Energy Savings Potential in Lighting of New Residential Dwellings

Karl R. Stum, Portland Energy Conservation, Inc.

Electrical energy consumed by lighting represents a significant portion of the total electrical energy used in residential dwellings. This study is the result of an extensive analysis to estimate the energy savings potential for lighting in new residential construction. Each room in three building prototypes was analyzed using a comprehensive residential lighting analysis spreadsheet which compared incandescent fixtures, compact fluorescent fixtures, timers and occupancy sensors. Both single family and multifamily dwellings of varying sizes were evaluated, as well as common areas in multifamily buildings. The space cooling and heating impacts for two climates were then analyzed. Standard lumen depreciation factors, lumen depreciation from heat build-up in compact fluorescent fixtures, lamp life depreciation from short cycling times, ballast factor, color rendition, power factor, peak hour use as well as lamp and fixture costs, attractiveness and availability were each accounted for. The results showed the current lighting energy savings technical potential for new residential dwellings to be over 50 percent, without the use of Edison-based compact fluorescent lamps.

Methodology

Overview

The energy savings potential of efficient lighting in new dwellings was determined by first developing prototypical building models. A 900 square feet (sf) multifamily, a 1500 sf single family and a 2500 sf single family were used. Then, conventional lighting practice was established for each room or space -- the *base case*. Next, currently available efficient light fixtures and/or controls that provided equivalent light levels were identified for each room. After analyzing the options for each room, the most promising option was incorporated as the *upgraded case* for that room. The annual energy use for the base case and the upgraded case, per room and per dwelling, was compared to determine the energy-use savings (kWh) and the demand savings (kW). The analysis took into account the impact that the reduced lighting energy had on the space heating and cooling energy use.

The aesthetics and light quality of energy efficient light fixtures and their costs had to be determined since the potential energy savings are a function of how many fixtures are upgraded in each dwelling, as well as which rooms are upgraded. The life of the fixture and lamp (bulb) are also factors that were considered.

The current technology that provided the savings in most rooms was the use of light fixtures with compact fluorescent (CFL) lamps. CFL lamps have an efficacy (light output per power input) much higher than incandescent lamps. A 13 Watt (W) CFL has a net efficacy, after depreciation factors, of about 38 lumens per Watt. A 60W incandescent lamp has an efficacy of about 14 lumens per Watt. In addition, the CFL lasts four to seven times as long as the incandescent lamp, depending on the average duration of the fixture on-time (cycling time).

From a utility perspective, the energy savings cannot be considered to persist over time if the energy efficient CFL lamps could be replaced with inefficient incandescent lamps once they burned out. Therefore, all analysis was done using fixtures that were made only for pin-based CFL lamps.

Costs and savings were computed for each fixture, for the current maximum technical potential of the entire dwelling and for upgrading the dwelling in three levels of lighting upgrades: 25 percent, 50 percent and 75 percent of all fixtures being upgraded. The rooms expected to be most popular to upgrade from the builder's perspective (easy to install, least expensive; least impact on aesthetics), were used in the 25 percent upgrade and then the next most likely rooms added to reach 50 percent, and repeated to reach 70 percent.

Energy Savings

There are a number of parameters that require quantification in order to determine the energy savings from using more efficient lighting systems in dwellings.

Number of Baseline Fixtures and Wattages. The number of light fixtures per dwelling and their wattages in the baseline cases were determined. Using information from building surveys in Los Angeles (PECI 1991), Sacramento (PECI 1991), and from PECI staff with experience in residential design, prototypes were developed for a 900 sf multifamily unit, a 1500 sf single family dwelling, a 2500 sf single family dwelling and for multifamily common areas. The assumed total number of incandescent sockets was calibrated by comparing the 1500 sf prototype with a study which metered part of the light fixtures in each of 53 homes in Yakima, Washington for three months. (Delta-T Inc. 1990)

Preliminary results from the first six months of another study in Washington, which metered every fixture in six homes, support the prototype assumptions (Manclark, Nelson 1992), (Personal communication, Bruce Manclark, May 28, 1992).

Fixture On-Times. Reasonable assumptions were made as to the intended or needed hours per day and the unintended or unnecessary hours per day that each fixture will be turned on. The unintended on-time is necessary to analyze the value of occupancy sensors and timers. The accuracy of the assumptions for individual rooms cannot be verified, since no extant metering studies have been extensive enough to establish on-time correlations by room. However, the unintended on-time assumptions were compared to a survey of 90 homeowners who were asked to estimate the wasted on-time in their home by room (BEACON 1992). To maintain a conservative position, the unintended on-time used in this paper ranged from 50 percent to 90 percent of those reported in the BEACON survey. The aggregate on-times in combination with the assumed wattages were calibrated against the Yakima study by comparing the annual energy consumed by the entire dwelling lighting in the Yakima metering studies with that predicted using the 1500 sf prototype. Good agreement was found. Also taken into account were the results of a lighting survey by Seattle City Light (Dethman, King 1991) of 454 dwelling owners who reported the hours per day they turned light fixtures on. On-time averages were also compared with assumptions from others in the field of energy conservation from the Northeast (Cowell, Gag, and Kelly 1992). Further validation of the aggregate energy use from lighting was made from a review of a less related end-use study. (EPRI 1991) The above sources indicate that lighting energy use in dwellings may be significantly larger than what some utility forecasters have been using (CEC 1983). Table 1a and 1b includes the values for these on-time assumptions. The dwelling average daily on-time (intended plus unintended on-times) was 2.75 hours per fixture, with the range being from .5 to 6.7 hours per day.

Wattage of Upgraded Fixtures. To determine the wattage of each suitable fixture upgrade, the lumen output of both the baseline and the upgraded fixture was needed.

This information was used to ensure that the upgraded fixture provided a light level equal to that of the baseline fixture. It was assumed that the room wattages in the base case prototypes provided adequate light levels.

The net lamp lumen or light output of a CFL is a function of a number of factors. All decrease the lamp lumens from their nominal initial value. Communication with ballast manufacturers revealed that the ballast factor for magnetic CFL ballasts is about .98. The nominal lamp lumen depreciation factor over time averages .85. The factor for lumen depreciation from heat buildup in current recess cans and enclosed fixtures averages .85 (LBL 1990). To account for dust on fixtures with lenses a dirt depreciation factor of .95 was used.

The coefficient of utilization factor, CU, of a fixture accounts for the way light leaves the fixture and is distributed throughout a given room. The CU factors used for each fixture in each room were taken from typical values determined from actual light level measurements taken in a typical dwelling. Typical CU values ranged from .3 for recessed cans in halls to .65 for ceiling surface fixtures in a living room. The average light level in a room is determined by multiplying all the above lumen depreciation factors together and then multiplying by the initial lamp lumens and by the number of lamps, all divided by the floor area. The above factors, except the CU and the dirt depreciation factor, applied to a nominal 900 lumen, 13W CFL lamp result in only 637 lumens of net output which is only 80 percent of a 60 W incandescent lamp.

Incandescent lamps of, course, have no ballast factor and are assumed to have no lamp heat depreciation. Information from technical services of two of the main lamp manufacturers in the United States revealed that 40 to 75W incandescent lamps have a normal lamp lumen depreciation factor of about .90.

Light Quality. The light color quality of compact fluorescent lamps is generally considerably better than conventional tube fluorescent lamps and approaches that of incandescent lamps. Thus, light quality of CFL lamps should not affect their acceptance.

Table 1a. Baseline Fixtures and Chosen Upgrades -- Dwelling Interior and Exterior

Room	Category	Fixture Description	# of Fixt's	Fixt.+ Lamp Cost	Control Cost	Intended On-time per day (hrs)	Unintended On-time per day (hrs)	Watts / Fixture	Avg. Cycling Time (hrs)
Bdrm.,	Baseline	2-table lamps	2	$2	$0	1.75	0.45	60	0.44
Master	Upgrade	PL Ceiling drum	1	$65	$0	1.75	0.45	32	0.44
Bdrm.,	Baseline	Incand. Ceiling drum	1	$41	$0	2.1	1.3	120	0.68
Child	Upgrade	PL Ceiling drum	1	$60	$0	2.1	1.3	32	0.68
Hall	Baseline	Incand. Ceiling drum	5	$33	$0	3.15	0.8	60	0.66
	Upgrade	PL Ceiling drum	5	$57	$0	3.15	0.8	22	0.66
Closet,	Baseline	Incand. Ceiling drum	1	$22	$0	0.65	0.42	60	0.21
Walkin	Upgrade	PL Ceiling drum	1	$47	$0	0.65	0.42	22	0.21
Bath,	Baseline	Bar, Fluor.	1	$44	$0	1.8	0.55	35	0.47
Master	Upgrade	Bar, Fluor. w/ sensor	1	$85	$45	1.8	0.15	35	0.31
Bath,	Baseline	Recess can incand.	1	$26	$0	1.9	0.42	75	0.47
Aux. Rm.	Upgrade	PL Ceiling drum	1	$47	$0	1.9	0.42	22	0.47
Bath,	Baseline	Bar, Fluor.	1	$44	$0	1.15	1.13	35	0.44
Child	Upgrade	Bar, Fluor. w/ sensor	1	$85	$45	1.15	0.15	35	0.27
Kitchen,	Baseline	Fluor. 34W_T12, M.bal, 4-lamp.	1	$66	$0	5.5	1.2	192	0.84
Main Lt.	Upgrade	Fluor. 32W_T8, E.bal, 4-lamp	1	$88	$0	5.5	1.2	114	0.84
Kitchen,	Baseline	Recess can incand.	1	$26	$0	2.7	1.0	75	0.74
Sink	Upgrade	PL Ceiling drum	1	$47	$0	2.7	1.0	22	0.74
Living Rm.	Baseline	2-table lamps	2	$2	$0	1.9	0.82	75	0.68
	Upgrade	PL Ceiling drum	1	$65	$0	1.9	0.82	32	0.68
Family Rm.	Baseline	Incand. Ceiling drum	1	$45	$0	2.7	0.95	180	0.73
	Upgrade	PL Ceiling drum	1	$65	$0	2.7	0.95	50	0.73
Entry/	Baseline	Recess can, incand.	3	$26	$0	2.7	0.86	75	0.71
Accents	Upgrade	PL Ceiling drum	3	$47	$0	2.7	0.86	22	0.71
Utility Rm.	Baseline	Incand. Ceiling drum	1	$40	$0	0.7	0.65	180	0.45
	Upgrade	Fluor. 40W_T12, M.bal, 2-lamp	1	$65	$0	0.7	0.65	86	0.45
Study	Baseline	Incand. Ceiling drum	1	$45	$0	0.7	0.34	180	0.35
	Upgrade	PL Ceiling drum	1	$65	$0	0.7	0.34	50	0.35
Garage	Baseline	Porcelain open bulb	3	$3	$0	0.25	0.6	75	0.18
	Upgrade	Fluor. 40W_T12, M.bal, 2-lamp	2	$23	$0	0.25	0.6	86	0.18
Exterior	Baseline	Wall, incand.	3	$36	$0	2.7	0.9	60	1.8
Front	Upgrade	Wall, PL	3	$60	$0	2.7	0.9	17	1.8
Exterior	Baseline	Wall, incand.	3	$36	$0	0.3	0.45	60	0.38
Rear	Upgrade	Wall, PL	3	$60	$0	0.3	0.45	17	0.38
Dining Rm.	Baseline No Upgrade	Hanging Chandelier	1	n/a	n/a	2.3	0.7	240	-
Eating Nook	Baseline No Upgrade	Hanging Chandelier	1	n/a	n/a	2.3	0.7	240	-

E.bal = electronic ballast, M.bal = magnetic ballast

Energy Calculations. The annual energy savings from using more efficient lighting systems in dwellings is the difference in energy use between the base and the upgraded cases. The annual energy "used" by light fixture of the same kind in a room is found from:

Energy Used =

[Watts per fixture] x [number of fixtures] x [hours of operation per year]

+ [added heating energy required due to more efficient lights]

- [reduced cooling energy required due to more efficient lights](1)

Interactive Effects. The increase in heating energy due to using lights that have lower wattage was based on an examination of typical load shapes for winter lighting and winter space heating which plot the percent of the total space conditioning and lighting energy used each hour. It was estimated that for a day of significant heating,

Table 1b. Baseline Fixtures and Chosen Upgrades -- Multifamily Common Areas

Room	Category	Fixture Description	# of Fixt's	Fixt.+ Lamp Cost	Control Cost	Intended On-time per day (hrs)	Unintended On-time per day (hrs)	Watts / Fixture	Avg. Cycling Time (hrs)
Enclosed	Baseline	Fluor. 34W_T12, M.bal, 2-lamp.	1	$43	$0	24	0	72	cont.
Garages	Upgrade	Fluor. 32W_T8, E.bal, 2-lamp	1	$66	$0	24	0	62	cont.
Carports & & Covered	Baseline	Fluor. 34W_T12, M.bal, 2-lamp.	1	$43	$0	11	0	72	11
Walkways	Upgrade	Fluor. 32W_T8, E.bal, 2-lamp	1	$66	$0	11	0	62	11
Lounges	Baseline	Recess can incand.	1	$26	$0	7	4	75	5.5
	Upgrade	Recess can PL + sensor	1	$100	$45	7	0.5	32	0.94
Lounges	Baseline	Fluor. 34W_T12, M.bal, 2-lamp.	1	$43	$0	7	4	72	5.5
	Upgrade	Fluor. 32W_T8, E.bal, 2-lamp	1	$66	$45	7	0.5	62	0.94
Corridor	Baseline	Fluor. 34W_T12, M.bal, 2-lamp.	1	$43	$0	24	0	72	cont.
Main Lts.	Upgrade	Fluor. 32W_T8, E.bal, 2-lamp	1	$66	$0	24	0	62	cont.
Corridor	Baseline	Incand.	1	$68	$0	24	0	40	cont.
Exit Signs	Upgrade	Fluor. PL	1	$92	$0	24	0	11	cont.

E.bal = electronic ballast, M.bal = magnetic ballast

87 percent of the lighting energy use will contribute to reducing space heating. The number of days that this impact occurs, at this magnitude, was taken to be 75 percent of the total number of days that any auxiliary heating occurs.

In a similar manner the impact of lighting energy on space cooling energy was determined. It was estimated that about 75 percent of the lighting energy will directly cause an increase in space cooling energy. The number of days of cooling was treated the same as in the heating case.

The net heating days for the cooling dominated climate in this study was 77, and 160 for the heating dominated climate. The number of net cooling days for the cooling dominated climate was 120 and no cooling was assumed for the heating dominated climate. The air conditioning Seasonal Energy Efficiency Ratio (SEER) was assumed to be 10, the heatpump Heating Seasonal Performance Factor (HSPF) 6.8 and the gas furnace Annual Fuel Utilization Efficiency (AFUE) .78.

Peak Demand Savings. The peak demand savings from the dwelling interior lighting was taken from the above-mentioned load shapes. For the building peak cooling hour (one hour between 5 to 7 pm), the lighting energy is about six percent of its daily total. For the space heating peak (one hour from 6 to 8 am) the lighting is about four percent of its daily total. Thus, the peak hour demand savings is estimated to be six percent for summer and four percent for winter, of the kW reduction due to the reduced wattage fixture(s) assuming no coincidence diversity.

Fixture Upgrade Options. The energy use of the baseline fixture(s) in each room of each prototype for both climates was compared with two to four optional upgrades, consisting of higher efficacy fixtures and/or controls. The summary results use only one of the upgrade options for each room. The basic assumptions for the baseline and the *chosen* upgrade are found in Table 1a and 1b.

Efficient Lighting Measure Costs

The parameters affecting the cost of a more efficient light fixture are the location of the fixture and its purpose. These are important factors since the selection of available compact fluorescent fixtures, while growing, is currently not comparable to the lines of incandescent fixtures. Costs were obtained for all fixtures, lamps and controls with the CFL fixtures having high power factor ballasts. No contractor markup was assumed.

Lamp Life. The cost of a permanent lighting measure to the utility offering incentives is only the first cost. However, the potential of the technology is tied to the attractiveness of the measure to the end-user. The frequency and cost of lamp replacement is therefore important. The lamp life of compact fluorescent lamps has been heavily advertised to be about 10,000 hours. However, this rating is based on three hour cycling times (on-time duration per switching) which is much greater than the estimated average residential cycling time of one quarter to 1 1/4 hour. CFL lamp manufacturers agree that the nominal lamp life drastically drops for reduced cycling times. An equation that was developed for T-12 lamps with magnetic ballasts in 1988 (Carriere, Rea 1988) gives the closest agreement to the information received from the CFL lamp manufacturers. It is used for CFL lamp life in this study which varies by room (see Figure 1). Most CFL lamps in residential use will last only 4,000 to 7,000 hours of their nominal 10,000 hour rating.

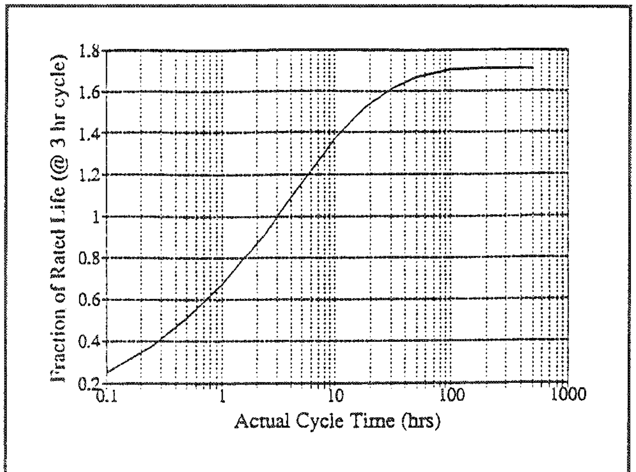

Figure 1. Fluorescent Lamp Life

It is claimed that CFL lamps with special "soft-start" integral electronic ballasts (screw-in Edison based sockets) are unaffected by cycling times down to as low as five minutes. However, such ballasts are currently unavailable in "hard wired" CFL fixtures. Incandescent lamp life is apparently not affected by cycling times and range from 850 to 1000 hours.

Cost-Effectiveness

From a utility point-of-view the cost effectiveness of offering incentives for improved lighting is based on the amount of the incentive, the annual energy (kWh) saved and its value, and the demand savings and its value. Environmental externalities should also be taken into account regarding air pollution and special disposal cost issues for both incandescent and CFL lamps. Power quality issues (power factor and harmonic distortion) are also a concern to utilities. However, the cost of obtaining the kWh savings in this study was measured only by computing a levelized cost of the annual kWh saved over the life of the measure. The measure cost was the incremental first cost or added cost of the upgraded fixture. The measure life was assumed to be 20 years and the discount rate was assumed to be .075 per year.

Results

The average savings for each housing type and climate are found in Tables 2 through 4. Each table shows the current maximum technical potential, and the costs and savings if approximately 70 percent of the fixtures were upgraded, if 50 percent of the fixtures were upgraded, if 25 percent of the fixtures were upgraded and the per fixture average. Table 5 summarizes the results for multifamily common areas.

Upgrades in Kitchen and Baths

The baseline main lighting in kitchen and baths was assumed to be standard conventional fluorescent, due to building energy codes. Because the current selection of high efficacy fluorescent fixtures for baths is extremely small, the bath upgrade was limited to an occupancy sensor, which was not very cost effective. However, the kitchen was upgraded with high efficacy 32W T-8 lamps and electronic ballasts which gave savings of 190 kWh per year.

Recess Down Lights

The popular recess down lights which have been used in virtually every location in a dwelling can be difficult to upgrade with a CFL can. A residential CFL recess can is available, but it allows for only one 13W lamp and is expensive, especially if it must be IC rated (for insulation contact). This lamp will not give equivalent light output to a 60W incandescent lamp. In applications where light levels are important, a commercial fixture which uses 2-13W lamps will be required, or at minimum a can with 1-lamp with a highly reflective inside (not white). For most cases in this study, the incandescent can was upgraded with a surface mounted fixture, which has a cost less than upgrading with a recess CFL can and the light output is greater.

Switched Outlet Circuits

In many master bedrooms, the only lights are table lamps switched at the door. No overhead lighting is used, except for some occasional recess down lights (cans). The general lighting is achieved by the table lamps. The only currently viable and persistent upgrade from incandescent table lamps is to trade to a central ceiling CFL fixture. This is a significant change in aesthetics and is expensive, since the upgrade cost is not simply a differential, but is the full cost of the added fixture. The same problem exists in living and family rooms. This conversion to a ceiling fixture was the upgrade choice for the master bedroom and living room.

Table 2. Lighting Energy Savings - Residential New Construction

Single Family
2500 sf

Total Fixtures = 36

		# of Fixt's Upgraded	% of Fixt's Upgraded	Added Cost	Watts per sf	LIGHTING SAVINGS: Cooling Dominated Climate (1): Electric Heating X, Electric Cooling X: Annual kWh	Summer Peak (W)	Level. Cost ($/kWh)	Cooling Dominated Climate (1): Electric Heating O, Electric Cooling X: Annual kWh	Summer Peak (W)	Level. Cost ($/kWh)	% kWh Saved	Heating Dominated Climate (2): E. Heat X, E. Cool O: Annual kWh	Level. Cost ($/kWh)	Heating Dominated Climate (2): Electric Heating O, Electric Cooling O: Annual kWh	Level. Cost ($/kWh)	% kWh Saved
Baseline Use Per House (not savings)					1.30	3183			3466				2820		3409		
Potential	Per House	29	81%	$692	0.62	1669	102	$0.041	1846	102	$0.037	53.3%	1443	$0.047	1811	$0.038	53.1%
Level 3	Per House	25	69%	$558	0.71	1393	88	$0.039	1557	88	$0.035	44.9%	1183	$0.046	1524	$0.036	44.7%
	Avg. Per Fixture			$22		56	3.5	$0.056	62	3.5	$0.052		47	$0.062	61	$0.053	
Level 2	Per House	18	50%	$354	0.91	900	59	$0.039	1004	59	$0.035	29.0%	767	$0.045	983	$0.035	28.8%
	Avg. Per Fixture			$20		50	3.3	$0.045	56	3.3	$0.042		43	$0.048	55	$0.043	
Level 1	Per House	9	25%	$146	1.11	375	29	$0.038	415	29	$0.037	12.0%	323	$0.044	407	$0.035	11.9%
	Avg. Per Fixture			$16		42	3.2	$0.036	46	3.2	$0.035		36	$0.039	45	$0.035	

Table 3. Lighting Energy Savings - Residential New Construction

Single Family 1500 sf Total Fixtures = 30		# of Fixt's Upgraded	% of Fixt's Upgraded	Added Cost	Watts per sf	LIGHTING SAVINGS: Cooling Dominated Climate (1): Electric Heating X, Electric Cooling X: Annual kWh	Summer Peak (W)	Level. Cost ($/kWh)	Electric Heating O, Electric Cooling X: Annual kWh	Summer Peak (W)	Level. Cost ($/kWh)	% kWh Saved	Heating Dominated Climate (2): E. Heat X, E. Cool O: Annual kWh	Level. Cost ($/kWh)	Electric Heating O, Electric Cooling O: Annual kWh	Level. Cost ($/kWh)	% kWh Saved
Baseline Use Per House (not savings)					1.84	2774			3020				2459		2971		
Potential	Per House	23	77%	$555	0.84	1463	90	$0.037	1614	90	$0.034	53.4%	1269	$0.043	1584	$0.034	53.3%
Level 3	Per House	21	70%	$429	0.98	1291	77	$0.033	1422	77	$0.030	47.1%	1124	$0.037	1396	$0.030	47.0%
	Avg. Per Fixture			$20		61	3.7	$0.028	68	3.7	$0.027		54	$0.031	66	$0.027	
Level 2	Per House	15	50%	$285	1.22	838	56	$0.033	935	56	$0.030	30.9%	715	$0.039	915	$0.031	30.8%
	Avg. Per Fixture			$19		56	3.7	$0.023	62	3.7	$0.022		48	$0.025	61	$0.022	
Level 1	Per House	8	27%	$118	1.48	463	32	$0.025	514	32	$0.022	17.0%	398	$0.029	504	$0.023	17.0%
	Avg. Per Fixture			$15		58	4.0	$0.016	64	4.0	$0.015		50	$0.016	63	$0.015	

(1) 120 days of significant cooling (ALL days with auxilliary cooling x .75), Los Angeles. 77 days of significant heating (ALL days with auxilliary heating x .75), Los Angeles.
(2) 0 days of cooling, Spokane. 160 days of significant heating (ALL days with auxilliary heating x .75), Spokane.
(3) Upgraded means primarily going from incandescent fixtures to compact fluorescent fixtures with high power factor ballasts. See Table 1.
** Lighting energy = [energy used by lights alone] - [light energy contributing to space heating] + [light energy contributing to space cooling]
** Levelized cost is based on added upgrade cost over a 20 year life at a .075 discount rate.
** Watts per sf is all fixture wattage, including 2 lamps per switched outlet circuit and exterior fixtures divided by the conditioned floor area.

Table 4. Lighting Energy Savings - Residential New Construction

Multifamily 900 sf Total Fixtures = 15		# of Fixt's Upgraded	% of Fixt's Upgraded	Added Cost	Watts per sf	LIGHTING SAVINGS: Cooling Dominated Climate (1), Electric Heating X, Electric Cooling X: Annual kWh	Summer Peak (W)	Level. Cost ($/kWh)	Cooling Dominated Climate (1), Electric Heating O, Electric Cooling X: Annual kWh	Summer Peak (W)	Level. Cost ($/kWh)	% kWh Saved	Heating Dominated Climate (2), E. Heat X, E. Cool O: Annual kWh	Level. Cost ($/kWh)	Heating Dominated Climate (2), Electric Heating O, Electric Cooling O: Annual kWh	Level. Cost ($/kWh)	% kWh Saved
Baseline Use Per House (not savings)					1.48	1491			1622				1324		1596		
Potential	Per House	12	80%	$402	0.71	718	42	$0.055	792	42	$0.050	48.8%	624	$0.063	819	$0.051	48.7%
Level 3	Per House	10	67%	$274	0.84	677	37	$0.040	746	37	$0.036	46.0%	589	$0.046	864	$0.037	45.9%
	Avg. Per Fixture			$27		68	3.7	$0.022	75	3.7	$0.020		59	$0.026	73	$0.020	
Level 2	Per House	7	47%	$164	1.03	457	24	$0.035	513	24	$0.031	31.6%	386	$0.042	502	$0.032	31.4%
	Avg. Per Fixture			$23		65	3.5	$0.016	73	3.5	$0.015		55	$0.020	72	$0.015	
Level 1	Per House	4	27%	$90	1.19	279	16	$0.032	313	16	$0.028	19.3%	236	$0.038	307	$0.029	19.2%
	Avg. Per Fixture			$23		70	3.9	$0.010	78	3.9	$0.009		59	$0.011	77	$0.009	

** See Notes under Table 3.

Table 5. Lighting Energy Savings, Per Fixture - Multifamily Common Areas

Location	Baseline			Upgrade						Levelized Cost of Savings ($/kWh)
	Baseline Fixture Description	Input Watts		Upgrade Fixture Descriptions	Input Watts	Upgrade Added Cost (1)	Annual kWh Saved	Peak Reduction (W)		
Covered Carports	4' Fluor. 2-lamp Fixture	72	a	FI32W.T8 w/ elec. ballast	62	$23	40	10 Wint.		$0.056
	FI34W.T12 w/ Mag. ballast		b	70W High Press. Sodium	62	$43	40	10 Wint.		$0.105
Enclosed Parking Garages	Same as Carports	72	a	FI32W.T8 w/ elec. ballast	62	$23	87	10 Both		$0.026
			b	70W High Press. Sodium	62	$43	87	10 Both		$0.048
Covered Balcony or Walkways	Same as Carports	72	a	FI32W.T8 w/ elec. ballast	62	$23	40	10 Wint.		$0.056
			b	70W High Press. Sodium	62	$43	40	10 Wint.		$0.105
Lounges	Recess cans, incand.	75	a	Rec. std. can fluor.	17	$83	176	2.6 Sum.		$0.046
			b	Rec. std. can fluor. + sensor	17	$93	218	2.6 Sum.		$0.042
	Same as Carports	72	a	FI32W.T8 w/ elec. ballast	62	$23	41	.7 Both		$0.055
			b	FI32W.T8 w/ elec. bal. + sensor	62	$68	122	.7 Both		$0.054
Corridors and Halls	Same as Carports	72	a	FI32W.T8 w/ elec. ballast	62	$23	87	10 Both		$0.026
Exit Signs	Incand. 40W	40	a	PL 11W	11	$25	254	29 Both		$0.010

* Added Cost is the price for fixture(s) + lamps + the proportional cost of controls based on 6 fixtures per occupancy sensor.

** Savings are for all climates except the lounge which are for the no elec. heating case in Los Angeles. See Table 1 for on-time assumptions.

*** Peak Savings: Wint. = winter, Sum. = summer, Both = both.

Chandeliers

Hanging chandeliers and/or paddle fan fixtures in the dining room, the breakfast nook, the stairway, entry or vaulted ceiling area, currently have virtually no potential for upgrading. They use small, visible incandescent lamps and there are very few hanging CFL fixtures available and none that match the current incandescent styles. Occupancy sensors were analyzed for these situations and found not to be effective, since they could actually cause an increase in on-time instead of less, due to people normally passing through these areas without necessarily turning on the light. Subsequently, the dining room and breakfast nook were not upgraded in any of the prototypes.

Controls

For most rooms, occupancy (motion) sensors and timers were analyzed with both incandescent and CFL fixtures. They typically saved only 18 to 42 percent of what a CFL upgrade alone saved and were thus not the chosen upgrade in any dwelling interior rooms. In addition, the savings persistence of conventional wall timers and sensors is questionable because they are occupant dependent. Electronic auto-off bulb inserts showed very low levelized costs on incandescent bulbs, but their gross kWh savings were also much lower than CFL lamps. However, they are recommended in the few areas where CFL fixtures cannot currently be used. Sensors were very effective in multifamily common area lounges. (See Table 5)

Dimmers

Dimmers were analyzed for the dining and breakfast nook incandescent chandelier fixtures but are not recommended as a persistent measure. *Dimmers should not be used with CFLs since they present an electrical safety hazard.*

Multifamily Common Areas

Table 5 summarizes the savings from lighting savings per fixture for multifamily common areas. These areas offer significant savings at low levelized costs. Exterior security lighting was not analyzed because the baseline was the use of metal halide lamps and there is currently little potential savings for upgrading this lamp. Additional savings not analyzed can be realized for the multifamily enclosed garages by installing timers that will turn off one-third to one-half of the light fixtures during the middle of the night when the garage has little use.

Effects on Space Conditioning

It was found that in Los Angeles, the air conditioning energy savings from more efficient fixtures was just over 2 percent of the interior lighting energy savings alone. Thus, this effect can be ignored in most cases. However, heating impacts are more significant and should not be ignored in electric heating cases. In Los Angeles, the more efficient fixtures cause a net increase in space heating energy equal to 11 percent of the interior lighting kWh savings, and in Spokane a 23 percent increase.

Costs and Savings Averages

Tables 2-5 show that the average cost per fixture increased consistently as the number of fixtures was upgraded. The average kWh saved per fixture upgrade also rose as the number of upgraded fixtures increased, meaning that the more expensive upgrades were less popular, but saved proportionately more energy. There was also a definite trend for the average levelized cost of savings to rise in a similar manner. This occurred because, proportionally, the average added cost per fixture increased at a higher rate than the kWh savings. It should be realized that the average fixture savings will not be realized when only one or two fixtures are upgraded, if low-use fixtures are chosen.

Conclusion

This comprehensive study shows that it is currently feasible to reduce the lighting energy use in newly constructed dwellings by over 50 percent. For a 1500 sf dwelling, this represents a savings of 1400 kWh. This resource can be achieved at a levelized cost of less than \$.04 per annual kWh saved, even when offering incentives at full incremental cost. Program costs have not been included. The study also shows that upgrading as few as 25 percent of the total dwelling fixtures offers significant savings at an even lower levelized cost. Large savings are also available if fixtures in multifamily common areas are upgraded. The savings are achieved primarily by upgrading incandescent lamp light fixtures to high power factor compact fluorescent "hard wired" fixtures, and by upgrading standard fluorescent fixtures to higher efficacy fluorescent lamps with electronic ballasts.

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