all of the lights. The office is converted to bi-level switching through installation of a bi-level switch with occupancy sensors, a bi-level ballast, and appropriate rewiring. The bi-level switch is set to operate in the auto-on at 50%, auto-off setting, where lights are switched on automatically at the low level (50%) upon occupancy, the remaining lights can be switched on manually, all lights can be switched off manually, and lights are turned off automatically after the office is unoccupied for a period of time.

For this follow-up analysis, an alternate hypothetical baseline condition is used: an individual office with a single-level switch with occupancy sensor operating all of the lights on or off. Baseline hours of operation are calculated at 2,250 hours per year, using the current BPA assumptions for baseline office lighting operation (3,000 hr/yr) and for occupancy sensor savings (25%). The office is converted to bi-level switching through installation of a bi-level switch with occupancy sensor, a bi-level ballast, and appropriate rewiring. The bi-level switch is set to operate in the auto-on at 50%, auto-off setting. Savings are calculated as the difference between the baseline condition and the bi-level switching condition.

The economic performance is calculated for both a retrofit and new construction scenario. The energy savings for both scenarios will be the same because the baseline and proposed cases are the same.

However, the estimated installed cost will be different for the two scenarios. For the retrofit scenario, the installed cost is the total labor and material cost of a new bi-level switching system, assuming all new equipment is needed, including a bi-level ballast. For the new construction scenario, the installed cost is the incremental material cost of installing the bi-level occupancy sensor switch and other materials as compared to a single-level occupancy sensor switch. Labor costs are assumed to be equal for wiring either the bi-level switch or the single-level switch in the new construction scenario.

Detailed calculations can be found in Appendix A. A summary of the economic performance is provided in the tables below.

Table 7: Economic Performance, New Construction

	Baseline kWh/yr	Savings			Installed Cost ($)	Payback yrs
		kWh/yr	%	$/yr		
Small Office	266	88	33%	$7.73	$50	7
Large Office	797	264	33%	$23.19	$110	5

Table 8: Economic Performance, Retrofit

	Baseline kWh/yr	Savings			Installed Cost ($)	Payback yrs
		kWh/yr	%	$/yr		
Small Office	266	88	33%	$7.73	$360	47
Large Office	797	264	33%	$23.19	$870	38

The economic performance of this hypothetical baseline condition is improved slightly from the baseline condition analyzed in the original report, with the payback period reduced by about one to two years. This improvement is due to the higher calculated savings from use of the BPA assumptions for baseline hours of lighting operation.

The analysis of perimeter and interior offices indicates that energy savings in perimeter offices are higher than in interior offices, and are higher than the savings measured for the average of all of the offices, as shown in the original report. Similarly, the payback period is shorter than the payback period calculated in the original report using average data for all offices. As compared to the analysis based on average data for all offices, energy savings in perimeter offices are about 10% higher and payback periods are about six months to one year shorter in new construction scenarios and three to four years shorter in retrofit scenarios. Applying these impacts to this hypothetical baseline condition,

- For a new construction scenario, the payback period in perimeter offices will be approximately six years in a small office and four years in a large office.
- For a retrofit scenario, the payback period in perimeter offices will be approximately 44 years in a small office and 35 years in a large office.

Baseline of Manual Bi-level Switching

In the original report, the baseline condition is an existing individual office with a single-level manual switch operating all of the lights on or off. The office is converted to bi-level switching through installation of a bi-level switch with occupancy sensors, a bi-level ballast, and appropriate rewiring. The bi-level switch is set to operate in the auto-on at 50%, auto-off setting.

For this follow-up analysis, an alternate hypothetical baseline condition is used: an existing individual office with a manual bi-level switch operating all of the lights off, half of the lights on, or all of the lights on. The office is converted to bi-level switching through installation of a bi-level switch with occupancy sensors. Baseline hours of operation are calculated at 3,000 hours per year, using the current BPA assumptions for baseline office lighting operation. The bi-level switch is set to operate in the auto-on at 50%, auto-off setting. Savings are calculated as the difference between the baseline condition and the bi-level switching condition.

The original study did not provide measured data for this baseline condition. However, two other studies[1] were found that estimated the savings from implementing manual bi-level switching as compared to manual single-level switching. These savings were then compared to the savings calculated in this study for conversion from manual single-level switching to bi-level switching with an occupancy sensor. The incremental savings between these two savings estimates is used for this analysis.

Savings Analysis	**Percent Savings**
Research findings[1]: AVERAGE percent energy savings for use of manual bi-level switching as compared to manual single-level switching	23%
Measured savings: AVERAGE percent energy savings for use of bi-level switching with occupancy sensor set for auto-on at 50% as compared to manual single-level switching	37%
Incremental savings: AVERAGE percent energy savings for use of bi-level switching with occupancy sensor set for auto-on at 50% as compared to manual bi-level switching	**14%**

The economic performance is calculated for both a retrofit and new construction scenario. The energy savings for both scenarios will be the same because the baseline and proposed cases are the same. However, the estimated installed cost will be different for the two scenarios.

- For the retrofit scenario, the installed cost is the total labor and material cost to convert from the manual bi-level switch to the bi-level switch with occupancy sensor. In this case, the baseline situation already includes wiring for bi-level operation. Neither new wiring nor bi-level ballast is needed.
- For the new construction scenario, the installed cost is the incremental material cost of installing the bi-level occupancy sensor switch, and other materials, as compared to a manual bi-level switch. Labor costs are assumed to be equal for wiring either the bi-level switch with occupancy sensor or the manual single-level switch.

[1] "Lighting Controls Effectiveness Assessment - Final Report on Bi-level Lighting Study," May 2002, ADM Associates (Savings = 21.6%). "The Usefulness of Bi-Level Switching," Technical Note: August 1999 Revised, Lawrence Berkeley National Lab (Savings = 24.0%). Average of two studies: savings = 23%.

Detailed calculations can be found in Appendix A. A summary of the economic performance is provided in the tables below.

Table 9: Economic Performance, New Construction

	Baseline kWh/yr	Savings			Installed Cost ($)	Payback yrs
		kWh/yr	%	$/yr		
Small Office	354	50	14%	$4.42	$93	21
Large Office	1,062	151	14%	$13.25	$488	37

Table 10: Economic Performance, Retrofit

	Baseline kWh/yr	Savings			Installed Cost ($)	Payback yrs
		kWh/yr	%	$/yr		
Small Office	354	50	14%	$4.42	$164	37
Large Office	1,062	151	14%	$13.25	$502	38

For the retrofit case, the economic performance of this hypothetical baseline condition is improved somewhat from the baseline condition analyzed in the original report. While the estimated energy savings is lower (14% as compared to 37%), the installed cost is reduced even more significantly (54% for a small office and 42% for a large office) since the labor cost for rewiring to bi-level operation is not required. The payback period drops from 48 to 37 years for a small office and from 39 to 38 years for a large office. The economic performance is improved to a greater extent in the small offices because the rewiring labor cost is a larger part of the total cost. Therefore, the installed cost is reduced more significantly when the rewiring labor cost is eliminated.

However, for the new construction case, the economic performance of this hypothetical baseline condition is worse than that for the baseline condition analyzed in the original report. The estimated energy savings are noticeably lower (14% as compared to 33%). But more significantly, the installed cost is higher. In the original report, the installed cost is the incremental material cost of installing the bi-level occupancy sensor switch, and other materials, as compared to a single-level switch with occupancy sensor, with labor costs assumed to be equal.

In this follow-up analysis, the installed cost is the incremental material cost of installing the bi-level occupancy sensor switch, and other materials, as compared to a manual bi-level switch. So for this hypothetical baseline condition, incremental costs for occupancy sensors are included. Again, labor costs are assumed to be equal. The payback period increases from 9 to 21 years for a small office and from 6 to 37 years for a large office. The economic performance is affected to a greater extent in the large offices because the incremental costs include a ceiling-mounted occupancy sensor.

Alternative Installation Strategies

One variable that can influence payback calculations is installation cost. As discussed in the original report, there are several different options for achieving bi-level switching, each with a different installation cost:

1. **Install new bi-level ballasts:** The bi-level switch can be wired to new bi-level ballasts in each luminaire. Bi-level ballasts are available that operate at 50% and 100% power levels. These ballasts have two line inputs that can be connected to the two relays of the bi-level switch. When one relay is engaged, the lights operate at 50% power. When both relays are engaged, the lamps operate at full power.
2. **Rewire existing ballasts, switch alternate luminaires:** The bi-level switch can be wired to existing ballasts so that one relay operates half of the luminaires in the office while the second relay operates the remaining luminaires.
3. **Rewire existing ballasts, tandem wiring[2]:** The bi-level switch can be wired to existing ballasts so that one relay operates half of the lamps in each of the luminaires in the office while the second relay operates the remaining lamps in each of the luminaires.

The economic analysis presented in the original report is based on the first option, installation of new bi-level ballasts. For this follow-up report, the impact on economic performance was evaluated for options 2 and 3.

As noted in the original report, the preferred method for a particular installation depends on a number of factors, including the existing lighting configuration, desired lighting uniformity, and project cost. For instance, installing new bi-level ballasts will provide the same level of lighting uniformity as the existing lighting system, while rewiring the existing ballasts to switch alternate luminaires may result in less uniform lighting.

New Construction Case

For the new construction case, the original analysis assumed that there is no incremental labor cost for wiring a new office lighting system as bi-level switching over the labor required to wire the baseline single-level switching. In this case, eliminating the incremental cost of the bi-level ballast can reduce the total cost to a larger extent and have a larger impact on the payback period.

A summary of the impact on installed cost and payback period is provided in Table 11.

[2] Tandem wiring is typically accomplished by rewiring the existing ballasts such that each ballast energizes lamps in adjacent fixtures, rather than energizing lamps in the same fixture. For instance, in an office with two fixtures (fixture #1 and fixture #2), each with two lamps, the ballast in fixture #1 would be wired to energize one lamp in each fixture while the ballast in fixture #2 would be wired to energize the remaining lamp in each fixture.

Table 11: Installed Cost and Payback, New Construction

	Small Office			Large Office		
	Energy Cost Savings ($/yr)	Installed Cost ($)	Payback (yrs)	Energy Cost Savings ($/yr)	Installed Cost ($)	Payback (yrs)
Option 1	$5.62	$50	9	$17.04	$110	6
Options 2 and 3	$5.62	$22	4	$17.04	$24	1

Retrofit Scenario

For options 2 and 3, the cost of a bi-level ballast would not be included and the material cost would be lower. The maintenace supervisor at Pierce County was contacted to determine the impact on labor cost for these two options as compared to option 1. Since in all cases the office lighting must be rewired from single-level operation to bi-level operation, the maintenance supervisor judged that the labor cost for all three scenarios would be essentially the same. Therefore, since the cost of the bi-level ballast (approximately $30 each) is a small percentage of the total cost and the labor cost does not change, the overall impact on the payback period is small.

A summary of the impact on installed cost and payback period is provided in Table 12.

Table 12: Installed Cost, Retrofit

	Small Office			Large Office		
	Energy Cost Savings ($/yr)	Installed Cost ($)	Payback (yrs)	Energy Cost Savings ($/yr)	Installed Cost ($)	Payback (yrs)
Option 1	$7.47	$360	48	$22.31	$870	39
Options 2 and 3	$7.47	$303	41	$22.31	$698	31

The analysis of perimeter and interior offices indicates that energy savings in perimeter offices are higher than in interior offices and higher than the savings measured for the average of all of the offices, as shown in the original report. Similarly, the payback period is shorter than the payback period calculated in the original report using average data for all offices. As compared to the analysis based on average data for all offices, energy savings in perimeter offices are about 10% higher and payback periods are about six months to one year shorter in new construction scenarios and three to four years shorter in retrofit scenarios.

Applying these impacts to these alternate installation strategies (options 2 and 3) for a new construction scenario, the payback period in perimeter offices will be approximately three years in a small office and less than one year in a large office. For a retrofit scenario, the payback period in perimeter offices will be approximately 38 years in a small office and 38 years in a large office.

Conclusions and Recommendations

This follow-up report documents additional analyses performed using data from the original emerging technology assessment study, "Bi-Level Office Lighting with Occupancy Sensors," http://www.e3tnw.org/Documents/Bi-Level%20Office%20Lighting-FinalReport.pdf.

The follow-up results reconfirm that lighting energy savings can be achieved through the use of bi-level switching and that the level of savings and cost effectiveness varies depending on a number of factors, including the baseline assumed, lighting hours of operation, installation labor costs, utility incentives and energy costs.

In retrofit situations, payback periods are universally long. A limiting factor for cost effectiveness in these situations is the efficient baseline lighting systems using high-efficiency T8 lamps, electronic ballasts, and occupancy sensors that are becoming more common in office buildings. With a relatively low total annual baseline energy use and associated energy cost for lighting in individual offices, savings are limited.

However, in a new construction situation, the payback period for installing bi-level lighting controls with occupancy sensors can be favorable, under eight years for many situations. In particular, when a bi-level lighting system can be installed in a new facility using one of the alternative wiring strategies, the payback period can be as low as one year.

If a utility energy efficiency rebate is available, project economics can be improved. For a new construction scenario, a utility rebate to reduce the incremental installed cost can have a measureable impact on the payback period. However, for retrofit situations, the payback period will be shortened only insignificantly if the installed cost is reduced by typical rebate levels.

In perimeter offices with daylighting, overhead electric lighting is operated in the low setting for longer hours as compared to lighting operation in interior offices. As a result, energy savings in perimeter offices are higher as compared to interior offices and project economics are more favorable. This finding has implications for energy efficiency programs designed to capture energy savings in daylit spaces. Where rebates are provided for lighting controls (such as dimming ballasts) in daylit spaces, use of bi-level lighting with occupancy sensors could be considered as an alternative control strategy.

Appendix A

Energy Savings and Economic Performance Analyses

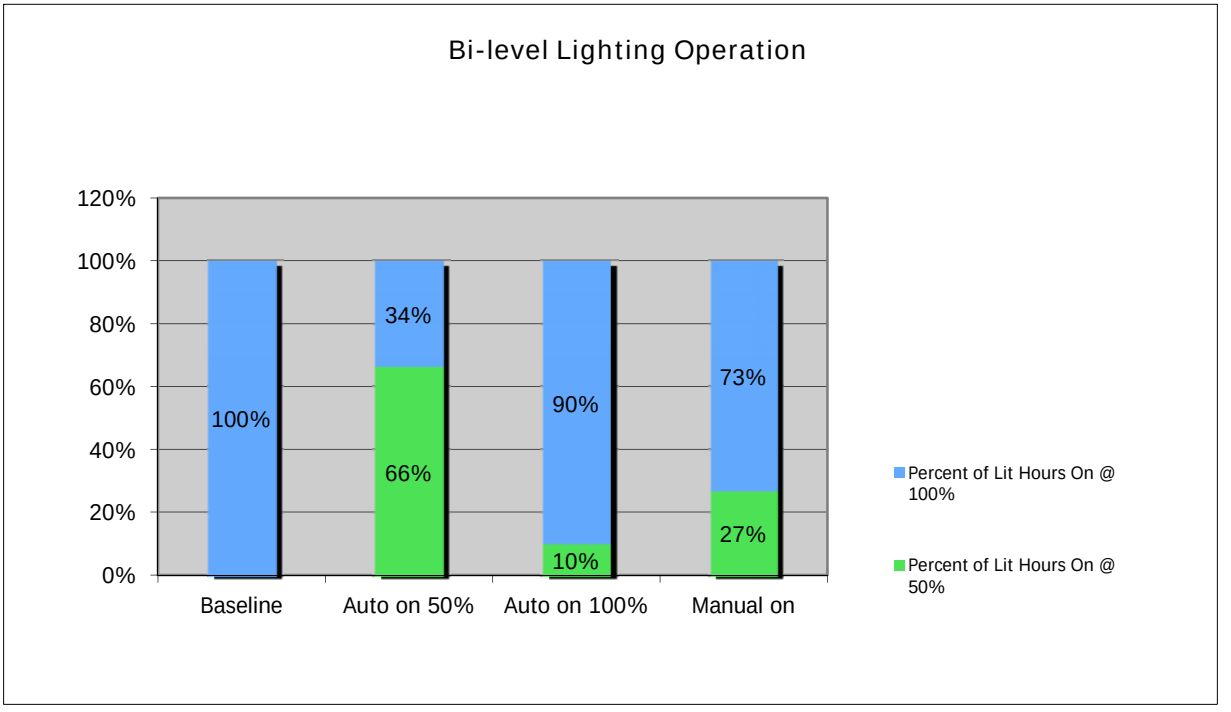
Project: Bi-Level Office Lighting
Facility: Pierce County County-City Building Retrofit Case

Scenario Descriptions

Baseline	Manual switch, single level, all on or all off.
Scenario 1	Auto on at 50%, auto off with occupancy sensor.
Scenario 2	Auto on at 50%, auto off with occupancy sensor.
Scenario 3	Manual on, bi-level: 50% or 100%, auto off with occupancy sensor.

Lighting Operation Summary

	Average Annual Hours Lights On	Percent of Lit Hours On @ 100%	Percent of Lit Hours On @ 50%	Average Annual Hours Lights On @ 100%	Average Annual Hours Lights On @ 50%
Baseline	1924	100%	0%	1924	0
Auto on 50%	1799	34%	66%	611	1188
Auto on 100%	1793	90%	10%	1614	179
Manual on	1655	73%	27%	1208	447

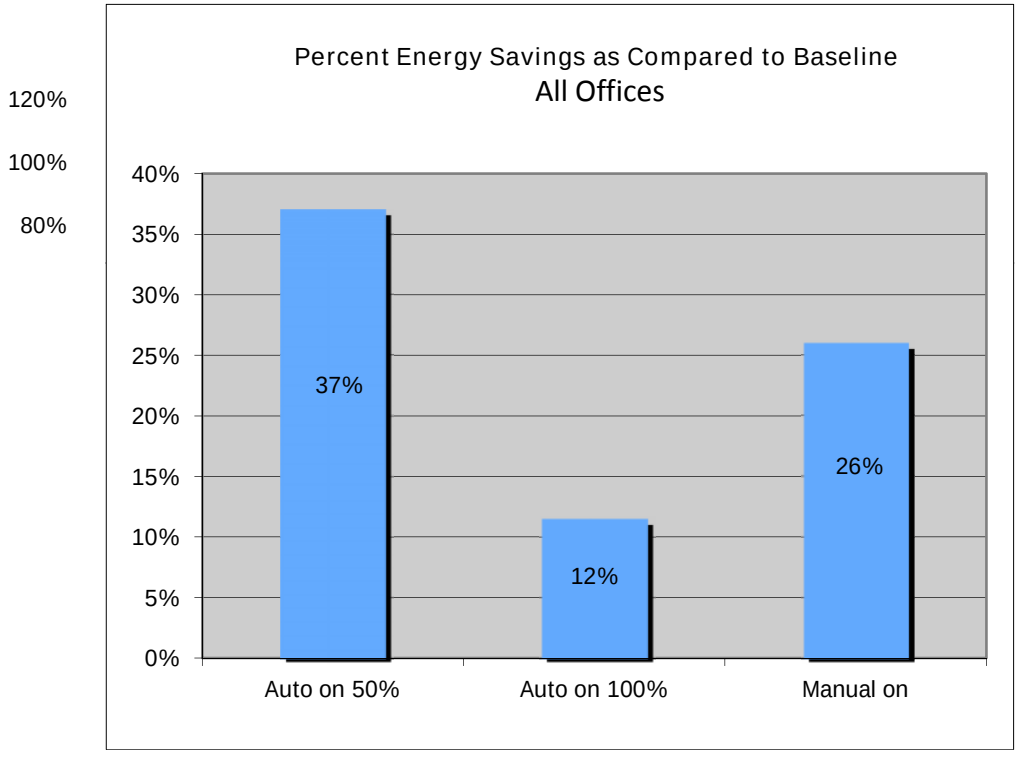


Project: Bi-Level Office Lighting
Facility: Pierce County County-City Building Retrofit Case

Energy Savings

	Small Office			Large Office		
	Average kWh/yr	**Savings (kWh/yr)**	**Percent Savings**	**Average kWh/yr**	**Savings (kWh/yr)**	**Percent Savings**
Baseline	227			681		
Auto on 50%	142	85	37%	427	254	37%
Auto on 100%	201	26	12%	603	78	12%
Manual on	169	58	26%	507	174	26%

Bi-level Lighting Operation



Project: Bi-Level Office Lighting Perimeter vs Interior Offices
Facility: Pierce County County-City Building Retrofit Case

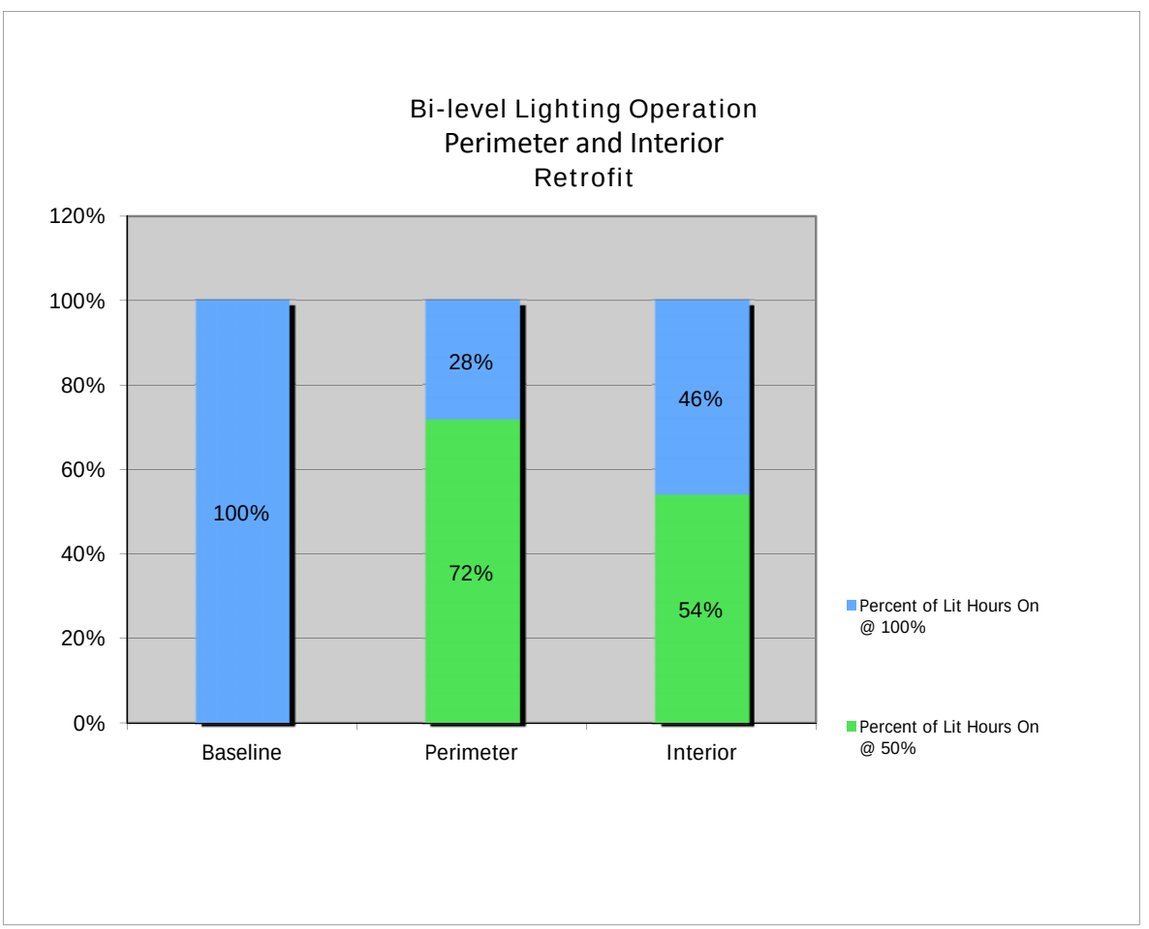
Calculate the savings and economics for the perimeter offices and for the interior offices, assuming a basecase of manual, single level switching and a Scenario 1 retrofit case of bi-level switching, auto-on at 50%.

Scenario Descriptions

Baseline	Manual switch, single level, all on or all off.
Scenario 1	Auto on at 50%, auto off with occupancy sensor.

Lighting Operation Summary

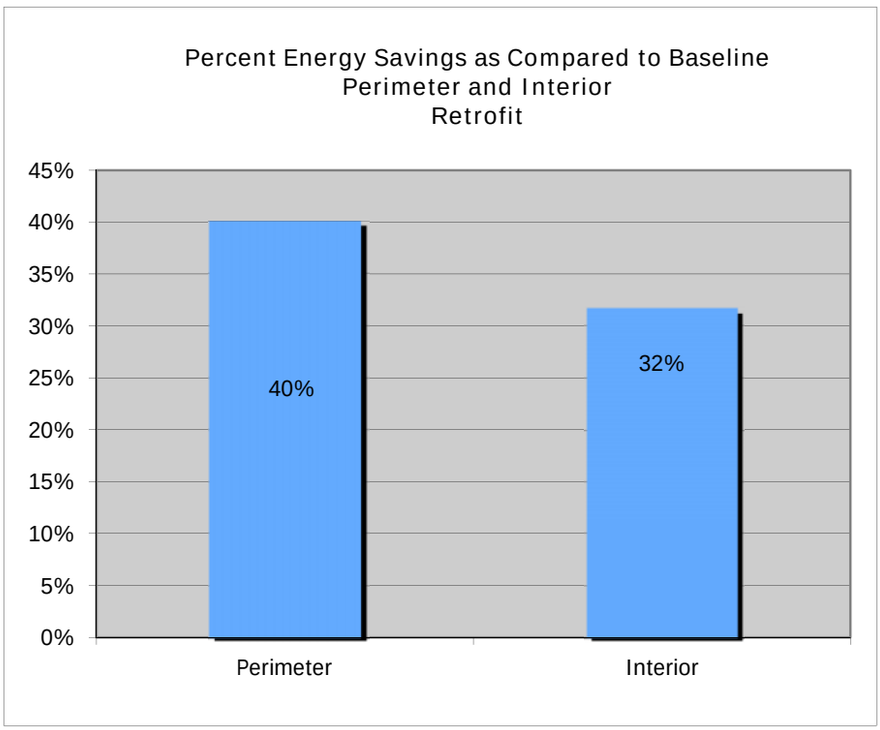
	Average Annual Hours Lights On	Percent of Lit Hours On @ 100%	Percent of Lit Hours On @ 50%	Average Annual Hours Lights On @ 100%	Average Annual Hours Lights On @ 50%
Baseline	1924	100%	0%	1924	0
Perimeter	1799	28%	72%	510	1289
Interior	1799	46%	54%	828	971



Project: Bi-Level Office Lighting Perimeter vs Interior Offices
Facility: Pierce County County-City Building Retrofit Case

Energy Savings

	Small Office			Large Office		
	Average kWh/yr	**Savings (kWh/yr)**	**Percent Savings**	**Average kWh/yr**	**Savings (kWh/yr)**	**Percent Savings**
Baseline	227			681		
Scenario 1, Perimeter	136	91	40%	409	272	40%
Scenario 1, Interior	155	72	32%	465	216	32%



120%

100%

Bi Level Office Lighting
Savings Calculations Retrofit Case

Small Office
Perimeter and Interior Offices

Individual offices in the Pierce County City-County building were converted from manual, single level switching to bi-level switching with occupancy sensors and bi level ballasts. Lighting operation for each scenario was monitored in numerous offices. Energy savings and simple payback period are calculated for the monitored scenarios listed below.

Basecase Scenario

Small office, Two fixtures, each with 2, T8 lamps and electronic ballast. Single manual switch (0% or 100%).

Power per fixture: 2L, T8, EB [1]	0.059	kW/fix
Number of fixtures	2	
Power per office	0.118	kW
Incentive per office:	$35	

Control Retrofit Scenario - T8 lamps and electronic bi-level ballasts, wall occupancy sensors

1 Convert to bi-level switching with occ sensor, auto-on at 50%.

	Savings		Installed Cost	Payback	Installed Cost w Incentive	Payback w Incentive
	kWh/yr	$/yr	$	yrs	$	yrs
Perimeter Offices	91	$8.19	$360	44	$325	40
Interior Offices	72	$6.48	$360	56	$325	50

Perimeter Offices

Assumptions

Energy Rate	$0.09	Note 2
Basecase hours, manual	1924	hr/yr
Post retrofit hours	1799	hr/yr
Bilevel: % hours at low, auto-on 50%	72%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.118		1924	1924		227	$20.43
Proposed	0.118	0.059	1799	510	1289	136	$12.24
Savings						91	$8.19
% Savings						40%	

Estimated cost	$360	installed cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	44 years	

Bi Level Office Lighting
Savings Calculations Retrofit Case Small Office
Perimeter and Interior Offices

Interior Offices

Assumptions

Energy Rate	$0.09	
Basecase hours, manual	1924	hr/yr
Post retrofit hours	1799	hr/yr
Bilevel: % hours at low, auto-on 50%	54%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.118		1924	1924		227	$20.43
Proposed	0.118	0.059	1799	828	971	155	$13.95
Savings						72	$6.48
% Savings						32%	

Estimated cost	$360	installed cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	56 years	

Note 1: Ref: BPA Ltg Calculator, Standard 4' T8 2L, 32 W 80+CRI with NLO ballast, (2-F32T8)
Note 2: Ref: US Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, For Washington, commercial sector. August 2010. Tax and fee multiplier of 20% added.

Bi Level Office Lighting
Savings Calculations Retrofit Case

Large Office
Perimeter and Interior Offices

Individual offices in the Pierce County City-County building were converted from manual, single level switching to bi-level switching with occupancy sensors and bi level ballasts. Lighting operation for each scenario was monitored in numerous offices. Energy savings and simple payback period are calculated for the monitored scenarios listed below.

Basecase Scenario

Large office, six fixtures, each with 2, T8 lamps and electronic ballast. Single manual switch (0% or 100%). Configuration for typical large office in study.

Power per fixture: 2L, T8, EB [1]	0.059	kW/fix
Number of fixtures	6	
Power per office	0.354	kW
Incentive per office:	$60	

Control Retrofit Scenarios - T8 lamps and electronic bi-level ballasts, ceiling occupancy sensors

1 Convert to bi-level switching with occ sensor, auto-on at 50%.

	Savings		Installed Cost	Payback	Installed Cost w/ Incentive	Payback w/ Incentive
	kWh/yr	$/yr	$	yrs	$	yrs
Perimeter Offices	272	$24.48	$870	36	$810	33
Interior Offices	216	$19.44	$870	45	$810	42

Perimeter Offices

Assumptions

Energy Rate	$0.09	
Basecase hours, manual	1924	hr/yr
Post retrofit hours	1799	hr/yr
Bilevel: % hours at low, auto-on 50%	72%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.354		1924	1924		681	$61.29
Proposed	0.354	0.177	1799	510	1289	409	$36.81
Savings						272	$24.48
% Savings						40%	

Estimated cost	$870	installed cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	36 years	

Bi Level Office Lighting
Savings Calculations

Retrofit Case

Large Office
Perimeter and Interior Offices

Interior Offices

Assumptions

Energy Rate	$0.09	
Basecase hours, manual	1924	hr/yr
Post retrofit hours	1799	hr/yr
Bilevel: % hours at low, auto-on 50%	54%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.354		1924	1924		681	$61.29
Proposed	0.354	0.177	1799	828	971	465	$41.85
Savings						216	$19.44
% Savings						32%	

Estimated cost	$870	installed cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	45 years	

Note 1: Ref: BPA Ltg Calculator, Standard 4' T8 2L, 32 W 80+CRI with NLO ballast, (2-F32T8)
Note 2: Ref: US Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, For Washington, commercial sector. August 2010. Tax and fee multiplier of 20% added.

Bi Level Office Lighting

Installation Costs Retrofit Scenario

Means Data

	Rate incl O&P	
Electrician	$75.30	
Helper	$51.60	
Install Cost		
Adder	90%	Avg for NW
Avg Rate	$57.11	Assume 1 Elec+1 Helper

Control Retrofit Scenarios

Small office: Add bi-level wall switch with occ sensor and bi-level ballasts.

Large office: Add bi-level wall switch, ceiling occ sensor and bi-level ballasts.

INSTALLED COSTS

Small office: Add bi-level wall switch with occ sensor and bi-level ballasts.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	1	$10.00	$10.00	0.25	0.25	$57.11	$14.28	$24.28	estimate
2	Bi-level wall switch w occ sensor, dual technology, incl commissioning.	1	$107.12	$107.12	1	1	$57.11	$57.11	$164.23	See attached sheet: Material Costs
3	Bi-level ballast	2	$28.66	$57.32	1	2	$57.11	$114.22	$171.54	See attached sheet: Material Costs
	Subtotal			$174.44		3.25		$185.61	$360.05	
4	Misc						0%		$0.00	estimate
	TOTAL								$360	

Large office: Add bi-level wall switch, ceiling occ sensor and bi-level ballasts.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	1	$10.00	$10.00	0.25	0.25	$57.11	$14.28	$24.28	estimate
2	Bi-level ballast	6	$28.66	$171.96	0.5	3	$57.11	$171.33	$343.29	See attached sheet: Material Costs
3	BI-level wall switch	1	$36.73	$36.73	1	1	$57.11	$57.11	$93.84	See attached sheet: Material Costs
4	Ceiling occupancy sensor	1	$174.52	$174.52	1	1	$57.11	$57.11	$231.63	See attached sheet: Material Costs
5	Room Controller	1	$110.19	$110.19	0.5	0.5	$57.11	$28.56	$138.75	See attached sheet: Material Costs
6	Cable	2	$4.73	$9.46	0.25	0.5	$57.11	$28.56	$38.02	See attached sheet: Material Costs
	Subtotal			$512.85		6.25		$356.95	$869.80	
7	Misc						0%		0	
	TOTAL								$870	

Assume no bi-level ballast, same labor hours to rewire to alternate fixture switching or tandem lamp switching.
Pierce County electricians were consulted to obtain estimate of labor required for the alternate installation strategies.
No significant difference in labor hours were judged to be required.
Labor hours required for all three scenarios were estimated to be essentially the same.

Small office: Add bi-level wall switch with occ sensor and rewire.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	1	$10.00	$10.00	0.25	0.25	$57.11	$14.28	$24.28	estimate
2	dual technology, incl commissioning.	1	$107.12	$107.12	1	1	$57.11	$57.11	$164.23	See attached sheet: Material Costs
3	Rewire luminaires	2	$0.00	$0.00	1	2	$57.11	$114.22	$114.22	See attached sheet: Material Costs
	Subtotal			$117.12		3.25		$185.61	$302.73	
4	Misc						0%		$0.00	estimate
	TOTAL								$303	

Large office: Add bi-level wall switch, ceiling occ sensor and rewire.

	Materials	Labor

	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	1	$10.00	$10.00	0.25	0.25	$57.11	$14.28	$24.28	estimate
2	Rewire luminaires	6	$0.00	$0.00	0.5	3	$57.11	$171.33	$171.33	See attached sheet: Material Costs
3	BI-level wall switch	1	$36.73	$36.73	1	1	$57.11	$57.11	$93.84	See attached sheet: Material Costs
4	Ceiling occupancy sensor	1	$174.52	$174.52	1	1	$57.11	$57.11	$231.63	See attached sheet: Material Costs
5	Room Controller	1	$110.19	$110.19	0.5	0.5	$57.11	$28.56	$138.75	See attached sheet: Material Costs
6	Cable	2	$4.73	$9.46	0.25	0.5	$57.11	$28.56	$38.02	See attached sheet: Material Costs
	Subtotal			$340.89		6.25		$356.95	$697.84	
7	Misc						0%		0	
	TOTAL								$698	

Project: Bi-Level Office Lighting Perimeter vs Interior Offices
Facility: Pierce County County-City Building New Construction

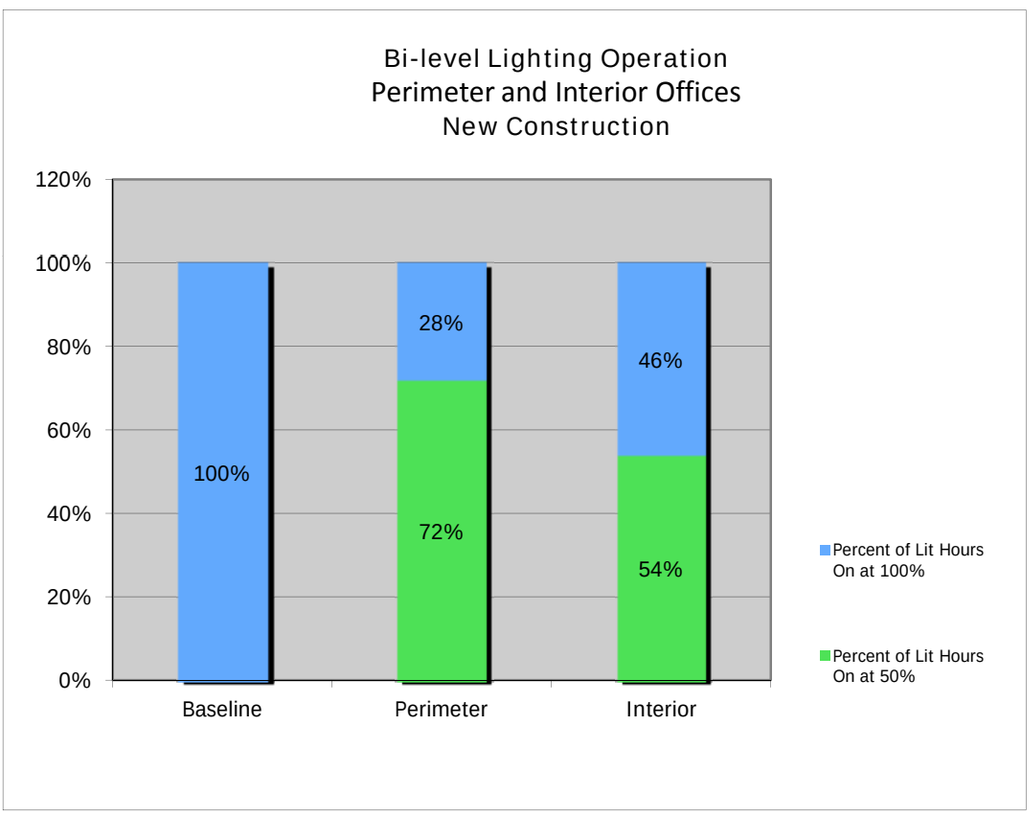
Calculate the savings and economics for the perimeter offices and for the interior offices, assuming a base case of manual, single-level switching and a Scenario 1 retrofit case of bi-level switching, auto-on at 50%.

Scenario Descriptions

Baseline	Single level occupancy sensor switch, set at manual on, auto off. (Use total hours monitored for Scenario 3)
Scenario 1	Auto on at 50%, auto off with occupancy sensor.

Lighting Operation Summary

	Average Annual Hours Lights On	Percent of Lit Hours On at 100%	Percent of Lit Hours On at 50%	Average Annual Hours Lights On at 100%	Average Annual Hours Lights On at 50%
Baseline	1655	100%	0%	1655	0
Perimeter	1655	28%	72%	469	1186
Interior	1655	46%	54%	762	893

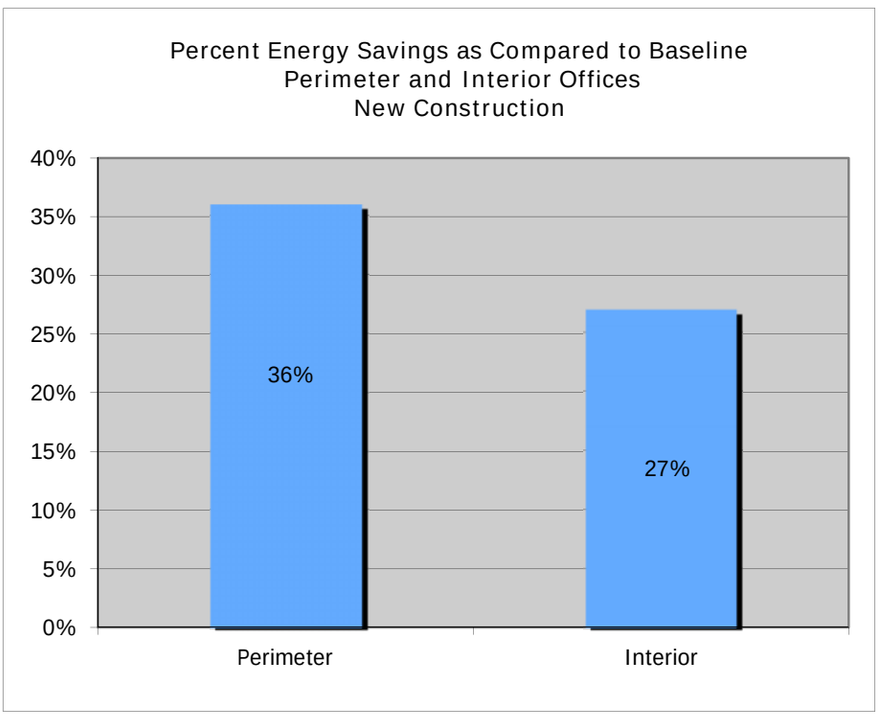


Energy Savings

Baseline Perimeter Interior

Project: Bi-Level Office Lighting Perimeter vs Interior Offices
Facility: Pierce County County-City Building New Construction

	Small Office			Large Office		
	Average kWh/yr	**Savings (kWh/yr)**	**Percent Savings**	**Average kWh/yr**	**Savings (kWh/yr)**	**Percent Savings**
Baseline	195			586		
Scenario 1, Perimeter	125	70	36%	376	210	36%
Scenario 1, Interior	143	52	27%	428	158	27%



120%

100%

Bi Level Office Lighting
Savings Calculations — New Construction — Small Office
Perimeter and Interior Offices

Under a new construction/major remodel scenario, the economic analysis is based on incremental cost and savings as compared to the lighting system that would have been installed. The basecase lighting system for this analysis is the minimum code-compliant lighting system.

Basecase hours are assumed as the annual hours monitored for the matching switch situation - single level manual on, auto off (Scenario 3).

Basecase Scenario - Code-compliant Retrofit

Small office, Two fixtures, each with 2, T8 lamps and electronic ballast. Single switch (0% or 100%) with occupancy sensor. Manual on/auto off.

Power per fixture: 2L, T8, EB [1]	0.059	kW/fix
Number of fixtures	2	
Power per office	0.118	kW

Control Retrofit Scenarios - T8 lamps and electronic bi-level ballasts, wall occupancy sensors

1 Upgrade to bi-level occ sensor, auto-on at 50%.

	Savings		Installed Cost	Payback
	kWh/yr	$/yr	$	yrs
Perimeter Offices	70	$6.30	$50	8
Interior Offices	52	$4.68	$50	11

Perimeter Offices

Assumptions

Energy Rate	$0.09	
Basecase hours, manual	1655	hr/yr
Post retrofit hours	1655	hr/yr
Bilevel: % hours at low, auto-on 50%	72%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.118		1655	1655		195	$17.55
Proposed	0.118	0.059	1655	469	1186	125	$11.25
Savings						70	$6.30
% Savings						36%	

Estimated cost	$50	incremental cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	8 years	

Bi Level Office Lighting
Savings Calculations

New Construction

Small Office
Perimeter and Interior Offices

Interior Offices

Assumptions

Energy Rate	$0.09	
Basecase hours, manual	1655	hr/yr
Post retrofit hours	1655	hr/yr
Bilevel: % hours at low, auto-on 50%	54%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.118		1655	1655		195	$17.55
Proposed	0.118	0.059	1655	762	893	143	$12.87
Savings						52	$4.68
% Savings						27%	

Estimated cost	$50	incremental cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	11 years	

Note 1: Ref: BPA Ltg Calculator, Standard 4' T8 2L, 32 W 80+CRI with NLO ballast, (2-F32T8)
Note 2: Ref: US Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, For Washington, commercial sector. August 2010. Tax and fee multiplier of 20% added.

Bi Level Office Lighting
Savings Calculations — New Construction — Large Office
Perimeter and Interior Offices

Under a new construction/major remodel scenario, the economic analysis is based on incremental cost and savings as compared to the lighting system that would have been installed. The basecase lighting system for this analysis is the minimum code-compliant lighting system.

Base-case hours are assumed as the annual hours monitored for the matching switch situation - single level, manual on, auto off (Scenario 3).

Basecase Scenario - Code-compliant Retrofit

Large office, six fixtures, each with 2, T8 lamps and electronic ballast. Single manual switch (0% or 100%). Configuration for typical large office in study.

Power per fixture: 2L, T8, EB [1]	0.059	kW/fix
Number of fixtures	6	
Power per office	0.354	kW

Control Retrofit Scenarios - T8 lamps and electronic bi-level ballasts, ceiling occupancy sensors

1 Upgrade to bi-level occ sensor, auto-on at 50%.

	Savings		Installed Cost	Payback
	kWh/yr	$/yr	$	yrs
Perimeter Offices	210	$18.90	$110	6
Interior Offices	158	$14.22	$110	8

Perimeter Offices

Assumptions

Energy Rate	$0.09	
Basecase hours, manual	1655	hr/yr
Post retrofit hours	1655	hr/yr
Bilevel: % hours at low, auto-on 50%	72%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.354		1655	1655		586	$52.74
Proposed	0.354	0.177	1655	469	1186	376	$33.84
Savings						210	$18.90
% Savings						36%	

Estimated cost	$110	incremental cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	6 years	

Bi Level Office Lighting
Savings Calculations

New Construction

Large Office
Perimeter and Interior Offices

Interior Offices

Assumptions

Energy Rate	$0.09	
Basecase hours, manual	1655	hr/yr
Post retrofit hours	1655	hr/yr
Bilevel: % hours at low, auto-on 50%	54%	

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.354		1655	1655		586	$52.74
Proposed	0.354	0.177	1655	762	893	428	$38.52
Savings						158	$14.22
% Savings						27%	

Estimated cost	$110	incremental cost, switch & ballast plus rewiring to bilevel (See attached cost calculations)
Simple payback	8 years	

Note 1: Ref: BPA Ltg Calculator, Standard 4' T8 2L, 32 W 80+CRI with NLO ballast, (2-F32T8)
Note 2: Ref: US Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, For Washington, commercial sector. August 2010. Tax and fee multiplier of 20% added.

Bi Level Office Lighting
Installation Costs New Construction/Major Remodel

Control Retrofit Scenarios
Small office: Upgrade from single level OS wall switch/sensor to bi-level wall switch/sensor and to bi-level ballasts.
Large office: Upgrade from single level wall switch to bi level wall switch and to bi-level b

Means Data

	Rate incl O&P	
Electrician	$75.30	
Helper	$51.60	
Install Cost		
Adder	90%	Avg for NW
Avg Rate	$57.11	Assume 1 Elec+1 Helper

CODE REQUIRES OCC SENSOR
Include bi-level ballast.
Small Office
Incremental cost of bi-level wall switch/sensor as compared to single level wall switch/sensor.
Incremental cost of bi-level ballast over single level ballast.
Incremental cost of labor is assumed to be zero. Installation of both systems should require roughly the same effort.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0	0	$57.11	$0.00	$0.00	estimate
2	Bi-level wall switch w occ sensor, dual technology, incl commissioning.	1	$21.87	$21.87	0	0	$57.11	$0.00	$21.87	See attached sheet: Material Costs
3	Bi-level ballast	2	$14.19	$28.38	0	0	$57.11	$0.00	$28.38	See attached sheet: Material Costs
	Subtotal			$50.25		0		$0.00	$50.25	
4	Misc						0%		$0.00	estimate
	TOTAL								$50	

Large Office
Incremental cost of bi-level wall switch as compared to single level wall switch.
Incremental cost of bi-level ballast over single level ballast.
Incremental cost of dual relay room controller over single relay room controller.
Incremental cost of labor is assumed to be zero. Installation of both systems should require roughly the same effort.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0	0	$57.11	$0.00	$0.00	estimate
2	Bi-level ballast	6	$14.19	$85.14	0	0	$57.11	$0.00	$85.14	See attached sheet: Material Costs
3	BI-level wall switch	1	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
4	Ceiling occupancy sensor	0	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
5	Room Controller	1	$24.49	$24.49	0	0	$57.11	$0.00	$24.49	See attached sheet: Material Costs
6	Cable	0	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
	Subtotal			$109.63		0		$0.00	$109.63	
7	Misc						0%		0	
	TOTAL								$110	

Assume no bi-level ballast, wire to alternate fixture switching or tandem lamp switching.
Small Office
Incremental cost of bi-level wall switch/sensor as compared to single level wall switch/sensor.
Incremental cost of labor is assumed to be zero. Installation of both systems should require roughly the same effort.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0	0	$57.11	$0.00	$0.00	estimate
2	Bi-level wall switch w occ sensor, dual technology, incl commissioning.	1	$21.87	$21.87	0	0	$57.11	$0.00	$21.87	See attached sheet: Material Costs

Bi Level Office Lighting
Installation Costs New Construction/Major Remodel

3	Bi-level ballast	2	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
	Subtotal			$21.87		0		$0.00	$21.87	
4	Misc						0%		$0.00	estimate
	TOTAL								$22	

Bi Level Office Lighting

Installation Costs New Construction/Major Remodel

Large Office

Incremental cost of bi-level wall switch as compared to single level wall switch.
Incremental cost of dual relay room controller over single relay room controller.
Incremental cost of labor is assumed to be zero. Installation of both systems should require roughly the same effort.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0	0	$57.11	$0.00	$0.00	estimate
2	Bi-level ballast	6	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
3	BI-level wall switch	1	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
4	Ceiling occupancy sensor	0	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
5	Room Controller	1	$24.49	$24.49	0	0	$57.11	$0.00	$24.49	See attached sheet: Material Costs
6	Cable	0	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
	Subtotal			$24.49		0		$0.00	$24.49	
7	Misc						0%		0	
	TOTAL								$24	

NO CODE REQUIREMENT FOR OCC SENSOR - USE FOR BPA INCENTIVE ANALYSIS

Assume no bi-level ballast, wire to alternate fixture switching or tandem lamp switching.

Small Office

Incremental cost of bi-level wall switch/sensor as compared to single level wall switch.
Incremental cost of labor is assumed to be zero. Installation of both systems should require roughly the same effort.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0	0	$57.11	$0.00	$0.00	estimate
2	Bi-level wall switch w occ sensor, dual technology, incl commissioning.	1	$70.40	$70.40	0	0	$57.11	$0.00	$70.40	See attached sheet: Material Costs
3	Bi-level ballast	2	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
	Subtotal			$70.40		0		$0.00	$70.40	
4	Misc						0%		$0.00	estimate
	TOTAL								$70	

Large Office

Incremental cost of bi-level wall switch as compared to single level wall switch.
Incremental cost of a ceiling occupancy sensor.
Incremental cost of dual relay room controller over single relay room controller.
Incremental cost of labor is assumed to be zero. Installation of both systems should require roughly the same effort.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0	0	$57.11	$0.00	$0.00	estimate
2	Bi-level ballast	6	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
3	BI-level wall switch	1	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
4	Ceiling occupancy sensor	1	$174.52	$174.52	0	0	$57.11	$0.00	$174.52	See attached sheet: Material Costs
5	Room Controller	1	$24.49	$24.49	0	0	$57.11	$0.00	$24.49	See attached sheet: Material Costs
6	Cable	0	$0.00	$0.00	0	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
	Subtotal			$199.00		0		$0.00	$199.00	

Bi Level Office Lighting
Installation Costs New Construction/Major Remodel

7	Misc	0%	0
	TOTAL		$199

Bi Level Office Lighting
Material Costs

Actual costs paid by project to local distributor, including tax and shipping.

Tacoma sales tax	9.3%
Estimate shipping adder	2.0%
Total adder	11.3%

Retrofit Case

Small Office	Cost each		Description
Bi-level ballast	$28.66		Sylvania Quicktronic Prostart T8 Quickstep Bi-level Dimming Ballast. Item number: 49157. Model number: QHES2x32T8/UNV PSN-SC
BI-level wall switch sensor	$107.12		Wattstopper DW-200 Dual Technology Dual Relay Wall Switch Sensor

Large Office	Cost each		Description
Bi-level ballast	$28.66		Sylvania Quicktronic Prostart T8 Quickstep Bi-level Dimming Ballast. Item number: 49157. Model number: QHES2x32T8/UNV PSN-SC
BI-level wall switch	$36.73		Wattstopper LMSW-102 Series Digital Wall Switches
Ceiling occupancy sensor	$174.52		Sensor
Room Controller	$110.19		Wattstopper LMRC-102 Series Digital On/Off Room Controller
Cable	$4.73		Wattstopper LMRJ Series Per-Terminated Cales and Sement Network Wire

New Construction/Major Remodel Case
Baseline Single level Occupancy Sensor Control

Small Office	Cost each	Incremental Cost	Description
Single level ballast	$14.47		Sylvania Quicktronic T8 electronic ballast, single level.
Bi-level ballast	$28.66	$14.19	Sylvania Quicktronic Prostart T8 Quickstep Bi-level Dimming Ballast. Item number: 49157. Model number: QHES2x32T8/UNV PSN-SC
Single level wall switch sensor.	$85.25		Wattstopper DW-100 Dual Technology Single Relay Wall Switch Sensor
BI-level wall switch sensor	$107.12	$21.87	Wattstopper DW-200 Dual Technology Dual Relay Wall Switch Sensor

Large Office	Cost each	Incremental Cost	Description
Single level ballast	$14.47		Sylvania Quicktronic T8 electronic ballast, single level.
Bi-level ballast	$28.66	$14.19	Sylvania Quicktronic Prostart T8 Quickstep Bi-level Dimming Ballast. Item number: 49157. Model number: QHES2x32T8/UNV PSN-SC
Single level wall switch	$36.73		Wattstopper LMSW-101 Series Digital Wall Switches
BI-level wall switch	$36.73	$0.00	Wattstopper LMSW-102 Series Digital Wall Switches
Single relay room controller	$85.70		Wattstopper LMRC-101 Series Digital On/Off Room Controller
Dual Relay Room Controller	$110.19	$24.49	Wattstopper LMRC-102 Series Digital On/Off Room Controller

New Construction/Major Remodel Case
Baseline Manual Bi-level Switch

Small Office	Cost each	Incremental Cost	Description
Manual bi-level wall switch	$13.92		Leviton Décor, Single Pole ($6.26 ea, Per Grainger)
BI-level wall switch sensor	$107.12	$93.20	Wattstopper DW-200 Dual Technology Dual Relay Wall Switch Sensor

Large Office	Cost each	Incremental Cost	Description
Manual bi-level wall switch	$13.92		Leviton Décor, Single Pole ($6.26 ea, Per Grainger)
BI-level wall switch	$36.73	$22.81	Wattstopper LMSW-102 Series Digital Wall Switches

Bi Level Office Lighting — BPA Incentive Program Case
Savings Calculations — Basecase: Single Level Switch (0% or 100%) with Occupancy Sensor

The economic performance of a hypothetical situation of implementing bi-level lighting with an occupancy sensor at the auto-on at 50% sett
the BPA assumptions, as compared to a baseline of single level switching (0 or 100%) with an occupancy sensor installed was analyzed.
Calculate payback for both a retrofit and new construction scenario. Savings for both scenarios will be the same, but installed cost will be di
Retrofit scenario installed cost is the total cost of a new bi-level switching system, assuming all new equipment needed, including bi-level b
New construction scenario installed cost is the incremental cost of installing the bi-level occupancy sensor switch, and other materials, as c
to the single level occupancy sensor switch. Initial wiring costs are assumed to be equal for both scenarios.

RETROFIT	Basecase	Savings			Installed Cost[4]	Payback
Option	kWh/yr	kWh/yr	%	$/yr	$	yrs
Small Office	266	88	33%	$7.73	$360	47
Large Office	797	264	33%	$23.19	$870	38

NEW CONSTRUCTION	Basecase	Savings			Installed Cost[4]	Payback
Option	kWh/yr	kWh/yr	%	$/yr	$	yrs
Small Office	266	88	33%	$7.73	$50	7
Large Office	797	264	33%	$23.19	$110	5

Assumptions

Energy Rate[2]	$0.09
Basecase hours, OS[3]	2250 hr/yr
Bilevel: % hours at low, auto-on 50%	66%

Basecase Scenario Small Office

Small office, Two fixtures, each with 2, T8 lamps and electronic ballast. Single level switch (0% or 100%) with occupancy sensor.

Power per fixture: 2L, T8, EB [1]	0.059 kW/fix
Number of fixtures	2
Power per office	0.118 kW

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.118		2250	2250		266	$23.37
Proposed	0.118	0.059	2250	764	1486	178	$15.64
Savings						88	$7.73
% Savings						33%	

Basecase Scenario Large Office

Large office, six fixtures, each with 2, T8 lamps and electronic ballast. Single manual switch (0% or 100%).

Power per fixture: 2L, T8, EB [1]	0.059 kW/fix
Number of fixtures	6
Power per office	0.354 kW

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.354		2250	2250		797	$70.01
Proposed	0.354	0.177	2250	764	1486	533	$46.82
Savings						264	$23.19
% Savings						33%	

Note 1: Ref: BPA Ltg Calculator, Standard 4' T8 2L, 32 W 80+CRI with NLO ballast, (2-F32T8)
Note 2: Ref: US Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, For Washington, commercial sector. August 2010. Tax and fee multiplier of 20% added.

Bi Level Office Lighting	BPA Incentive Program Case
Savings Calculations	Basecase: Single Level Switch (0% or 100%) with Occupancy Sensor

Note 3: Ref: BPA Ltg Calculator, office lighting hours w manual switch: 3,000 hr/yr (12 hr/dy, 5 dy/wk, 50 wk/yr)
Assumed reduction in lighting hours for standard OS of 25%. Resulting basecase hours of 2,250 hr/yr.
Note 4: See attached cost calculations

Bi Level Office Lighting
Savings Calculations Baseline: Manual Bi-Level Switch

The economic performance for a hypothetical situation with a baseline of manual bi-level switching was analyzed.
This study did not provide data to answer this question directly. However, other studies were found that estimated the savings from implementation of manual bi-level switching as compared to manual single level switching. These savings were then compared to the savings calculated in this study.

Savings Analysis

Research findings, AVERAGE % energy savings from manual bi-level switching as compared to manual single level switching [0]	22.8%
Measured savings, % energy savings from bi-level switching w/ OS, auto on at 50% as compared to manual single level switc	37.0%
Incremental savings, OS w auto on at 50% setting	14.2%

Economic Analysis
The following assumptions were used in this analysis.
- incremental energy savings for bi-level switching with occupancy sensors, auto-on at 50%, as calculated above
- current BPA assumption for baseline office lighting operation – 3,000 hr/yr
- average electric rate – $0.09/kWh (average rate for large commercial customers in Washington state)
- installation costs include only bi-level occupancy sensor switches, no rewiring is required or bi-level ballast

Retrofit	Basecase	Savings			Installed Cost[4]	Payback
Option	kWh/yr	kWh/yr	%	$/yr	$	yrs
Small Office	354	50	14.2%	$4.42	$164	37
Large Office	1062	151	14.2%	$13.25	$502	38

New Construction	Basecase	Savings			Installed Cost[4]	Payback
Option	kWh/yr	kWh/yr	%	$/yr	$	yrs
Small Office	354	50	14.2%	$4.42	$93	21
Large Office	1062	151	14.2%	$13.25	$488	37

Assumptions

Energy Rate[2]	$0.09
Basecase hours, manual[3]	3000 hr/yr

Small Office
Small office, Two fixtures, each with 2, T8 lamps and electronic ballast. Single manual switch (0% or 100%).

Power per fixture: 2L, T8, EB [1]	0.059 kW/fix
Number of fixtures	2
Power per office	0.118 kW
Incremental % energy savings	14.2%

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.118		3000	3000		354	$31.10
Proposed						304	$26.68
Savings						50	$4.42
% Savings						14%	

Large Office
Large office, six fixtures, each with 2, T8 lamps and electronic ballast. Single manual switch (0% or 100%). Configuration for typical large office in study.

Power per fixture: 2L, T8, EB [1]	0.059 kW/fix
Number of fixtures	6
Power per office	0.354 kW
Incremental % energy savings	14.2%

Savings

	kW high	kW low	Total Hrs	hr/yr high	hr/yr low	kWh/yr total	$/yr
Base case	0.354		3000	3000		1062	$93.29
Proposed						911	$80.04
Savings						151	$13.25
% Savings						14%	

Note 0: Reference studies cited below, average of two studies, Savings = 22.8%
"Lighting Controls Effectiveness Assessment - Final Report on Bi-level Lighting Study", May 2002, ADM Associates. Savings = 21.6%
"The Usefulness of Bi-Level Switching" Technical Note: August 1999 Revised, Lawrence Berkeley National Lab. Savings = 24.0%
Note 1: Ref: BPA Ltg Calculator, Standard 4' T8 2L, 32 W 80+CRI with NLO ballast, (2-F32T8)
Note 2: Ref: US Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, For Washington, commercial sector. August 2010. Tax and fee multiplier of 20% added.
Note 3: Ref: BPA Ltg Calculator, basecase office lighting hours, 12 hr/dy, 5 dy/wk, 50 wk/yr
Note 4: See attached cost calculations

Bi Level Office Lighting

Installation Costs Baseline: Manual Bi-Level Switch

Means Data

	Rate incl O&P	
Electrician	$75.30	
Helper	$51.60	
Install Cost A	90%	Avg for NW
Avg Rate	$57.11	Assume 1 Elec+1 Helper

Control Retrofit Scenarios

Small office: Add bi-level wall switch with occ sensor and bi-level ballasts.

Large office: Add bi-level wall switch, ceiling occ sensor and bi-level ballasts.

INSTALLED COSTS

Existing situation is manual bi-level switch, so rooms are already wired for bi-level operation. Cost is only for installation of bi-level occupancy sensor switches. No bi-level ballast required.

Retrofit

total labor and material cost to convert from the manual bi-level switch to the bi-level switch with occupancy sensor

Small office: Add bi-level wall switch with occ sensor and bi-level ballasts.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0.25	0	$57.11	$0.00	$0.00	estimate
2	Bi-level wall switch w occ sensor, dual technology, incl commissioning.	1	$107.12	$107.12	1	1	$57.11	$57.11	$164.23	See attached sheet: Material Costs
3	Bi-level ballast	0	$28.66	$0.00	1	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
	Subtotal			$107.12		1		$57.11	$164.23	
4	Misc						0%		$0.00	estimate
	TOTAL								$164	

Large office: Add bi-level wall switch, ceiling occ sensor and bi-level ballasts.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0.25	0	$57.11	$0.00	$0.00	estimate
2	Bi-level ballast	0	$28.66	$0.00	0.5	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
3	BI-level wall switch	1	$36.73	$36.73	1	1	$57.11	$57.11	$93.84	See attached sheet: Material Costs
4	Ceiling occupancy sensor	1	$174.52	$174.52	1	1	$57.11	$57.11	$231.63	See attached sheet: Material Costs
5	Room Controller	1	$110.19	$110.19	0.5	0.5	$57.11	$28.56	$138.75	See attached sheet: Material Costs
6	Cable	2	$4.73	$9.46	0.25	0.5	$57.11	$28.56	$38.02	See attached sheet: Material Costs
	Subtotal			$330.89		3		$171.34	$502.23	
7	Misc						0%		0	
	TOTAL								$502	

New Construction

incremental material cost of installing the bi-level occupancy sensor switch, and other materials, as compared to a manual bi-level switch

Small office: Install bi-level wall switch with occ sensor instead of manual bi-level switch.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0.25	0	$57.11	$0.00	$0.00	estimate
2	Bi-level wall switch w occ sensor, dual technology, incl commissioning.	1	$93.20	$93.20	1	0	$57.11	$0.00	$93.20	See attached sheet: Material Costs
3	Bi-level ballast	0	$28.66	$0.00	1	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
	Subtotal			$93.20		0		$0.00	$93.20	
4	Misc						0%		$0.00	estimate
	TOTAL								$93	

Large office: Install ceiling occupancy sensor, room controllers and automatic bi-level wall switch.

		Materials			Labor					
	Item	Qty	Cost/ea	Total	Hr/ unit	Total hr	Rate	Total	Total Matls + Labor	Note
1	Wire and misc materials.	0	$10.00	$0.00	0.25	0	$57.11	$0.00	$0.00	estimate
2	Bi-level ballast	0	$28.66	$0.00	0.5	0	$57.11	$0.00	$0.00	See attached sheet: Material Costs
3	BI-level wall switch	1	$22.81	$22.81	1	1	$57.11	$57.11	$79.92	See attached sheet: Material Costs
4	Ceiling occupancy sensor	1	$174.52	$174.52	1	1	$57.11	$57.11	$231.63	See attached sheet: Material Costs
5	Room Controller	1	$110.19	$110.19	0.5	0.5	$57.11	$28.56	$138.75	See attached sheet: Material Costs
6	Cable	2	$4.73	$9.46	0.25	0.5	$57.11	$28.56	$38.02	See attached sheet: Material Costs
	Subtotal			$316.97		3		$171.34	$488.31	

7	Misc	0%	0
	TOTAL		$488