Baseline Residential Lighting Energy Use Study

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The number of hours residential lights are operated is a crucial variable in determining the cost-effectiveness of lighting programs, both in retrofit settings and for new construction. Earlier efforts at establishing lighting use characteristics in the residential sector have depended on manufacturers' estimates and/or self-report surveys of residential utility customers. Accurate information on actual operating profiles for various types of lights in a range of residential settings will permit program designers to target those lights which are operated longest and thus are most cost-effective to replace with efficient equipment.

The Baseline Residential Lighting Energy Use Study, funded by the Bonneville Power Administration, is designed to establish actual on-hours for all lights in a sample of 161 Northwest residences. The information will be used to establish which lamp replacements are typically cost-effective in the residential sector. The project employs run-time lighting loggers to measure the number of hours residential interior and exterior lights are operated.

The most important results of this study are:

The average residential lighting energy use is about 1,800 kWh/year/household

Approximately one third less energy is used for lighting in the months in which there is more sunlight then in the months when there is less sunlight.

Replacing 50–150 W lamps that are on at least three hours per day with compact fluorescent lamps (CFL) provides a resource with a levelized cost of approximately 28 mill with a simple payback of three years assuming $15 per CFL and $0.04 per kWh.

INTRODUCTION

In late 1992 the Conservation Office at Tacoma Public Utilities proposed an investigation of residential energy lighting use in the Pacific Northwest. Earlier efforts at establishing lighting use characteristics in the residential sector have depended on manufacturers' estimates and/or self-report surveys of residential utility customers (Schlegel 1994) (Jennings, Brown, Moezzi, Mills, Sardinsky, Heckendorn, Lerman, Tribwell, 1996). In 1989 residential lighting energy use was estimated to be 4.9% (710 kWh) of 14,493 kWh annual household electric energy consumption for the Pacific Northwest (Northwest Power Planning Council, 1991). The results of an extensive telephone survey in the Northeast (Leslie, Conway 1993) determined that residential lighting consumed 10% of the total annual household electricity used. The only measured residential lighting energy use study conducted before this study began, had a sample size of 53 homes in Yakima, WA collecting data for 3-4 months in the winter had an average annual lighting energy use of 2,900 kWh and found there to be 30% of the fixtures on three or more hours per day (Manclark, 1991). Accurate information on actual operating profiles for various types of lights in a range of residential settings was and is needed to permit program designers to target those lights which are operated longest and thus are most cost-effective to replace with efficient equipment.

Together with staff at the Bonneville Power Administration Tacoma developed a research plan for establishing baseline usage in single family homes in the region. Tacoma recruited utility participants, procured necessary metering equipment for the study, trained staff at participating utilities and launched the research program in the spring of 1993. This report uses data available as of December 19, 1995, which is final data covering the full 24 month data collection period. While the study is designed to provide a *reasonably* representative sample with results to be extended to the BPA region; it is not a rigorous statistical study study.

Seven utilities participated in the study:

Tacoma Public Utilities, lead
City of Port Angeles
Peninsula Light Company
Portland General Electric
Eugene Water & Electric Board
Pacific County PUD #2

Snohomish County PUD

The data were collected using Pacific Science and Technology's run time loggers mounted to light fixtures in customer homes. These loggers count the number of hours the lights are on. The study uses data from 161 Pacific Northwest residences that had the loggers installed for six or twelve month periods.

OBJECTIVES

The study was designed to collect data to determine:

(1) On average, how much energy is consumed by lighting per residence

(2) The percentage of fixtures in the study that have lamps in use three hours or more per day for specific locations (e.g. living room, kitchen, porches, bathroom, bedroom, yard/driveway).

(3) On average, the annual residential lighting energy use savings of replacing the incandescent lamps with a wattage between 50 and 150 with compact fluorescent lamps.

METHODOLOGY

The data analysis presented here uses data from about 1,250 loggers[1] installed in 161 single family owner-occupied residences (of which one is a mobile home and five are single family renter-occupied residences) for four to twelve months. Loggers were installed on an average of 82% of the fixtures at each house to record run times (N = 3,904 individual fixtures logged).

Since this is a study in seven different utility service areas working with 161 different customer households, it has not been possible to precisely synchronize the start and stop data collection dates. The four data collection periods roughly are:

Period 1	July 13, 1993—February 4, 1994
Period 2	February 5, 1994—August 31, 1994
Period 3	September 1, 1994—February 28, 1995
Period 4	March 1, 1995—August 31,1995

Houses whose readings fell predominantly in Period 1 were considered Period 1 houses. The same logic was applied to the remaining three time periods.

Customer Selection Process. Each utility in the study was asked to recruit sets of customers who would represent their service area in terms of building size, number of occupants, and weekday occupancy. The customers had to agree to participate for six or twelve months during which time the loggers would be read by utility energy auditors. The customers agreed to not make any changes in the way they used their lights and to not change the inventory of lamps and fixtures while the loggers were installed. Some of the utilities had customer characteristics surveys so they could target their recruitment and others used what they considered was common knowledge of their communities.

Annualized Data. The data was *annualized,* meaning that the total hours logged were divided by the total days installed and multiplied by days per year. The annualized data was then divided in half to approximate half-year usage. The data has been separated into the four periods described above. The first and third period data had four to six months of data per customer whereas the second and fourth periods have six to twelve months per customer. The report combines data from Periods 1 and 3 to represent the darker half of the year, and Periods 2 and 4 to represent the lighter half of the year.

Results What follows is a brief look at the data from all four data collection periods in order to answer the research questions set out in the Evaluation Plan.

(1) On average, how much energy is consumed by lighting per residence?

The half-year lighting energy usage per household varied from 8 to 3,773 kWh with an average of 1,179 kWh for Period 1, 815 kWh for Period 2, 1,019 kWh for Period 3, and 629 kWh for Period 4. The weighted average of half-year usage for Periods 1 and 3 is 1,099 kWh and for Periods 2 and 4 is 722 kWh. For the entire data set, the weighted average is 1,818 kWh per year ranging from 1,444 kWh per year for Periods 2 and 4 to 2,196 kWh per year for Periods 1 and 3. Table 1 summarizes annual lighting energy use by period of data collection.[2]

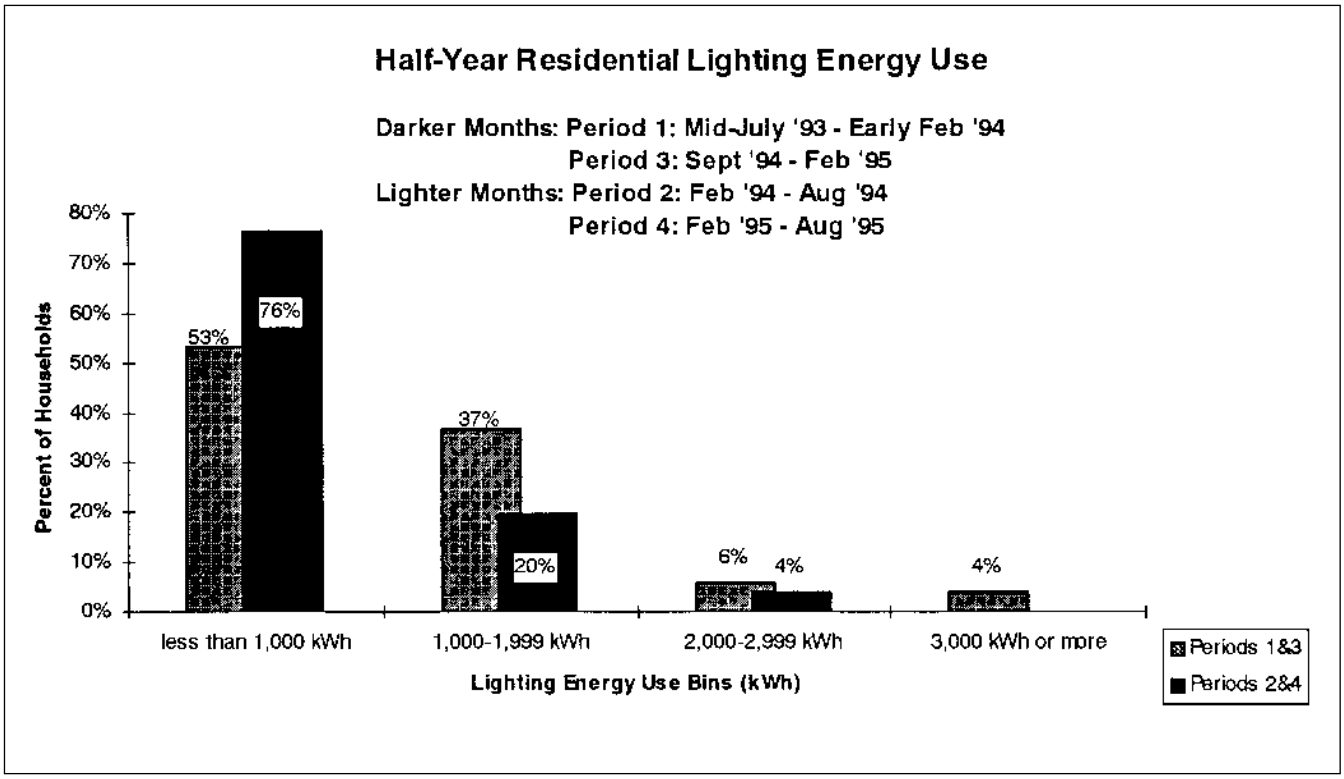
Period 1	July 13, 1993—February 4, 1994
Period 2	February 5, 1994—August 31, 1994
Period 3	September 1, 1994—February 28, 1995
Period 4	March 1, 1995—August 31,1995

The differences between the darker months: Periods 1&3 and the lighter months: Periods 2&4 are further detailed in Figure 1 below. In Periods 1&3, which covered much of winter, 53% of the households used less than 1,000 kWh per half-year, whereas in Periods 2&4, covering the lighter months of February through August, 76% of the households used less than 1,000 kWh per half-year. There was also a significant decrease in the number of homes using 1,000—1,999 kWh per half-year, from 37% of the customers for Period 1&3 to 20% of the customers for Period 2&4.

Table 1. *Annual Lighting Energy Use Per Household*

Period	Min & Max kWh per Half-yr per Customer	Average kWh per Half-yr per Customer	Weighted Average kWh/yr per Half-yr per Customer	N	Unique Customers
1	21–3,773	1,179		50	
2	8–2,673	815		51	
1 & 2	8–3,773		1,990	101	80
3	111–3,191	1,019		51	
4	168–2,677	629		51	
3&4	111–3,191		1,648	102	81
1&3	21–3,773	1,099	2,196	101	101
2&4	8–2,677	722	1,445	102	102
1,2,3,4	8–3,773		1,818	203	161

Figure 1. *Half-Year Residential Lighting Energy Use*



As seen in Table 2 below, average lighting energy use for the period the loggers were installed was 1,372 kWh. Average total electrical energy use for the same period was 14,889 kWh per home. Thus for these homes, lighting represents approximately 9% of total electrical usage for the period of the study. Some of these customers had loggers installed for six months and others for twelve months. Some had loggers installed over most of the heating season and others did not.[3] No attempt was made to identify space and water heating fuels, so the study participants may not be representative of heating fuel mixes for participating utilities. Notice that the standard deviations of their consumption data are high and N is relatively small. Accordingly, some caution should be exercised in extending these percentages to the region (Cahill, Ritland, Lin-Kelly 1992, 20, 84)[4].

(2) What is the percentage of fixtures in the study that have lamps in use three hours or more per day for specific locations (e.g. living room, kitchen, porches, bathroom, bedroom, yard/driveway)?

Assume that a lamp used three hours or more might be a candidate for replacement as a conservation measure. Table 3 below shows the percentage of fixtures in the study that have lamps in use three hours or more per day.

Initially the second Objective was framed in terms of the average number of hours per day lights are on for specific locations. The second Objective was changed to ask what percentage of fixtures are in use three or more hours per day, because when the average on-time hours per day for specific locations is looked at by itself, it tends to mask other data that would give a clearer understanding of the level of fixture usage. In Table 4 below, the average on-time in Periods 1 and 3 living rooms is 3 hours per day, but

Table 3. *Percentage of Fixtures On at Least 3 Hours per Day by Location*

Location	Period 1&3 % on at least 3 hrs	Period 2&4 % on at least 3 hrs
Living rooms	44%	27%
Kitchens	52%	33%
Porches	48%	34%
Bathrooms	14%	19%
Bedrooms	14%	8%
Master bedrooms	16%	8%
Yard/Driveway	30%	17%
Household	27%	19%

Table 2. *Average Household & Lighting Electricity Consumption During Logged Period*

Utilities	Whole House kWh	StdDev	Lighting kWh	StdDev	N Customers
Eugene W&E	9,738	5,369	1,002	696	40
Pacific	7,996	3,110	765	697	21
PGE	25,277	24,943	1,573	1,136	26
Peninsula	22,680	7,397	2,502	1,684	5
Port Angeles	13,678	6,433	1,059	967	23
Snohomish	13,195	5,329	1,690	845	5
Tacoma	11,656	5,302	1,014	691	41
Average	***14,889***	***8,269***	***1,372***	959	

Table 4. *Average On-Time for Selected Locations—Periods 1 and 3*

	N Fixtures	Fixtures per House	Average on-hrs/day	StdDev
Living rooms	252	2.5	3.1	3.8
Kitchens	292	2.9	3.9	4.2
Porches	84	.8	4.7	5.6
Bathrooms	279	2.8	1.7	3.6
Bedrooms	265	2.6	1.2	2.2
Master bedrooms	205	2.0	1.3	2.1
Yard/Driveway	121	1.2	3.4	4.6

as can be seen in the table above, 44% of the fixtures logged were on three or more hours per day. Another example that points out the effects of masking data is Yard/Driveways. The average on-time in Periods 1 and 3 Yard/Driveways is 2 hours per day, but as can be seen in the table above, 30% of the fixtures logged were on three or more hours per day.[5]

(3) On average, what would the annual residential lighting energy use savings be if the incandescent lamps with a wattage between 50 and 150 were replaced with compact fluorescent lamps?

Table 5 shows assumed wattages of compact fluorescent lamps corresponding to ranges of incandescent lamp wattages in a lamp replacement program.

Table 5. *Assumed Wattages of Replacement Lamps*

Incandescent Watts	Compact Fluorescent Watts
50–59	15
60–75	20
76–100	27
101–150	30

Tables 6 and 7 show the impact of replacing the lamps according to this scheme with appropriate compact fluorescent comparing the darker and lighter months usage. For example in Table 6, replacing all such lamps on for at least three hours per day would yield annual savings of about 146 kWh per lamp in Periods 1 and 3. The annual savings would be 172 kWh per lamp for replacing lamps left on four or more hours per day in Periods 1 and 3. Table 7 shows savings for comparable replacements for Periods 2 and 4 are smaller. It is unlikely that any program would be successful in replacing all of the eligible lamps, but this gives an indication of the maximum potential savings. It should be noted that the levelized cost in the table assumes no administrative costs and no benefits from avoided lamp replacement costs. The levelized cost of the resource acquired through replacement of incandescent lamps with compact fluorescent lamps is less than 30 mills and is relatively unaffected by which lamps are replaced. It is quite sensitive to the assumed cost of the replacement lamps.

On a programmatic basis it is unlikely that all lamps being promoted in a utility program would be placed in fixtures that are used at the threshold a utility decides is necessary for the resource to be acquired at the desired price. Referring back to Table 3, there are usually more fixtures in a room that are being used less than 3 hours per day than are. The exact placement of the lamps will depend on the customer's willingness and ability to accurately identify the lamps they use the most.

Incentive Lamp Placement. As an incentive to participate in the study, customers participating for six months were given five compact fluorescent lamps and for twelve months received ten. The incentive lamps had wattages ranging from 15W to 30W. The energy auditors looked at the last logger readings with the customer and decided where to install their incentive lamps. These replacements were made after measurements were taken and did not affect the study results.

It was found that with the run time and installed watts data being presented by an energy auditor to the customer, the incentive lamps were installed in the highest hours of use fixtures 66% of the time on average (N = 833 lamps in 19 location types). The incentive lamps were installed in the highest watt-hour fixtures 77% of the time. Customers chose to install incentive lamps in fixtures not in the top ten run times list for a house because of dissatisfaction with fit, color or brightness.

SUMMARY

The conclusions that can be arrived at from this study are relatively modest but they provide answers to questions for

Table 6. *Impact of Replacement of Selected Incandescent Lamps—Periods 1 and 3*

Period 1 Mid-July '93–Feb'94 Period 3 Late July '94–Apr '95	On-Time >=1 hr	On-Time >=2 hr	On-Time >=3 hr	On-Time >= 4 hr
Number of Lamps	1,146	739	508	383
Number of Houses	100	97	91	82
Annualized savings/lamp (kWh)	85	116	146	172
Value of savings @ $.04/kWh	$3.39	$4.62	$5.84	$6.89
Simple payback @ $15/lamp (yrs)	4.4	3.2	2.6	2.2
Levelized cost (10,000 hrs) mills	29.4	28.7	28.4	27.6

Table 7. *Impact of Replacement of Selected Incandescent Lamps—Periods 2 and 4*

Period 2 Early Feb '94–Aug '94 Period 4 Late Feb '95 - Late Nov '95	On-Time >=1 hr	On-Time >=2 hr	On-Time >=3 hr	On-Time >= 4 hr
Number of Lamps	901	546	289	207
Number of Houses	100	96	74	57
Annualized savings/lamp (kWh)	68	92	129	151
Value of savings @ $.04/kWh	$2.71	$3.69	$5.17	$6.04
Simple payback @ $15/lamp (yrs)	5.5	4.0	2.9	2.5
Levelized cost (10,000 hrs) mills	30.4	29.1	27.9	28.9

which, prior to this research, there were no actual measured data. After 24 months of collecting data in 161 electric utility customer homes in the Pacific Northwest, there is an indication of what the annual residential lighting usage is for the region. On average, the annual lighting usage per household in this study is about 1,800 kWh. Not surprisingly, it appears that approximately one-third less energy is used for lighting in the months in which there is more sunlight than in the months when there is less sunlight. Lighting use is highest in living rooms, kitchens and outdoor locations. From the data, replacing 50-150W lamps that are on at least three hours per day with compact fluorescent lamps provides a resource with a levelized cost of approximately 28 mills, with a simple pay-back of under three years, assuming compact fluorescents cost $15 each and electricity costs four cents per kilowatt hour. If one goes beyond these basic assumptions, the data need to be re-analyzed.

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Table 8. *Daily Average Hours of Lighting Operation*

	Hours of Use per Day
Living Room	3
Kitchen	4
Primary Bath	2
Primary Bedroom	1

State Department of Energy; Margaret Gardner, Northwest Power Planning Council; Judy Jennings and Mithra Moezzi, Lawrence Berkeley National Laboratory; Mark E. Frankel, Ecotope; Danny Parker and Lynn Schrumm, Florida Energy Center; Larry Ayers, EPRI Lighting; Greg Stolz, Germantown, MD.

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ENDNOTES

1. Pacific Science and Technology run time loggers. The study also used 20 Richard Westlake re-built run time loggers from the Grays Harbor PUD Compact Fluorescent Maximization Study By Delta-T.

2. The 23% difference in average kWh per half-yr per customer between Periods 2 and 4 is possibly due to the lighting energy consumption habits of the occupants or it may have something to do with factors outside the scope of this study to track.

3. Almost all of the logger installations for Peninsula, PGE, Port Angeles and Snohomish were for twelve months.

4. For the purposes of coming up with a rough estimate, note that in the BPA End-Use Load and Consumer Assessment Program (ELCAP), Dec 1992, the Base Case houses that were the age of the average homes in our study (30-50 years) and in the square footage range (1,726–2,475 ft^2) similar to the present study (2,000–2,999 ft^2), had a total household electrical usage averaging 23,704kWh/yr. The average household annualized lighting energy usage for the lighting logger study was 1,818 kWh per year which, would be 8% of total household electrical usage of the ELCAP participants mentioned above. The average of 1,372 kWh lighting usage for the logged period is about 9% of the household kWh for the logged period. The figure of 1,818 kWh per year for lighting mentioned above is 38% of the 4,751 kWh per year annual electrical usage for lights and conveniences measured by ELCAP;

a substantial portion of but, not greater than 4,751 kWh per year.

5. Average on-hours per day, ''rounded *down* to the next lowest whole hour'', reported in *Research for the Lighting Pattern Book for Homes* (Source: Leslie, Conway 1993, 14) shown in Table 8 are similar to those in Table 2-2. This data was collected through a telephone survey.

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