The effects of changing occupancy sensor timeout setting on energy savings, lamp cycling, and maintenance costs

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Introduction

Occupancy sensors currently are promoted as one of the most energy and cost-effective lighting control technologies. A fairly large body of literature exists that reports on the potential savings for using occupancy sensors. Savings of 10% to 19% have been reported for classrooms (Floyd, et al., 1995; Rundquist, 1996), of 27% to 43% in private offices (Maniccia et al., 1999; Seattle City Light, 1992). These studies primarily report single energy savings values based upon a single timeout setting. Although this information provides valuable energy savings evidence, it does not address the effect of changing timeout setting on switching frequency, maintenance costs and energy savings. Consequently, this leads to confusion in the industry about the appropriate timeout setting for applications, and about the effects of frequent switching on lamp life and maintenance costs.

One study (Richman, et al., 1996) reports potential energy savings of between 45% and 3% for timeout settings of 5-, 10-, 15-, and 20-minutes for private offices and between 86% and 73% for restrooms. Although informative, these results were based on limited sample sizes of four offices and one restroom, and did not address the impact on maintenance costs from more frequent lamp switching across typical time out settings.

To garner information about these effects, an occupancy monitoring study was conducted using buildings in 24 states owned and occupied by active participants in the

US. Environmental Protection Agency's Green Lights Program. The study participants included profit, not-for profit, service and manufacturing companies, healthcare organizations, primary and secondary education institutions, and local, state, and federal government entities. The diversity of age, size, efficiency, ownership and occupancy types for these buildings represented a typical cross section of the country's commercial building stock.

Methods

Data were collected for 14 days using the Watt Stopper Intellitimer Pro® IT100 light logger device for 180 spaces representing five applications (offices, restrooms, break rooms, conference rooms, and classrooms). Each space had no lighting controls installed, except for manual on/off switches. The light loggers were installed by building facility managers and maintenance staff. At the time of installation, room area, lighting load, and light logger location were documented. Data collection for each room occurred between February and September in 1997.

Each light logger recorded the date, time, and state of the light and/or occupancy in each room. Every time the occupancy or the lighting condition changed, the logger documented the time of day, date, and the change in condition. The data were downloaded to a computer and organized into consistent formats for data aggregation and analysis.

After reviewing the data files and eliminating those with inconsistent or incomplete data, 158 rooms remained in the data set consisting of 11 break rooms, 35 classrooms, 33 conference rooms, 37 private offices, and 42 restrooms.

An algorithm was developed to convert the data into data sets with one-minute increments. Once the data were converted, there were 20,160 one-minute events for each room for the 14-day monitoring period. There were cases when lights were turned on and off, but no occupant was ever detected in the space. This was considered a detection error, and was corrected by modifying the data set to switch the occupancy condition from unoccupied to occupied for those instances. This occurred for:

- six of the break rooms with detection errors ranging between one and 181 events (0% to 1% of the total events)
- 17 of the classrooms with detection errors ranging between one and 2,677 events (0% to 13% of the total events)
- 16 of the conference rooms with detection errors ranging between one and 1,681 events (0% to 8% of the total events)
- 17 of the private offices with detection errors ranging between one and 5,686 events (0% to 28% of the total events)
- seven of the restrooms with detection errors ranging between one and 275 events (0% to 1% of the total events)

Occupant switching and occupancy patterns were established using the modified data set, and are reported in this paper as “baseline" data. A second data set was created by modifying the baseline occupancy data to simulate the change in light usage if occupancy sensors using the 5-, 10-, 15-, and 20-minute timeout periods were installed. Energy use and annual energy and relamping costs were for the occupancy sensor simulations were then calculated and compared to the baseline data.

The connected lighting load for each room was used to determine lighting energy use. Lighting energy use was calculated by multiplying the connected lighting load by the time that the lights were on.

Results

Baseline data

Connected load and power density

Table 1 lists the descriptive statistics for room area, connected lighting load, and power density for each application. The sample sizes shown in this table are different from the sample sizes used for energy and economic analyses because the room dimensions for some of the rooms were not documented.

Occupancy

Table 2 lists the average percentage of time each application was occupied for the 14-day monitoring period. None of the spaces were occupied for more than 24% of the time, and the occupancy variance ranged between 6% and 12%.

Occupancy sensor simulations

Energy use, annual energy costs, and energy cost savings

Table 3 lists the calculated average daily energy use, annual energy costs, and energy cost savings for each application for the baseline data and each simulation. The 14-day data set was extrapolated to determine the annual costs and savings.

Table 3 illustrates that using occupancy sensors saves energy costs. Savings decrease as the time delay setting increases because lights remain on for a longer period of time while the room is unoccupied.

Restrooms have the highest overall potential for energy savings (between 47% and 60%) and break rooms have the lowest potential for energy savings (between 17% and 29%) for this data set. Between 52% and 58% energy cost savings can be achieved using occupancy sensors in classrooms, between 39% and 50% can be achieved in conference rooms, and between 28% and 38% can be achieved in private offices.

Table 3 provides valuable energy cost savings evidence, but it does not consider maintenance costs. Because lamps are turned off during unoccupied hours using occupancy sensors, lamp switching cycles will increase which will impact lamp life and therefore relamping costs. The lamp operating and starting times are illustrated in Table 4 which shows the maximum, minimum and average lamp operating and starting hours for the baseline and each occupancy sensor simulation for each application. The baseline values decrease when occupancy sensors are installed, and shorter lamp starting times correlate directly with increased switching cycles.

Effects of frequency switching on lamp life

Recent research has illustrated that operating 4-foot, T8 lamps on a 5-minute on, 5-minute off cycle will reduce their published lamp life. The amount of reduction is dependent upon the ballast circuit design (rapid-, instant-.or program-start) and the ratio of hot to cold cathode filament temperature (Narendran, 2000; NLPIP, 1998). This research has provided definitive evidence that short operating cycles will significantly impact lamp life.

Figure 1 illustrates a curve based on the NLPIP measured data that represents the expected lamp life for operating cycles shorter than three hours per start for four-foot, T8, two-lamp instant-start systems (Narendran, et al. 2000). The equation for this curve is listed below, and shows that lamp life is dependent upon the hours per start. The constants were derived from a best fitting curve to data collected by NLPIP on instant start lamps and ballast combinations. The model assumes that the loss of lamp life from continuous operation is independent from the loss of life from starting (Narendran, et al. 2000).

(Eqn 1) Calculated lamp life in hours = S / [(S X 0.0000314) + 0.0000548]

where: S = lamp starts per hour

Equation 1 was used for estimating the expected lamp life for the baseline and for each occupancy sensor simulation using the hours per start data shown in Table 4. Table 5 summarizes the calculated expected lamp life for each application.

For the baseline data, the expected lamp life for all of the applications is greater than the manufacturer reported lamp life of 20,000 hours. This result occurs because the average hours per start for each application for the baseline data are all greater than three hours per start. When occupancy sensors are added, the lamp life decreases for all of the applications because lamp switching frequency increases. The lamp life increases as timeout period increases because lamps remain on for a longer period of time.

Economic analyses

Simplified economic analyses were conducted to account for the effect on lamp life of increased switching frequency by comparing the change in annual energy and relamping costs for each occupancy sensor simulation to the baseline data. The economic analyses did not include ballast replacements, luminaire cleaning, or the time value of money. The analyses were conducted on a per luminaire per square foot basis to account for room area.

The following assumptions were used:

- three-lamp luminaire
- three 32-watt T-8 lamps per luminaire

- one 3-lamp electronic instant start ballast per luminaire(93-watts per luminaire)
- relamping costs of $2.50 per lamp (including $.50 for disposal)
- labor rate of $25.00 per hour
- relamping time of 10-minutes per lamp
- group relamping at 70% expected life
- energy rate of $0.08 per kilowatt hour
- equation 1 applies to 3-lamp electronic instant start ballast

The following equations were used for the economic analyses (IESNA, 1993):

Annual energy cost per luminaire = kW X E X t

where:

kW = 0.093 kW/luminaire

E = $0.08/kWh (energy cost)

t = annual operating time, in hours (from Table 6)

Annual relamping cost per luminaire = ((MC X t) +LC) X N

where:

MC =$25.00 (hourly labor rate for relamping)

t = 0.167 hours (replacement hours per lamp)

LC = $2.50 (cost per lamp)

N = number of lamps used per year

= (annual operating time/relamping interval) X 3 lamps per luminaire

The annual operating time and the group relamping time changed for each occupancy sensor simulation from the baseline value. The annual operating hours were determined by extrapolating the average data reported in Table 4 to an annual value, and the group relamping interval was determined by using 70% of the expected lamp life values listed in Table 5. The group relamping interval and average annual operating times used for the economic analyses are shown in Table 6.

The results of the economic analyses are illustrated in Table 7. Figures 2 through 4 illustrate the annual energy, relamping, and total costs in cost/luminaire/ft^2. The relamping intervals are listed in Table 8.

The results listed in Table 7 can be deceiving if not thoroughly understood and applied correctly. The magnitude of the impact of these results will depend upon the number of rooms and luminaires, room area, and the number and cost of sensors used in each application. In a typical office building, there are typically fewer break rooms, conference rooms, and restrooms than private offices. To illustrate this, simple payback calculations were conducted using the average room areas listed in Table 1 and assuming luminaire and sensor quantities representative of actual applications. The results are shown in Table 9.

Summary

Baseline data

The baseline data showed that the average percentage of time spaces were occupied varies by application. Break rooms were occupied the 24% of the time, restrooms 20%, classrooms 15%, private offices 18%, and conference rooms 11% of the time. In addition, the high variance and range of occupancy values indicates that occupancy was not consistent between the spaces for each application.

The baseline data also illustrates that manual switching habits varied and occupants were not always diligent about turning lights off. Lamps operated for as little as two hours in the conference rooms, and for as long as 14 days (336 hours) in the restrooms (Table 4). The shortest average starting time was seven minutes per start in the break rooms, and the longest average starting time was 14 days in the restrooms. On average, lamps operated approximately 59 hours per start in the restrooms, 10 hours per start in the private offices, 9 hours per start in the classrooms, six hours per start in the break rooms and five hours per start the conference rooms. These long starting times are also reflected in the calculated relamping intervals which showed that relamping times were long and ranged from 44 months for the restrooms to 113 months in the conference rooms.

Occupancy sensor simulations

The data analysis showed that using occupancy sensors will slightly increase relamping costs, but despite the increase, can significantly reduce annual energy costs. When these two parameters are combined, the overall annual energy and relamping costs are reduced per luminaire per unit area from between 12% and 45% depending on the application and time-out setting. Classrooms and restrooms had the highest percentage of total cost savings followed by conference rooms and private offices. The break rooms had the lowest percentage of total cost savings. Cost savings decreases as time out setting increases because lights remain on for a longer time period.

The variation of the total cost savings between the timeout settings ranged from 3% for the break rooms and classrooms, and 7% for the conference rooms. Savings ranged between 12% and 15% for the break rooms, between 42% and 45% for the classrooms, between 26% and 33% for the conference rooms, between 26% and 30% for the private offices, and between 40% and 45% for the restrooms.

The relamping intervals also provide valuable information. Common industry understanding is that using occupancy sensors reduce operating hours enough to extend lamp calendar life (and therefore relamping intervals) equal to or beyond the baseline behavior. For the timeout settings used in this analysis, this proved not to be the case. The relamping intervals for the 20-minute time out setting approached the baseline value, but did were not equal. The values would equal or exceed the baseline value at longer timeout settings which were not included in this analysis.

The payback analyses illustrate that when looking at specific applications, any of the time out settings may be used in classrooms, private offices, and restrooms if payback periods less than five years are considered acceptable. Using this criterion, the time out setting for break rooms would need to be set at 5-minutes, and for conference rooms time out settings of 5-, 10-, or 15-minutes are acceptable.

The payback was relatively constant between the timeout settings for the classrooms, private offices, and restrooms. The payback difference between the maximum and minimum values was 0.03 years (11 days) for the classroom, 0.02 years (seven days) for the private offices, and 0.13 years (slightly over one month) for the restrooms. The payback differences for the break rooms and conference rooms were much higher. The difference was 1.4 years (17 months) for the break rooms and 1.34 years (16 months) for the conference rooms.

Conclusions

The following conclusions can be reached from this analysis:

- the percentage of time spaces are occupied varies by application and will impact potential savings from occupancy sensors
- occupancy sensors save lighting energy
- despite increased relamping costs and decreased lamp life due to frequent switching, installing occupancy sensors saves lighting energy and reduces overall costs
- changing the timeout setting from 5- to 20-minutes in five minute increments slightly increases the total annual energy and relamping costs

- for the classrooms, private offices, and restrooms included in this analysis, installing occupancy sensors provides a reasonable payback for the analyzed time out settings
- because the cost differences are minimally different for the classrooms, private offices, and restrooms, the longest timeout setting should be considered to minimize false offs and assure occupant satisfaction
- for the break rooms, installing occupancy sensors provides a reasonable payback if the 5-minute time out setting is used, however, users should be cautioned that shorter timeout settings increase the likelihood of false offs and increases the possibility of user dissatisfaction
- for the conference rooms, installing occupancy sensors provides a reasonable payback if the 5-, 10-, or 15-minute time out settings are used

Acknowledgments

This study and the data analysis were sponsored by the United States Environmental Protection Agency. The completion of this paper involved important contributions from Jack Keller, Baker Electric, Des Moines, Iowa, who provided input to the installation and material costs used for the economic analyses.

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Tables

Table 1. Descriptive statistics for room area, connected lighting load, and power density for each application.

Application	Sample size		Area (ft^2)	Connected lighting load (W)	Power density (W/ft^2)
Break room	11	Minimum	160	276	1.21
		Maximum	986	1586	4.88
		Average	454	829	2.18
		σ	282	373	1.16
Classroom	31	Minimum	216	384	1.2
		Maximum	2400	7500	5.12
		Average	762	2152	2.81
		σ	511	1666	1.13
Conference room	26	Minimum	120	186	0.87
		Maximum	800	3776	9.44
		Average	363	833	2.54
		σ	203	691	1.87
Private office	30	Minimum	96	120	0.83
		Maximum	400	2436	7.61
		Average	175	417	2.36
		σ	65	420	1.59
Restroom	37	Minimum	36	64	0.55
		Maximum	2250	1750	6.4
		Average	236	317	1.74
		σ	356	297	1.18

Table 2. Descriptive statistics for the average percentage of time each space was occupied for the 14-day monitoring period.

Application	Sample size	Percentage occupancy			
		Minimum (%)	Maximum (%)	Average (%)	σ (%)
Break room	11	5	46	24	12
Classroom	35	3	27	15	8
Conference room	33	1	25	11	6
Private office	37	8	33	18	7
Restroom	42	4	57	20	12

Table 3. Average daily energy use, and annual energy costs and savings for each application.[1,2]

Application	Daily energy use (kWh/day)	Annual energy cost ($/year)	Annual energy cost savings ($/year)	Annual energy cost savings (%)
Break room				
Baseline	7.200	210.24	-	
5-minute	5.113	149.30	60.94	29%
10-minute	5.528	161.42	48.82	23%
15-minute	5.805	169.50	40.74	19%
20-minute	6.003	175.28	34.96	17%
Classroom				
Baseline	17.209	502.51	-	
5-minute	7.151	208.78	293.73	58%
10-minute	7.625	222.65	279.86	56%
15-minute	7.990	233.31	269.20	54%
20-minute	8.295	242.21	260.30	52%
Conference room				
Baseline	4.083	119.23	-	
5-minute	2.029	59.24	59.99	50%
10-minute	2.220	64.80	54.43	46%
15-minute	2.368	69.17	50.06	42%
20-minute	2.492	72.77	46.46	39%
Private office				
Baseline	3.335	97.38	-	
5-minute	2.059	60.13	37.25	38%
10-minute	2.201	64.27	33.11	34%
15-minute	2.305	67.31	30.07	31%
20-minute	2.387	69.70	27.68	28%
Restroom				
Baseline	5.600	163.52	-	
5-minute	2.246	65.56	97.96	60%
10-minute	2.556	74.67	88.85	54%
15-minute	2.788	81.38	82.14	50%
20-minute	2.970	86.76	76.76	47%

Footnotes:
1. Daily energy use = [(Operating time in hours during 14 day monitoring period) X kWh/day] / 14 days)
2. Annual energy cost = (kWh/day X 365 days/year X $.08/kWh)

Table 4. Average, maximum, and minimum lamp operating times in total hours and hours per start[1].

	Baseline		5-min		10-min		15-min		20-min	
	Operating hours	Hours/ start	Operating hours	Hours/ start	Operating hours	Hours/ start	Operating hours	Hours/ start	Operating hours	Hours/ start
Break room										
Maximum	268.5	13.31	171.6	1.90	196.8	3.06	214.5	4.05	226.9	4.67
Minimum	2.0	0.12	1.7	0.08	1.9	0.11	2.0	0.12	2.0	0.12
Average	***118.6***	***6.51***	***83.4***	***0.77***	***90.6***	***1.16***	***95.4***	***1.52***	***98.8***	***1.87***
Classroom										
Maximum	329.2	109.74	92.2	1.69	95.7	2.02	99.6	2.21	103.8	2.46
Minimum	9.8	0.15	8.7	0.12	9.2	0.14	9.5	0.14	9.7	0.14
Average	***104.8***	***9.34***	***47.0***	***0.68***	***50.2***	***0.87***	***52.6***	***1.00***	***54.6***	***1.14***
Conference room										
Maximum	328.8	73.06	104.1	1.40	128.0	1.60	145.0	1.79	158.3	2.00
Minimum	2.0	0.34	1.8	0.20	1.9	0.23	2.0	0.24	2.0	0.25
Average	***68.2***	***5.22***	***34.9***	***0.59***	***38.1***	***0.70***	***40.6***	***0.80***	***42.7***	***0.90***
Private office										
Maximum	302.6	151.32	110.4	2.39	119.0	2.55	125.6	2.59	130.6	2.83
Minimum	25.7	0.39	24.2	0.32	25.0	0.37	25.3	0.38	25.5	0.39
Average	***112.2***	***10.14***	***65.1***	***0.80***	***69.4***	***1.06***	***72.6***	***1.28***	***75.2***	***1.49***
Restroom										
Maximum	336.0	336.00	219.3	1.32	229.9	2.97	238.4	5.28	250.6	9.33
Minimum	24.1	0.31	10.6	0.11	12.5	0.14	14.3	0.16	15.9	0.18
Average	***225.0***	***59.33***	***86.9***	***0.43***	***100.8***	***0.71***	***111.0***	***1.04***	***118.8***	***1.40***

Footnotes:
1. Listed values were averaged over the 14-day monitoring period.

Table 5. Expected lamp life calculated using Equation 1.

	Baseline (hrs)	5 -min (hrs)	10-min (hrs)	15-min (hrs)	20-min (hrs)
Break room	25114	9750	12716	14825	16473
Classroom	26833	8930	10595	11601	12583
Conference room	23867	8046	9117	10010	10836
Private office	27171	10010	12034	13475	14667
Restroom	30937	6296	9210	11892	14176

Table 6. Group relamping intervals and average annual lamp operating times used for the economic analyses.

Application	Parameter	Baseline (hrs)	5-min (hrs)	10-min (hrs)	15-min (hrs)	20-min (hrs)
Break room	Relamping interval	17580	6825	8901	10378	11531
	Operating time	3092	2174	2362	2487	2576
Classroom	Relamping interval	18783	6251	7417	8121	8808
	Operating time	2732	1225	1309	1371	1424
Conference room	Relamping interval	16707	5632	6382	7007	7585
	Operating time	1778	910	993	1059	1113
Private office	Relamping interval	19020	7007	8424	9433	10267
	Operating time	2925	1697	1809	1893	1961
Restroom	Relamping interval	21656	4407	6447	8324	9923
	Operating time	5866	2266	2628	2894	3097

Table 7. Economic analysis summary.

	Baseline		5 -min		10-min		15-min		20-min	
	$/lum	$/lum/ft^2	$/lum	$/lum/ft^2	$/lum	$/lum/ft^2	$/lum	$/lum/ft^2	$/lum	$/lum/ft^2
Break room										
Annual energy cost	23.00	0.05	16.18	0.04	17.57	0.04	18.50	0.04	19.17	0.04
Annual relamping cost	3.52	0.01	6.37	0.01	5.31	0.01	4.79	0.01	4.47	0.01
Total cost	26.52	0.06	22.55	0.05	22.88	0.05	23.30	0.05	23.63	0.05
Total cost savings (%)			15%	15%	14%	14%	12%	12%	11%	12%
Classroom										
Annual energy cost	20.33	0.03	9.11	0.01	9.74	0.01	10.20	0.01	10.60	0.01
Annual relamping cost	2.91	0.00	3.92	0.01	3.53	0.01	3.38	0.00	3.23	0.00
Total cost	23.24	0.03	13.03	0.02	13.27	0.02	13.58	0.02	13.83	0.02
Total cost savings (%)			44%	45%	43%	42%	42%	45%	40%	42%
Conference room										
Annual energy cost	13.23	0.04	6.77	0.02	7.39	0.02	7.88	0.02	8.28	0.02
Annual relamping cost	2.13	0.01	3.23	0.01	3.11	0.01	3.02	0.01	2.94	0.01
Total cost	15.36	0.04	10.00	0.03	10.50	0.03	10.90	0.03	11.22	0.03
Total cost savings (%)			35%	33%	32%	31%	29%	29%	27%	26%
Private office										
Annual energy cost	21.76	0.12	12.63	0.07	13.46	0.08	14.08	0.08	14.59	0.08
Annual relamping cost	3.08	0.02	4.84	0.03	4.30	0.03	4.01	0.02	3.82	0.02
Total cost	24.84	0.14	17.47	0.10	17.75	0.10	18.10	0.10	18.41	0.11
Total cost savings (%)			30%	30%	29%	28%	27%	27%	26%	26%
Restroom										
Annual energy cost	43.64	0.19	16.86	0.07	19.55	0.08	21.53	0.09	23.04	0.10
Annual relamping cost	5.42	0.02	10.28	0.04	8.15	0.04	6.95	0.03	6.24	0.03
Total cost	49.06	0.21	27.14	0.12	27.71	0.12	28.48	0.12	29.28	0.12
Total cost savings (%)			45%	45%	44%	43%	42%	42%	40%	40%

Table 8. Calculated relamping intervals[1,2].

	Baseline (months)	5 -min (months)	10-min (months)	15-min (months)	20-min (months)
Break room	68	38	45	50	54
Classroom	83	61	68	71	74
Conference room	113	74	77	79	82
Private office	78	50	56	60	63
Restroom	44	23	29	35	38

Footnotes:

1. Relamping interval = ((expected lamp life X .70)/operating hours/year) X 12 months/year
2. Relamping intervals were rounded to the nearest month.

Table 9. Payback analysis[1].

Assumptions					
	Break room	**Classroom**	**Conference**	**Private office**	**Restroom**
Room area (ft^2)	454	762	363	175	236
Number of rooms	6	20	6	25	4
Total area (ft^2)	2,724	15,240	2,178	4,375	944
Coverage area per sensor (ft^2)	250	250	250	250	250
Number of sensors per room	2	3	2	1	1
Total number of sensors	12	60	12	25	4
Installed cost per sensor ($)	300	300	300	300	300
Total sensor installed cost ($)	3,600	18,000	3,600	7,500	1,200
Number of luminaires per room	5	10	5	2	2
Area per luminaire per room (ft^2)	91	76	73	88	118
Total number of luminaires	30	200	30	50	8

Cost ($/luminaire/ft^2)					
	Baseline	**5-min**	**10-min**	**15-min**	**20-min**
Break room	0.059	0.050	0.051	0.052	0.052
Classroom	0.031	0.017	0.018	0.017	0.018
Conference room	0.057	0.042	0.043	0.044	0.046
Private office	0.188	0.147	0.146	0.147	0.147
Restroom	0.272	0.181	0.175	0.174	0.175

Total Annual Cost ($)					
	Baseline	**5-min**	**10-min**	**15-min**	**20-min**
Break room	4,821	4,086	4,168	4,249	4,249
Classroom	94,488	51,816	54,864	51,816	54,864
Conference room	3,724	2,744	2,810	2,875	3,006
Private office	41,125	32,156	31,938	32,156	32,156
Restroom	2,054	1,367	1,322	1,314	1,322

Total Annual Savings ($)					
	Baseline	**5-min**	**10-min**	**15-min**	**20-min**
Break room	N/A	735	654	572	572
Classroom	N/A	42,672	39,624	42,672	39,624
Conference room	N/A	980	915	849	719
Private office	N/A	8,969	9,188	8,969	8,969
Restroom	N/A	687	733	740	733

Payback (yrs)					
	Baseline	**5-min**	**10-min**	**15-min**	**20-min**
Break room	**N/A**	**4.89**	**5.51**	**6.29**	**6.29**
Classroom	**N/A**	**0.42**	**0.45**	**0.42**	**0.45**
Conference room	**N/A**	**3.67**	**3.94**	**4.24**	**5.01**
Private office	**N/A**	**0.84**	**0.82**	**0.84**	**0.84**
Restroom	**N/A**	**1.75**	**1.64**	**1.62**	**1.64**

Figures

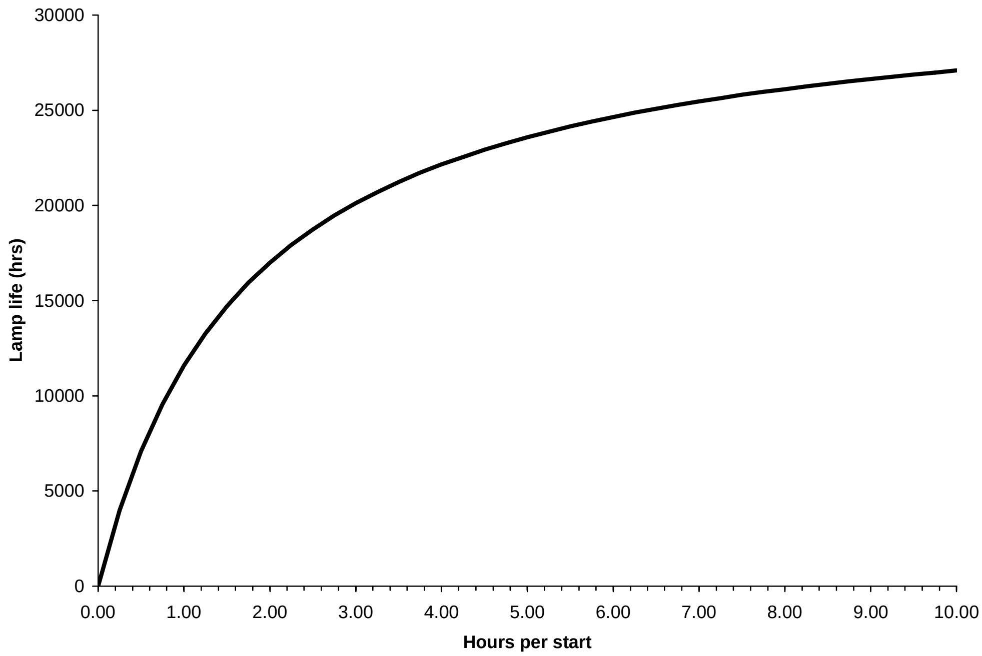

Figure 1. Expected lamp life for operating cycles shorter than three hours per start for instant-start systems (Reference LRC work and possibly paper).

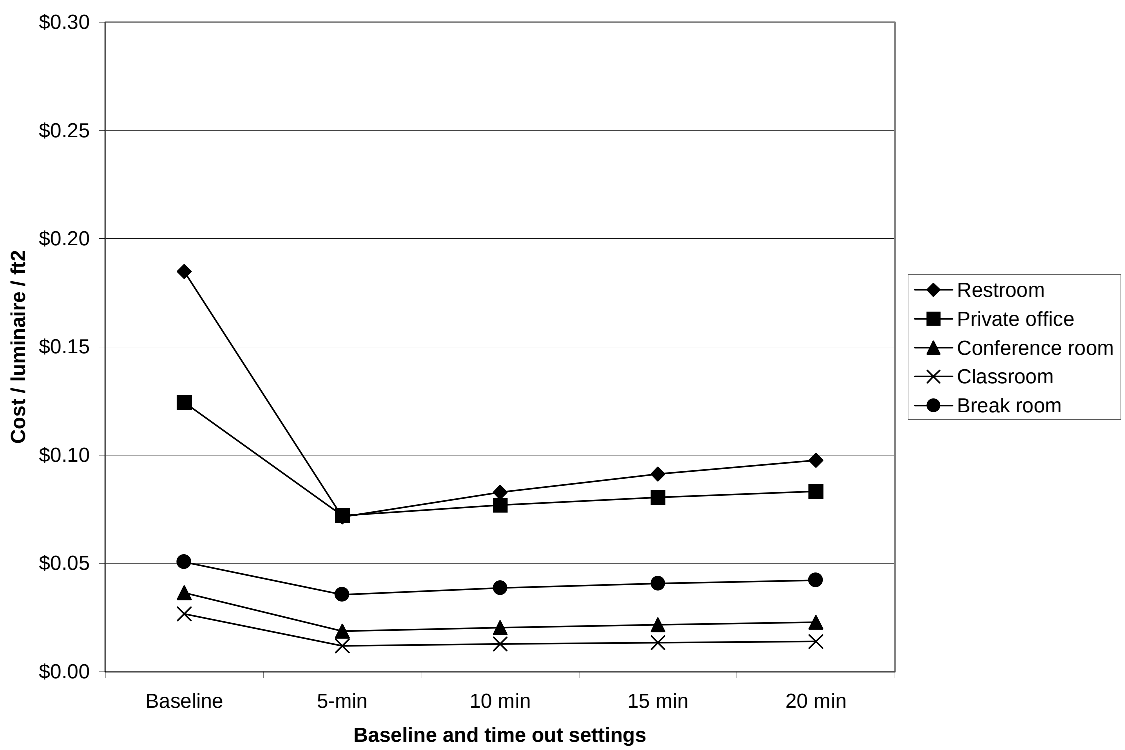

Figure 2. Annual energy costs for the baseline data, each simulation and application.

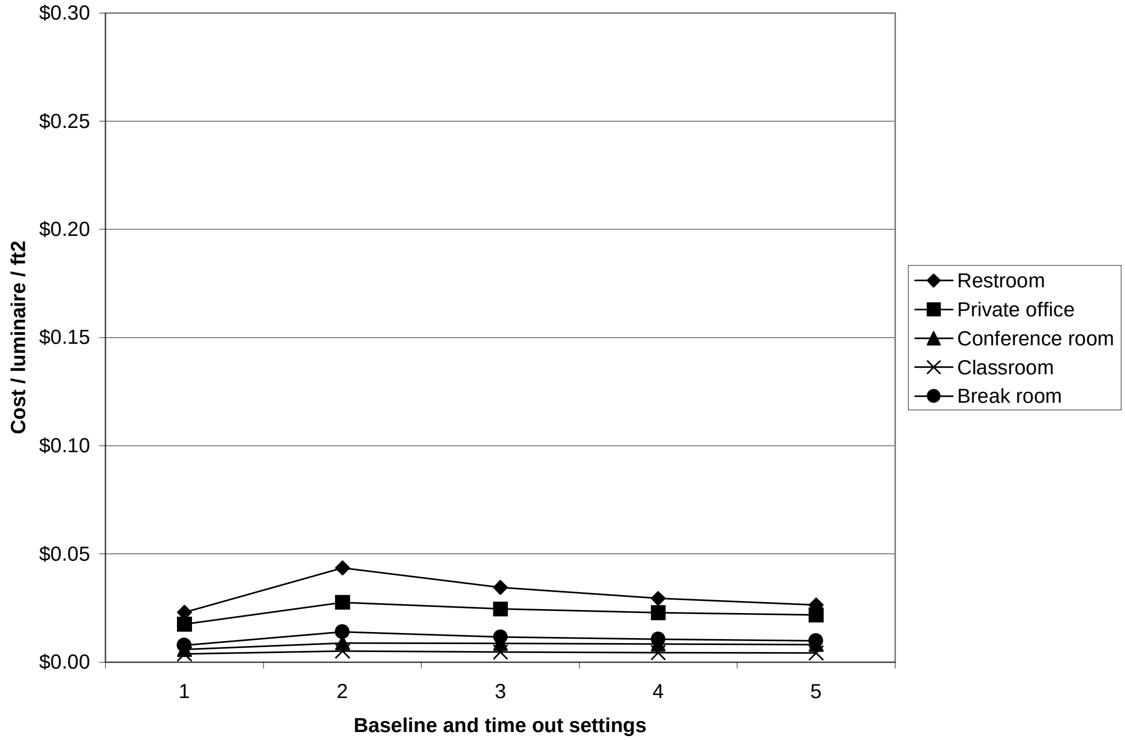

Figure 3. Annual relamping costs for the baseline data, each simulation and application.

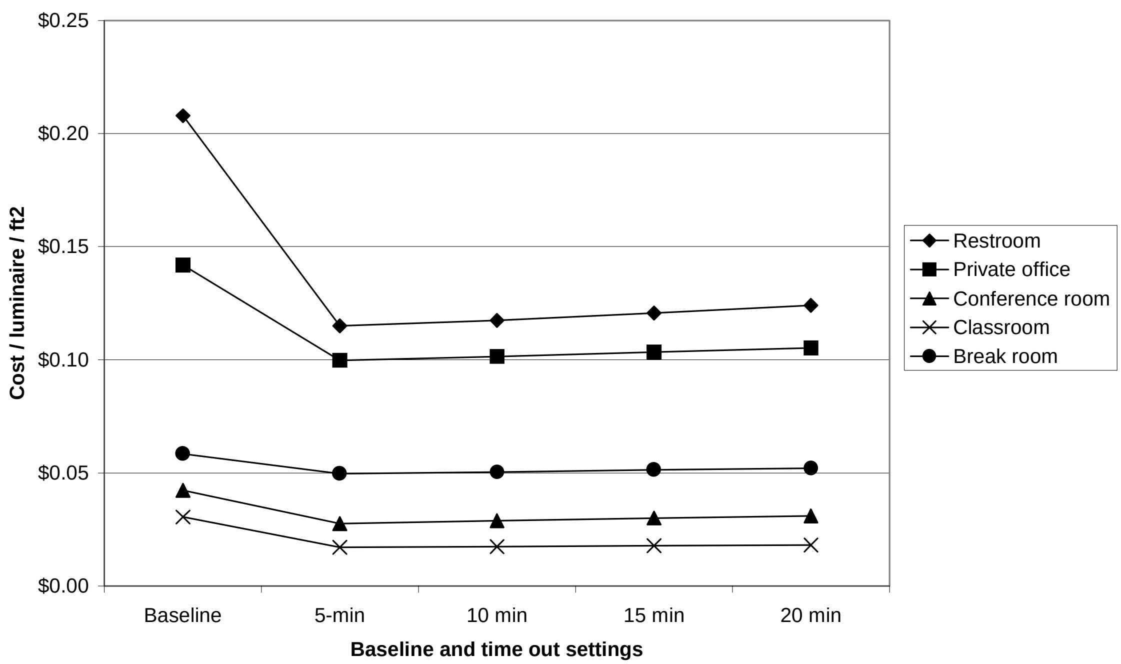

Figure 4. Total annual energy and relamping costs for the baseline data, each simulation and application.