IMPACT OF INTERIOR LIGHTING POWER REDUCTIONS ON COMMERCIAL BUILDING ENERGY USE

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ABSTRACT

Lighting energy conservation measures are typically recommended in commercial building energy audits. Over 60% of the cost in Bonneville Power's commercial building energy conservation programs are related to lighting.

To estimate lighting energy savings it is not uncommon to ignore detailed energy simulations which account for interactions of lighting with heating and cooling systems and simply multiply hours of use by wattage reduction. This paper investigates the potential error in performing simplified lighting calculations which ignore interactions.

A series of computerized hourly energy simulatinos, using the DOE-2.1C program, were conducted on prototypical small office and small retail buildings. For different interior lighting levels, annual energy consumption and lighting energy consumption are estimated. The prototypical buildings are modelled with different configurations, each of which is modelled using the different interior lighting levels. The energy simulations are performed for four pacific northwest cities: Seattle, WA, Yakima, WA, North Bend, OR, and Missoula, MT. The same prototypical buildings were input onto ASEAM-2.1 and modelled using slightly different weather data.

Results show that, regardless of the simulation model used, the error in performing a manual calculation to estimate lighting energy savings varies from a high of over 125% for a weather sensitive building in a cold climate to a low of 0% for a weatherized building in a moderate climate.

It is concluded that for these prototypical commercial buildings the impact of reductions in interior lighting power on total building energy usage is significantly different than a simple one-to-one, relationship. The impact depends on several factors such as:

INTRODUCTION

Interior lighting energy conservation measures (ECM's) are important in commercial building retrofit programs. As shown in Figures 1 and 2 they have accounted for over 60% of the energy savings and 60% of the cost in Bonneville Power Administration (BPA) commercial conservation projects conducted over the past several years.

To assess the cost-effectiveness of lighting ECM's for an individual job, several methods are available: simple manual calculation with and without corrections for heating and cooling system energy use, modified bin energy simulation, and detailed hourly simulations. Each of these methods have a cost and accuracy associated with them. The cost of the methods is dependent upon the amount of information needed to perform the estimate. Their accuracy is dependent upon how well they are able to simulate the increase in heating energy and decrease in cooling energy caused by lighting power reductions.

When performing building energy audits on small commercial buildings the use of computerized simulation software is usually not cost-justified. Similarly, for large buildings with only lighting measures the performance of computerized building energy simulations is not usually warranted because of the increased cost. A simple, accurate, and low cost method of estimating building energy savings is necessary for these situations because they are so common.

This paper describes and compares the methods available to estimate interior lighting measure energy savings. Two prototypical commercial buildings were used to establish annual energy use and energy savings caused by interior lighting measures. Weather data from four pacific northwest locations were used: Seattle, WA, Yakima, WA, Missoula, MT, and North Bend, OR with DOE-2.1C and Seattle, WA, Walla Walla, WA, Jackson Hole, WY, and Astoria, OR with ASEAM-2.1. The results from ASEAM-2.1 and the manual calculations were compared to the results from DOE-2.1C.

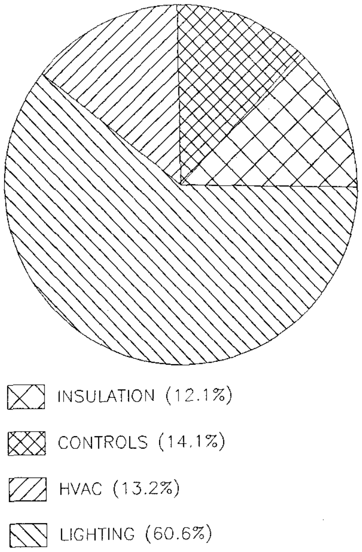

Figure 1:
Distribution of Energy Savings By Category

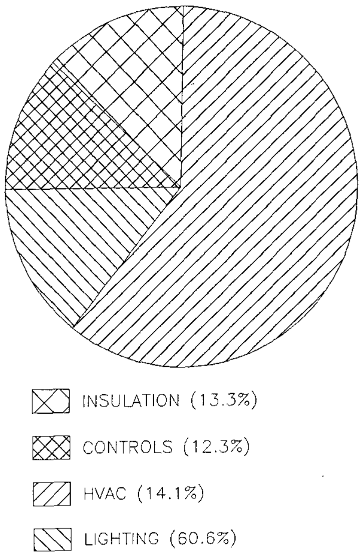

Figure 2:
Distribution of Retrofit Costs by Type

CALCULATION METHODS

Manual calculation without adjustment for HVAC interactions.

This method is recommended by the Illuminating Engineering Society in "IES Recommended Procedure for Energy Analysis of Building Lighting Designs and Installations", LEM-4-1984. The method says that the energy savings are equal to the change in lighting power times the number of hours of operation of the lighting system. In equation form:

$$E = (LP_1 - LP_2) * \text{hours/yr}$$

where,

E = Annual electric energy savings, kWh/yr

LP_1 = Existing lighting power, kW

LP_2 = Proposed lighting power, kW

Manual Calculation w/Adjustment for HVAC Interactions.

This method adjusts building energy savings caused by lighting power reductions by accounting for increases in building heating energy and decreases in building cooling energy. The measure of the amount of heating increase and/or cooling decrease is usually coincident hours. A load factor is either assumed to be a constant for simplicity or is determined using monthly energy bills or a simple building energy use model. This method is used by GTE Sylvania (ref. Relight Energy Analysis, RENA). It is required by BPA in Level 1 energy audits (commercial buildings which consume less than 150,000 kWh/yr of electric energy). In equation form:

$$E = (LP_1 - LP_2) * \text{hours/yr} - \text{heating increase} + \text{cooling decrease}$$

where,

E = Building energy savings, kWh/yr

LP_1 = Existing lighting power, kW

LP_2 = Proposed lighting power, kW

If heating is electric then:
heating increase = $(LP_1 - LP_2)$ * heating hours * load factor (typically 0.7), kWh/yr

If heating is non-electric then:
heating increase = $(LP_1 - LP_2)$ * heating hours * load factor (typically 0.7) / heating system efficiency, Btu/yr (other units have to be corrected)

cooling decrease = (LP_1 - LP_2) * cooling hours / cooling system efficiency (COP), kWh/yr

Bin Energy Simulation

This method is usually performed through the use of computer programs, because of the number of steps and calculations necessary to achieve the answer. The bin energy simulation used in this work was ASEAM-2.1. Bin energy simulations are required by BPA in Level 2 energy studies (commercial buildings which consume more than 150,000 kWh/yr). The bin method performs a calculation of building energy requirements for each 5 ^{o}F (sometimes 3 ^{o}F) change in outdoor temperature. The method accounts for interactions of lighting power with building heating and cooling systems.

The lighting input power is modeled as a heat gain to the building with a specified fraction going directly to the HVAC system return air. For every kWh reduction in lighting power there should be a corresponding increase in heating load and/or decrease in cooling load. The increase in heating load (over the hours a heating load is seen by the building) is linear with the lighting power reduction for electric resistance heat. With ASEAM 2.1, the hourly cooling load due to lights is:

> cooling load due to lights = lighting power * cooling load factor (CLF) * Diversity $Factor_1$ (DF_1) * Diversity $Factor_2$ (DF_2),
>
> where,
>
> DF_1 is the percentage of peak lighting power in use for that hour,
>
> DF_2 is the percentage of lighting used for a given month.

The CLF's used in ASEAM-2.1 are from tables given in the ASHRAE Fundamentals Handbook. Use of the CLF's result in reduced instantaneous cooling loads and increased lagging cooling load.

Hourly Simulation

Hourly simulations are performed through the use of computer programs. They are required by BPA for Level 3 energy studies (commercial buildings which consume more than 1,000,000 kWh/yr). The simulation used for this study was DOE-2.1C. DOE-2.1C performs hourly calculations of building loads and resultant energy requirements.

In DOE-2.1C fluorescent lighting input power is converted into three output components: infrared radiation, dissipated heat (conduction and convection), and light. Like ASEAM-2.1, not all lighting power has to be modelled as a building heat gain, a specified fraction can be directed to the return air. Eventually, over the course of a building simulation, all lighting power is converted to heat. The conversion is accomplished in a more sophisticated manner than CLF's through the use of weighting factors. Weighting factors are a "set of parameters that quantitatively determine how much of the energy is stored and how rapidly the stored energy is released during later hours" and, unlike CLF, are calculated for each hour of the day for each day of the simulation.

METHOD COMPARISON

To assess the accuracy of different methods for calculating interior lighting energy savings a comparison of results for two different building models was performed. The two building models used were developed by BPA to represent prototypical small retail and small office buildings currently in existence in the BPA service territory. This section describes the two buildings, the methodology used to develop lighting savings estimates, and the results from the different methods. Base building energy consumption for the small office is shown on Table 1 and Table 2 for the small retail.

Small Retail Building

Description: One story, rectangular, 4,875 square feet, small retail building. Customer hours are from 9 am to 7 pm Monday thru Friday, 10 am to 5 pm on Saturdays, and 1 pm to 5 pm on Sundays. Internal lighting is provided by recessed suspended fluorescent and incandescent fixtures. The overall lighting capacity is 1.93 W/sq. ft. (80 percent fluorescent, 20 percent incandescent). The building envelope is composed of the following components:

	Area (sq. ft.)	U-Value (Btu/hr/ sq.ft. F)	Loss Factor (Btu/hr/F)
Roof	4,875	0.17	829
Walls	2,160	0.26	562
Floors	4,375	0.043	210
Windows	210	1.04	218
Doors	205	0.71	146
Infiltration (0.15 air changes/hr)			568
TOTAL HEAT LOSS FACTOR			2,533

Packaged electric roof-top units serve the sales area (3,900 sq. ft.). Electric heating coils heat the sales area to 70 F during occupied hours and to 60 F during unoccupied hours. The units provide direct expansion cooling that cool the sales area to 74 F during occupied hours and remain off during unoccupied hours. An economizer cycle provides free cooling up to an outside air temperature of 74 F. The storage area (975 sq. ft.) is served by an electric resistance unit heater that maintains a constant temperature of 55 F.

Small Office Building

Description: Two story, rectangular, 4,880 square feet, small office building. The building is occupied from 8 am to 6 pm Monday thru Friday and 8 am to 12 noon on Saturday. Internal lighting is provided by recessed fluorescent fixtures and incandescent fixtures. The overall lighting capacity is 2.2 W/sq. ft. consisting of 1.7 W/sq. ft. recessed fluorescent, 0.3 W/sq. ft. incandescent overhead lighting, and 0.2 W/sq. ft. incandescent task lighting. The building envelope is comprised of the following:

	Area (sq. ft.)	U-Value (Btu/hr/ sq.ft. F)	Loss Factor (Btu/hr/F)
Roof	2,440	0.13	317
Walls	3,825	0.14	536
Floors	2,440	0.099	242
Windows	922	0.80	738
Doors	101	0.73	74
Infiltration (0.37 air changes/hr)			390
TOTAL HEAT LOSS FACTOR			2,297

Packaged electric roof-top units heat and cool the building. Electric heating coils heat the building to 72 F during occupied hours and to 62 F during unoccupied hours. The units provide direct expansion cooling that cool the building to 75 F during occupied hours and remain off during unoccupied hours.

Comparison Methodology

To assess the accuracy of the different methods, DOE-2.1C was established as the point of comparison. Each of the two building models were run on DOE-2.1C using four different weather sites (Seattle, WA, Yakima, WA, Missoula, MT, and North Bend, OR).

The baseline building models were modified to reflect model sensitivities and to test input assumptions resulting in two additional cases for each building model. The cases considered were: input assumptions (increased cooling thermostat setpoint, decreased heating thermostat setpoint, and decreased infiltration rates) and increased building insulation (R-11 wall insulation, R-30 ceiling insulation, and double glazing) combined with input assumptions.

For each of these cases the interior fluorescent lighting power was increased in steps of 1.0 W/sq. ft. from a low of 0.5 W/sq. ft. to a high of 3.5 W/sq. ft. The differences in building energy use between the different lighting levels corresponds to energy savings.

Identical building models were input to ASEAM 2.1 using slightly different weather sites: Seattle, WA, Walla Walla, WA, Astoria, OR, and Jackson Hole, WY. (These weather sites were chosen because they correspond more closely with the locations of the electric utilities operating the Commercial Incentives Pilot Program than the weather sites used with DOE-2.1C.) The results from these runs were compared to DOE-2.1C. For identical changes in lighting consumption, the estimated building energy savings were also compared.

Results

For each building configuration, when the interior lighting power was changed, the total building energy use changed. Table 3 shows the results when the small office building lighting power was changed from 2.5 W/sq. ft. to 1.5 W/sq. ft; Table 4 shows the results for the small retail building.

The manual method which corrects for HVAC energy use was not included in the above tables since it requires a knowledge of the load factor and this could be derived from the simulations. Instead the number of coincident heating and cooling hours which would result in the same answer as DOE-2.1C were derived for the different building configurations and climates and an equivalent load factor derived. The results are shown in Tables 5 and 6.

Varying the above base building models as described earlier to reflect possible variations in building configuration resulted in significantly different energy use patterns, as shown in Figure 3 for the small office building in Seattle.

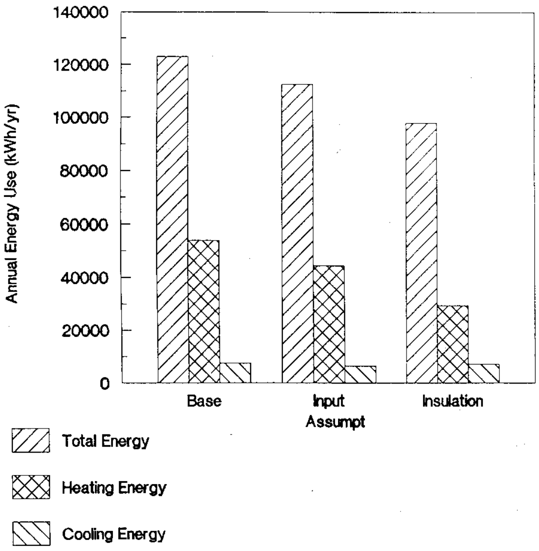

Figure 3
Small Office Energy Usage Comparison for Seattle

DISCUSSION

Using DOE-2.1C, a reduction in interior lighting power resulted in an increase in heating energy, a decrease in cooling energy, a decrease in lighting energy, and a decrease in total building energy. As shown in Figure 4, the total building energy use was linearly related to interior lighting levels for each climatic location used. The relation is linear for each building configuration (base building, input assumptions, and insulation) within each climate.

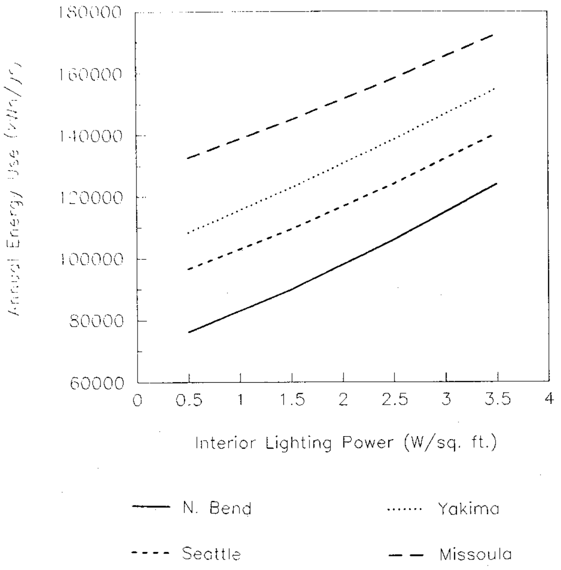

Figure 4:
Small Retail Energy Use Dependence On Interior Lighting Power

With ASEAM-2.1, results were similar to DOE-2.1C in that building energy use was linearly related to interior lighting levels with the relation being dependent on building configuration and climate. ASEAM-2.1 predicted significantly more cooling energy use than did DOE-2.1C. This resulted in ASEAM predicting more energy savings than DOE-2.1C because of larger reduced cooling energy.

Both DOE-2.1C and ASEAM-2.1 consistently predict less energy savings than the manual calculation without correcting for interactions method does. This is because the two buildings considered were heating dominated. When the two buildings were modeled as being insulated results from the manual calculation were significantly closer to DOE-2.1C results.

To account for non-electric heating systems, heat pump systems or buildings with no cooling would be relatively easy. For non-electric or heat pump heating the heating load factor would be adjusted by a heating system efficiency (less than 1 for non-electric possible 2 for air-source heat pump). For buildings with no cooling, the cooling load factor would be set to zero. These types of heating and cooling systems have a significant impact on the results.

Comparing DOE-2.1C and ASEAM-2.1 to the manual calculation with corrections for interactions method showed that correcting for heating and cooling energy was necessary but difficult to do without some sort of building simulation. The calculation used by GTE Sylvania in RENA adjusts lighting energy savings with coincident heating and cooling hours. This approach would be close to being accurate, but the number of coincident heating and cooling hours is a guess.

CONCLUSION

Based on the above, the following conclusions are reached:

> The best way to estimate lighting energy savings in a commercial building retrofit is through a detailed hourly simulation.
>
> Simpler methods need to account for heating and cooling energy increases and decreases because they are significant; energy savings were reduced by over 50% for some of the situations considered in this work.
>
> A simple and accurate way to account for heating and cooling system interactions was not evident.

REFERENCES

1. ASHRAE Handbook, 1981 Fundamentals.
2. Fireovid, J.a and Fryer, L.R., "ASEAM 2.1, A Simplified Energy Analysis Method, User's Manual", 2nd Edition ACEC Research & Management Foundation, 1987.
3. "DOE 2.1A Users Manual", Laurence Berkeley Laboratories, 1981.
4. Treado, S.J. and Bean, J.W., NISTER 83-3860: "The Interaction of Lighting, Heating, and Cooling Systems in Buildings", U.S. Dept. of Commerce, 1988.
5. IES Lighting Handbook, 1981 Reference Volume.

Table 1:
Small Office Base Building
DOE-2.1C Energy Consumption Estimates

	Space Heat (kWh/yr)	Space Cool (kWh/yr)	Lighting[1] (kWh/yr)	Misc[2] (kWh/yr)	Total (kWh/yr)
Missoula, MT	4,049	7,922	34,166	21,683	167,873
Yakima, WA	67,422	12,042	34,163	21,711	135,338
Seattle, WA	57,644	6,777	34,161	21,025	119,607
N. Bend, OR	41,362	4,832	34,155	20,527	100,876

Table 2:
Small Retail Base Building
DOE-2 Energy Consumption Estimates

	Space Heat (kWh/yr)	Space Cool (kWh/yr)	Lighting[1] (kWh/yr)	Misc[2] (kWh/yr)	Total (kWh/yr)
Missoula, MT	70,996	7,243	57,926	20,624	156,789
Yakima, WA	45,883	12,197	57,926	21,401	137,407
Seattle, WA	37,006	4,603	57,908	18,406	117,923
N. Bend, OR	21,770	1,544	57,890	15,391	96,595

Notes to Tables 1 and 2:

1. Lighting energy use includes both interior and exterior lighting.
2. Misc energy use includes fans, pumps, domestic hot water, and miscellaneous equipment.

Table 3: Small Office Building Estimated Energy Savings (kWh/yr)

A. Base Building

Site	DOE-2.1C	ASEAM-2.1	Manual w/o correction
Seattle, WA	6,542	8,424 (+29.%)	12,800 (+ 96.%)
Yakima, WA	7,715	9,570 (+24.%)	12,800 (+ 66.%)
Missoula, MT	5,696	7,564 (+33.%)	12,800 (+125.%)
N. Bend, OR	7,056	9,319 (+32.%)	12,800 (+ 81.%)

B. Input Assumptions

Site	DOE-2.1C	ASEAM-2.1	Manual w/o correction
Seattle, WA	6,842	7,277 (+6.4%)	12,800 (+ 87.%)
Yakima, WA	7,779	8,672 (+12.%)	12,800 (+ 65.%)
Missoula, MT	5,913	7,007 (+19.%)	12,800 (+117.%)
N. Bend, OR	7,172	7,491 (+4.5%)	12,800 (+ 79.%)

C. Fully Insulated w/ Input Assumptions

Site	DOE-2.1C	ASEAM-2.1	Manual w/o correction
Seattle, WA	7,685	8,355 (+8.7%)	12,800 (+ 67.%)
Yakima, WA	8,444	9,461 (+12.%)	12,800 (+ 52.%)
Missoula, MT	6,282	7,324 (+17.%)	12,800 (+104.%)
N. Bend, OR	8,638	9,118 (+5.6%)	12,800 (+ 48.%)

Table 4: Small Retail Building Estimated Energy Savings (kWh/yr)

A. Base Building

Site	DOE-2.1C	ASEAM-2.1	Manual w/o correction
Seattle, WA	15,341	18,451 (+20.%)	24,170 (+58.%)
Yakima, WA	17,234	19,504 (+13.%)	24,170 (+40.%)
Missoula, MT	14,357	17,201 (+20.%)	24,170 (+68.%)
N. Bend, OR	16,352	18,375 (+12.%)	24,170 (+48.%)

B. Input Assumptions

Site	DOE-2.1C	ASEAM-2.1	Manual w/o correction
Seattle, WA	14,857	18,967 (+28.%)	24,170 (+63.%)
Yakima, WA	17,079	19,962 (+17.%)	24,170 (+42.%)
Missoula, MT	14,239	16,847 (+18.%)	24,170 (+70.%)
N. Bend, OR	15,183	19,395 (+28.%)	24,170 (+59.%)

C. Fully Insulated w/ Input Assumptions

Site	DOE-2.1C	ASEAM-2.1	Manual w/o correction
Seattle, WA	20,521	24,165 (+18.%)	24,170 (+18.%)
Yakima, WA	21,148	24,030 (+14.%)	24,170 (+14.%)
Missoula, MT	17,577	20,149 (+15.%)	24,170 (+38.%)
N. Bend, OR	24,348	23,876 (-2.0%)	24,170 (-1.0%)

Notes to Tables 3 and 4:

1. ASEAM-2.1 used weather data representing: Seattle, WA, Walla Walla, WA, Jackson Hole, WY, and Astoria, OR.

Table 5:
Small Office Load Factors
(Reducing Lighting From 2.5 to 1.5 W/sq. ft.)

A. Base Building

	Lighting	Coincident		Load Factor	
Site	Hours	Heating Hours	Cooling Hours	Heating	Cooling
1. Seattle	2,626	1,589	275	0.60	0.10
2. N. Bend	2,626	1,539	306	0.59	0.12
3. Yakima	2,626	1,391	330	0.53	0.13
4. Missoula	2,626	1,708	234	0.65	0.09

B. Input Assumptions

	Lighting	Coincident		Load Factor	
Site	Hours	Heating Hours	Cooling Hours	Heating	Cooling
1. Seattle	2,626	1,497	249	0.57	0.09
2. N. Bend	2,624	1,427	231	0.54	0.09
3. Yakima	2,626	1,371	325	0.52	0.12
4. Missoula	2,627	1,661	229	0.63	0.09

C. Insulation

	Lighting	Coincident		Load Factor	
Site	Hours	Heating Hours	Cooling Hours	Heating	Cooling
1. Seattle	2,625	1,385	303	0.53	0.12
2. N. Bend	2,623	1,228	316	0.47	0.12
3. Yakima	2,626	1,294	824	0.49	0.31
4. Missoula	2,626	1,629	271	0.62	0.10

Table 6:
Small Retail Load Factors
(Reducing Lighting From 2.5 to 1.5 W/sq. ft.)

A. Base Building

	Lighting	Coincident		Load Factor	
Site	Hours	Heating Hours	Cooling Hours	Heating	Cooling
1. Seattle	4,953	2,155	219	0.44	0.04
2. N. Bend	4,953	1,927	130	0.39	0.03
3. Yakima	4,953	2,011	476	0.41	0.10
4. Missoula	4,953	2,393	287	0.48	0.06

B. Input Assumptions

	Lighting	Coincident		Load Factor	
Site	Hours	Heating Hours	Cooling Hours	Heating	Cooling
1. Seattle	4,953	2,221	186	0.45	0.04
2. N. Bend	4,953	2,089	77	0.42	0.02
3. Yakima	4,953	2,029	450	0.41	0.09
4. Missoula	4,953	2,403	267	0.49	0.05

C. Insulation

	Lighting	Coincident		Load Factor	
Site	Hours	Heating Hours	Cooling Hours	Heating	Cooling
1. Seattle	4,953	1,309	337	0.26	0.07
2. N. Bend	4,953	586	308	0.12	0.06
3. Yakima	4,953	1,369	564	0.28	0.11
4. Missoula	4,953	1,862	343	0.38	0.07

Notes to tables 5 and 6:

1. Lighting hours = (lighting energy decrease) / (lighting power decrease)
2. Coincident heating hours = (heating energy increase) / (lighting power decrease)
3. Coincident cooling hours = (cooling energy decrease) * (cooling COP (2.7)) / (lighting power decrease)
4. Heating load factor = (heating hours) / (lighting hours)
5. Cooling load factor = (cooling hours) / (lighting hours)