1991 Residential Appliance Saturation Survey -- A Profile of the Residential Lighting Load in Northern California

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In 1991 an on-site survey was conducted to determine the penetration of energy efficient technologies in the residential sector. This survey included a detailed inventory of existing lighting equipment in each residence. With 1,009 participating households, and an inventory of over 25,000 lamps taken, this survey provides the most comprehensive residential lighting data to date.

The survey was conducted by trained evaluators who recorded an inventory of all the accessible lamps in each household. Data was collected by room for four different lamp types, and included the wattage and number of lamps. Information about the type of fixture, switch for each lamp, and estimated hours of use was also collected for the primary living spaces of each residence.

The paper presents the methods and results of this survey. Penetration rates for the various lamp types (i.e., incandescent vs. fluorescent, incandescent flood lamps, and compact fluorescents) are reported. A summary of the customers' indicated use of lights by room and lamp type is also presented. An accurate profile of the residential lighting load, as well as an estimate of the average household energy consumption due to lighting, is presented. Finally, the detailed nature of the data allows us to give an estimate for the potential for retrofitting energy efficient lighting technologies in the residential sector.

Introduction

In 1991, a survey was conducted to determine what types of energy using appliances are most typically found in Northern California homes. As part of that survey, a detailed inventory of lighting equipment located in the homes was taken. Over 1,000 households were chosen in a stratified sample method, representing a service area of 3.9 million utility customers. The number of lamps and the nominal power was recorded for lamps in each room in the house. The type of switch used on the circuit, the fixture type, and the hours of use were recorded for high use areas. This paper presents the results of this survey, and estimates for typical residential connected lighting load and annual energy consumption. Finally, a preliminary analysis of the technical potential for compact fluorescent retrofits in the residential market is presented.

Survey Methods

Sample Selection and Marketing

A two-stage random sampling method was used to choose the 1000 survey participants. In the first stage, 250 customers were selected using simple random sampling from the utility's database of residential customer households. These 250 customers were used to define "areas" in the service territory. Each area was defined as the utility's meter reading route that included that customer's account.

The second stage involved the random sampling of forty customers within each area to form call lists for telemarketing. Customers were called in a random order until a quota sample of four customers were found that could participate in the study. In many cases, more than four appointments were made to allow for cancellations and "no-shows".

As in nearly all survey projects, trade-offs were made between keeping the cost of the surveys reasonable and having a sample that is free from any bias. The two-stage sampling method helped keep costs down by allowing a surveyor to complete four to five surveys in an area on the same day. Certain customers either did not want a survey performed on their home or were not available during the surveying period. This creates the possibility of a selection bias.

Efforts were taken to insure that the selection bias had as little impact on the results as possible. Telemarketing calls and survey appointments were made during daytime and evening hours, on both weekdays and weekends.

Customers were not told the specific objectives of the study. Telemarketers said only that a survey was being conducted to help the utility plan their residential programs and that a representative would visit their home. The two-stage sampling method insured that customers who would not, or could not participate were replaced with customers from the same or nearby neighborhoods.

We believe that the results of the survey are not significantly affected by any selection bias. However, this can be tested by comparing distribution of energy consumption for our sample to that of the overall population. Plans to perform this test are under consideration.

The Survey

Evaluators collected two types of data for all the rooms in each household. These included the number of lamps present, and the nominal power of the lamps. These data were also recorded under the type of lamp used in that area. Thus the number of fluorescent, compact fluorescent, incandescent, and incandescent spot or flood lamps in each room was recorded. Because there were more incandescents, two entries per room were included, as well as a "miscellaneous" category for anything not suitable or secondary to the above mentioned groups.

Additional data was taken for what were considered high use areas. Evaluators collected customers' estimates of daily use for each lamp, as well as the type of fixture and switch that was used for each lamp in these areas. Additional data was recorded for the hall, living room, kitchen, dining room and outdoor areas.

Weighting

The results for the 1,009 participating households were weighted to represent the total 3.9 million customers in the service territory. Weights were assigned to each area depending on the actual number of surveys in that area as compared to the expected number of surveys in the area based on population.

Sample Description

Most of the homes surveyed were one-story, single family homes between 800 and 2,000 square feet. A distribution of the size of the residences is shown in Figure 1. Single family homes made up 74% of the total, with multi-family dwellings comprising 22%, and mobile homes accounting for 3%.

Survey Results

Summary Information

A summary of the lighting inventory results is shown in Table 1. This table shows, by room and lamp type, the weighted number of respondents in each category. It also gives the average number of lamps, and the average number of watts for these lamps. The average use is also shown for the five high use areas for which data were collected. The columns containing averages only include the respondents in a given category (i.e., zeroes were skipped).

According to the survey, the typical home is lit primarily with incandescent lamps of about 60W--75W each. Fluorescent fixtures were common in kitchen and garage areas and were usually of the 4 ft--40W variety. Incandescent spot lights were most common in outdoor areas where they had an average size of about 100W. On average, one compact fluorescent lamp was found in half of the homes surveyed. That they were being used in these homes shows that progress has been made towards the acceptance of this new technology in the residential market.

Figure 2 shows the penetration for the various lighting types in the survey. Incandescents (excluding spot and flood lamps) made up the largest group with a penetration of 78.4%. Fluorescent fixtures were the second most common (9.0%) followed by incandescent spot and flood lamps (5.9%), miscellaneous (5.1%) and compact fluorescents (1.9%).

Switch Type

Most of the lamps identified through the survey were on standard wall switches. Data on switch types were recorded primarily to differentiate between locations where compact fluorescent lamps could be retrofitted and applications where they would not be suitable, such as circuits on dimmer switches. Although dimmable compact fluorescent lamps are becoming available, current costs are very high and availability is limited. Switch type was only recorded for the five high use areas in the survey, the hall, living room, kitchen, dining room and outdoor areas. Wall switches were used with 86.4% of the lamps surveyed, versus 6.6% using dimmer switches, 5.2% three way switches, 1.1% photocells and 0.7% on timers.

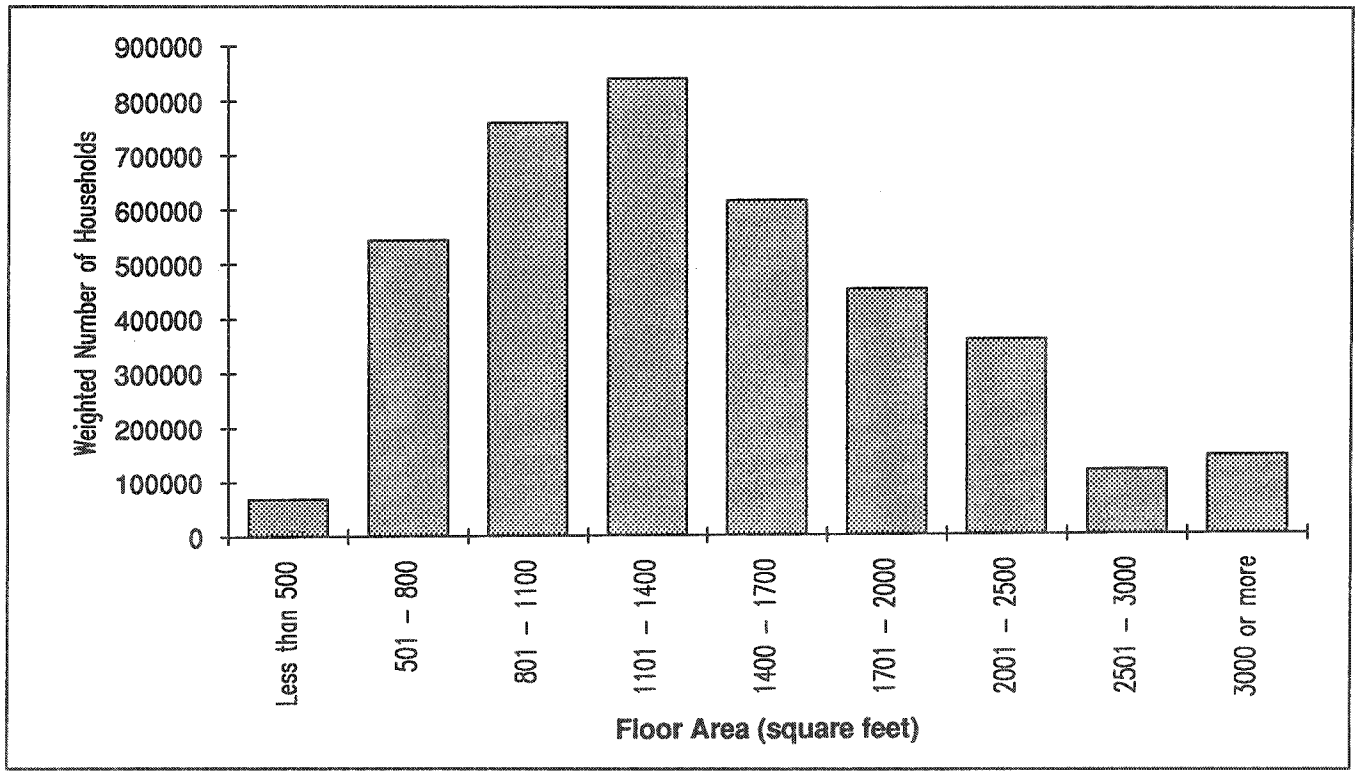

Figure 1. Distribution of Residence Size

Because only a small fraction of the switches (6.6%) were dimmers, this should not be a major barrier to the installation of compact fluorescents in residential applications. Dimmers were most commonly used in dining room applications where they made up 22.7% of all the switches.

Fixture Type

Most of the lamps in the survey were in ceiling fixtures. The type of fixture in which each lamp was located was recorded for the five high use areas; hall, living room, kitchen, dining room and outdoor areas. Ceiling fixtures accounted for 54.2% of all the lamps in the high use areas. Wall fixtures and free-standing lamps accounted for almost equal percentages, with 20.2% and 19.9% of the sample, respectively. Task lamps (desk and reading lamps) made up the remaining 5.8% of the lamps in these areas.

Ceiling fixtures were the predominant type in the hall, kitchen and dining room areas, accounting for more than 80% of the fixtures. Free-standing lamps were the most common type in the living room area, where they accounted for 66% of all fixtures. Outdoors, most of the lamps (85.7%) were in wall fixtures.

Residential Lighting Load

Given the detailed nature of the survey data collected from each household, an accurate depiction of the residential lighting load can be determined. The kW load for each lamp type in each room was calculated for every survey participant. The load was calculated by multiplying the number of lamps by the wattage for that lamp type, and dividing by 1,000. The results of the load calculation are shown by room and lamp type in Table 2.

The average total connected household lighting load for the customers was 1.8 kW. The largest portion of this load was in the bedrooms (21% of the total load). However, this may have resulted from survey entry limitations. Only one entry was provided for each type of bedroom lighting and may have actually been used to represent several bedrooms.

Incandescent lamps accounted for 79% of the total connected lighting load. The greatest incandescent load was in the bedrooms, bathrooms and living rooms. Incandescent spot or flood lamps represented about 8.4% of the total load, and were located predominantly outdoors. The load due to fluorescent lamps was greatest in the kitchen and garage areas and was about 7.6% of the total load.

Table 1. Summary of Existing Lighting Equipment

	Bath	Bed	Dining Room	Garage	Hall	Kitchen	Living Room	Other	Outdoor	Total
Fluorescent										
Weighted No. of Responses	314,324	182,247	79,726	1,053,978	70,098	1,597,045	126,488	234,258	48,507	3,706,671
Ave. No. of Lamps per Household	0.249	0.114	0.046	1.083	0.039	1.360	0.063	0.208	0.031	3.193
Ave. Watts per Lamp	38.0	37.7	38.0	46.6	48.9	39.2	47.3	38.8	35.8	41.1
Ave. Daily Use (hrs)	n/a	n/a	3.0	n/a	2.6	4.2	3.6	n/a	5.4	3.8
Compact Fluorescent										
Weighted No. of Responses	152,885	190,048	62,008	138,411	48,022	273,122	172,569	169,438	73,150	1,279,653
Ave. No. of Lamps per Household	0.098	0.083	0.044	0.051	0.017	0.100	0.064	0.072	0.022	0.552
Ave. Watts per Lamp	21.1	20.1	20.2	19.0	19.6	20.2	19.5	19.4	19.1	19.8
Ave. Daily Use (hrs)	n/a	n/a	5.2	n/a	1.6	2.7	4.7	n/a	3.0	3.5
Incandescent 1										
Weighted No. of Responses	3,647,947	3,573,958	2,622,374	1,627,235	3,261,905	2,928,934	3,555,320	1,451,213	3,128,193	25,797,079
Ave. No. of Lamps per Household	3.041	3.052	2.412	0.675	1.685	1.533	1.918	0.811	1.585	16.713
Ave. Watts per Lamp	65.6	69.2	56.3	82.0	62.6	72.2	78.7	72.2	63.8	69.2
Ave. Daily Use (hrs)	n/a	n/a	2.3	n/a	1.7	3.6	3.2	n/a	2.7	2.7
Incandescent 2										
Weighted No. of Responses	1,198,334	3,879,565	565,394	279,021	948,378	1,084,054	2,007,257	515,833	955,420	11,433,256
Ave. No. of Lamps per Household	0.866	1.618	0.417	0.113	0.513	0.416	0.917	0.280	0.463	6.378
Ave. Watts per Lamp	64.2	69.9	60.5	79.9	60.0	67.7	80.8	76.0	66.5	77.1
Ave. Daily Use (hrs)	n/a	n/a	1.8	n/a	1.5	2.6	2.6	n/a	2.4	2.2
Incandescent Spot/Flood										
Weighted No. of Responses	275,481	230,479	122,519	66,663	128,727	231,514	443,110	136,394	826,187	2,461,074
Ave. No. of Lamps per Household	0.149	0.160	0.083	0.026	0.108	0.161	0.329	0.099	0.614	1.730
Ave. Watts per Lamp	137.5	72.8	65.3	89.4	75.2	79.4	74.3	84.2	103.4	86.8
Ave. Daily Use (hrs)	n/a	n/a	1.7	n/a	1.9	3.3	2.9	n/a	1.8	2.3
Miscellaneous										
Weighted No. of Responses	177,347	462,415	169,623	106,658	114,640	314,989	761,138	142,705	262,570	2,512,085
Ave. No. of Lamps per Household	0.106	0.199	0.180	0.059	0.090	0.146	0.382	0.065	0.137	1.364
Ave. Watts per Lamp	76.1	77.7	38.6	41.7	57.6	35.1	82.8	94.6	124.4	69.8
Ave. Daily Use (hrs)	n/a	n/a	2.0	n/a	2.0	3.3	2.5	n/a	5.1	3.0

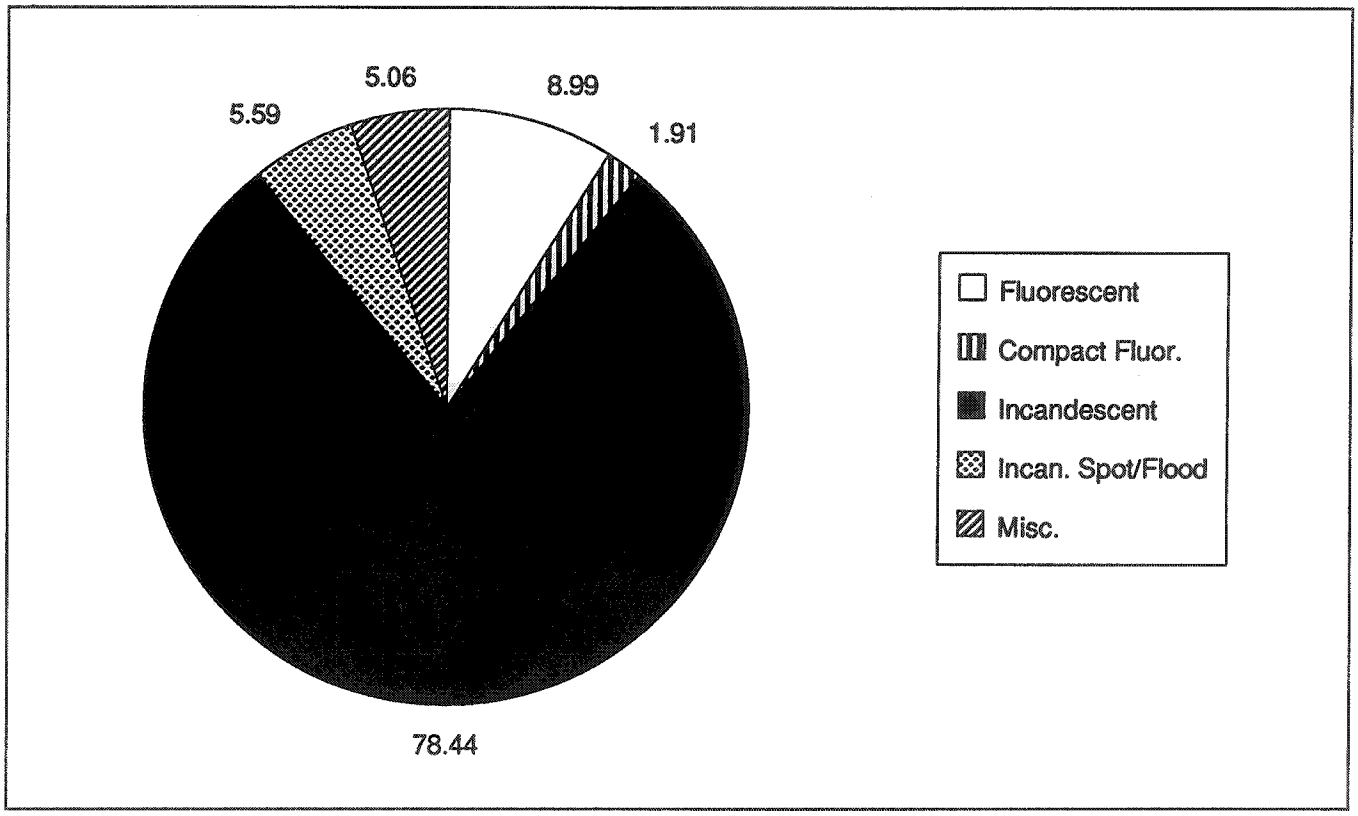

Figure 2. Most Existing Lamps Were Incandescents

Miscellaneous lamps made up 4.6% of the total. The smallest load was attributed to compact fluorescents, with 0.5% of the total load. A profile of the residential load by room and by lamp type is shown in Figure 3. The load graphed in the figure is the weighted average load including all the households, whether or not they had a particular appliance (i.e., zeroes were not skipped).

An average estimate of lighting load per square foot was also calculated. The survey classified homes into four types; single family, multi-family, mobile homes, and other. Single family homes had an average size of 1600 square feet, with an estimated average lighting load of 1.25 W/sf. Multi-family homes averaged 950 square feet, and had an average lighting load of 1.18 W/sf. There were only three respondents in the "other" category,

Table 2. Mean Connected Lighting Load (kW)

	Bath	Bed	Dining Room	Garage	Hall	Kitchen	Living Room	Other	Outdoor	Total
Fluorescent	0.010	0.004	0.002	0.050	0.002	0.054	0.003	0.009	0.001	0.135
Compact Fluor.	0.001	0.002	0.001	0.001	0.000	0.002	0.001	0.001	0.000	0.009
Incandescent 1	0.178	0.197	0.105	0.054	0.094	0.100	0.136	0.052	0.097	1.013
Incandescent 2	0.047	0.154	0.018	0.008	0.026	0.027	0.064	0.018	0.027	0.390
Incan. Spot/Flood	0.019	0.011	0.005	0.002	0.007	0.013	0.021	0.007	0.063	0.149
Miscellaneous	0.007	0.013	0.006	0.003	0.004	0.005	0.026	0.006	0.013	0.082
Total	0.262	0.382	0.137	0.117	0.133	0.201	0.252	0.093	0.201	1.779

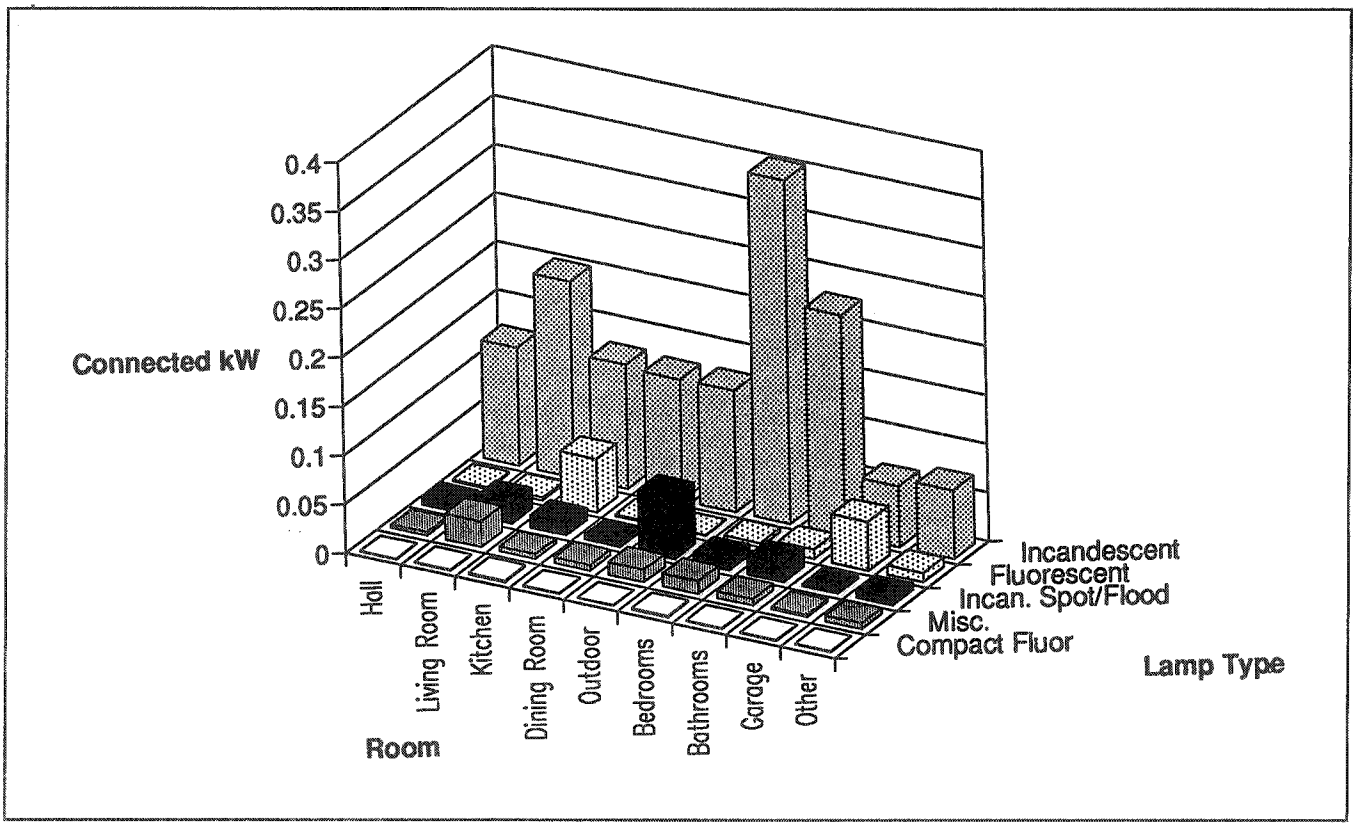

Figure 3. Profile of Mean Lighting Load per Residence (by room and lamp type)

which had an average size of 830 square feet and an estimated average load of 1.09 W/sf. The overall average dwelling size, without regard to type was 1400 square feet, and had an estimated average connected load of 1.24 W/sf.

Residential Lighting Energy Consumption

An estimate of the residential lighting energy consumption was also obtained from the collected data. Survey participants were asked to estimate the number of hours per day they used lights in the high use areas. These areas included the hall, living room, kitchen, dining room and outdoors. In the remaining areas (bedrooms, bathrooms, garage and other), a default value of two hours per day was used. It was also assumed that the daily use estimates would only be applied to 6 out of 7 days a week, to take in to account time spent away from the home.

Given the reported data and the assumptions above, the average annual lighting energy consumption per household was calculated to be 1,270 kWh. This average includes all households, whether or not they had a particular appliance (i.e., zeroes were not skipped). A summary of the average consumption by room and lamp type is given in Table 3. This information is also shown graphically in Figure 4.

DSM Potential Analysis

This section presents the results of a preliminary estimate of potential lighting savings. The estimates below represent an initial rough estimate using only two types of compact fluorescent retrofits. The compact fluorescent retrofit was chosen for this analysis because it offers significant potential for load reduction and energy conservation, as well as being cost-effective to both the customer and society. In addition, compact fluorescent lamps are becoming widely available at reasonable costs to customers. Current utility rebates and information programs for these lamps continue to make them even more accessible. New developments in compact fluorescent technology can be expected to further increase the number of applications for which they can be used.

The results shown in this section represent the maximum technical potential for residential application of compact fluorescent retrofits. These results are not intended to represent economic or program achievable savings.

Table 3. Mean Connected Lighting Load (kW)

	Bath	Bed	Dining Room	Garage	Hall	Kitchen	Living Room	Other	Outdoor	Total
Fluorescent	6.2	2.7	2.1	31.0	1.3	71.9	3.2	5.8	1.0	125.2
Compact Fluor.	0.8	1.0	1.3	0.5	0.1	1.7	1.5	0.8	0.5	8.0
Incandescent 1	111.4	123.6	75.2	34.0	40.2	110.7	129.8	32.5	70.0	736.3
Incandescent 2	29.6	96.5	9.2	4.9	12.1	22.0	51.2	11.1	10.1	255.9
Incan. Spot/Flood	12.0	6.8	2.6	1.5	4.5	13.2	18.1	4.4	26.9	90.2
Miscellaneous	4.3	8.2	3.1	1.6	2.0	5.6	20.5	3.7	9.4	58.5
Total	164.3	238.9	93.4	73.5	69.3	225.1	224.3	58.4	127.0	1274.1

We have used a conservative approach by only including compact fluorescent retrofits for this analysis. Certainly a much larger potential exists if other measures are included. A few measures that might be considered include: (1) Converting standard fluorescent lamps to T-8 lamps with electronic ballasts, (2) Delamping fluorescent fixtures and adding specular reflectors, (3) Converting incandescent flood lamps to compact fluorescent or halogen floods, and (4) Adding occupancy sensors or photocells to existing circuits. The compact fluorescent retrofit clearly represents the greatest potential impact, and has been shown to be universally cost-effective in high use areas.

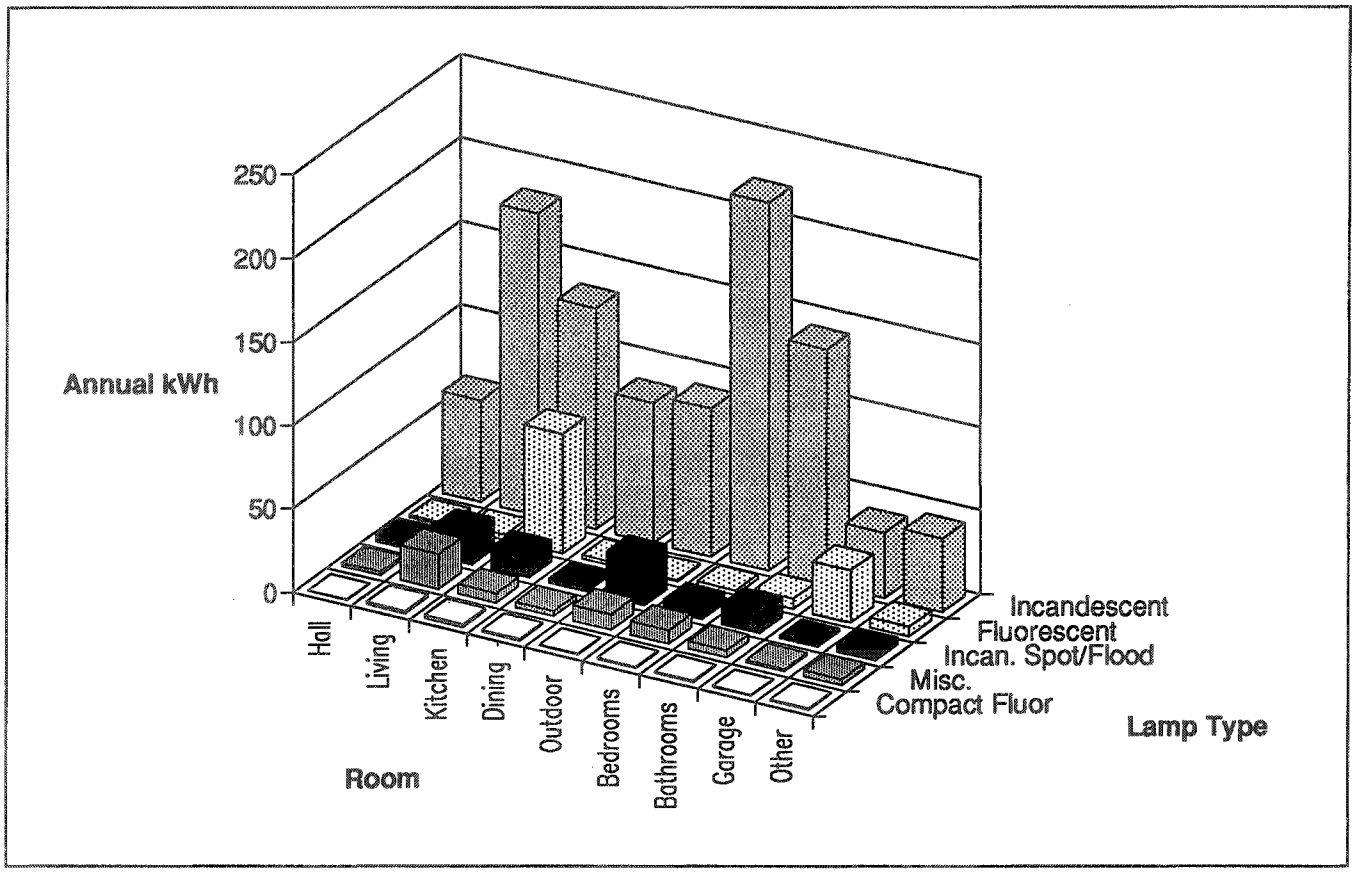

Figure 4. Summary of Lighting Load Energy Consumption (by room and lamp type)

Estimation Method

The retrofit potential for compact fluorescent lamps was estimated by considering only technologies that are currently available. As new products enter the market, this potential will undoubtedly increase.

The retrofit potential was calculated by considering only two types of retrofits. It was assumed that an 18W compact fluorescent lamp could be substituted for any incandescent lamp greater than 30W and less than 100W. For incandescents greater than 100W and less than or equal to 135W, it was assumed that a 28W compact fluorescent lamp would be suitable. These conversions were simulated in all the available incandescent lamps except spot or flood lamps. A further exclusion was made for those lamps on circuits with dimmer switches. The total number of possible retrofits was tabulated, as well as the load reduction and energy consumption for each one.

The estimate of potential savings was refined further by taking into account the feasibility of the retrofit in terms of size limitations. Currently available compact fluorescent lamps will not fit in every application where they might otherwise be acceptable. If a customer had all the leading edge technologies at his/her fingertips, this feasibility might be very high, or even 100%. However, the lamps now available in local hardware and retail lighting equipment stores do not fit in many residential fixtures. For this reason, we have applied a 50% feasibility factor to the estimates.

Number of Possible Retrofits

Given the above assumptions we estimate that in the weighted population of 3.9 million customers, a total of 34 million compact fluorescent lamps could be installed. This implies an average of 9 compact fluorescent lamps in each household. Note that this figure includes all the retrofits that are technically feasible, including some low-use lamps for which the retrofit would not be cost-effective. The average number of possible retrofits per room is shown in Figure 5.

Potential Connected Load Reduction

A substantial load reduction is possible with the compact fluorescent retrofit. In the weighted population of 3.9 million customers, the total reduction would be 1,600 MW of the total connected lighting load. The actual diversified effect of this load reduction on the peak would be much lower. The estimate represents an average household reduction of 0.410 kW, or 23% of the total lighting load. A summary of the kW reduction by room is shown in Figure 6.

Potential Energy Consumption Reduction

A large impact on residential lighting consumption could be made with the compact fluorescent retrofit. A total reduction of 1,200 GWh annually could be achieved in the total weighted population of 3.9 million customers. This represents an average household saving of 290 kWh annually, or 23% of the total consumption for lighting. The savings would amount to an average bill reduction of about $2.50 per month for each household. This estimate assumes that the current reported hours of daily use would not change after the retrofit. In other words, it does not take into account any "customer take back," or customers choosing to take part of the benefits in increased use of the lamps.

Conclusion

The residential lighting load in Northern California is primarily due to incandescent lighting. The average home has roughly 25 incandescent lamps, which make up about 80% of the lighting load. Because of the large number of incandescent lamps, a vast potential exists for installing compact fluorescent lamps. There are some barriers to retrofitting compact fluorescents such as size limitations and dimmer switches. However, even with these limitations, the residential market presents a great opportunity for energy efficient lighting improvements.

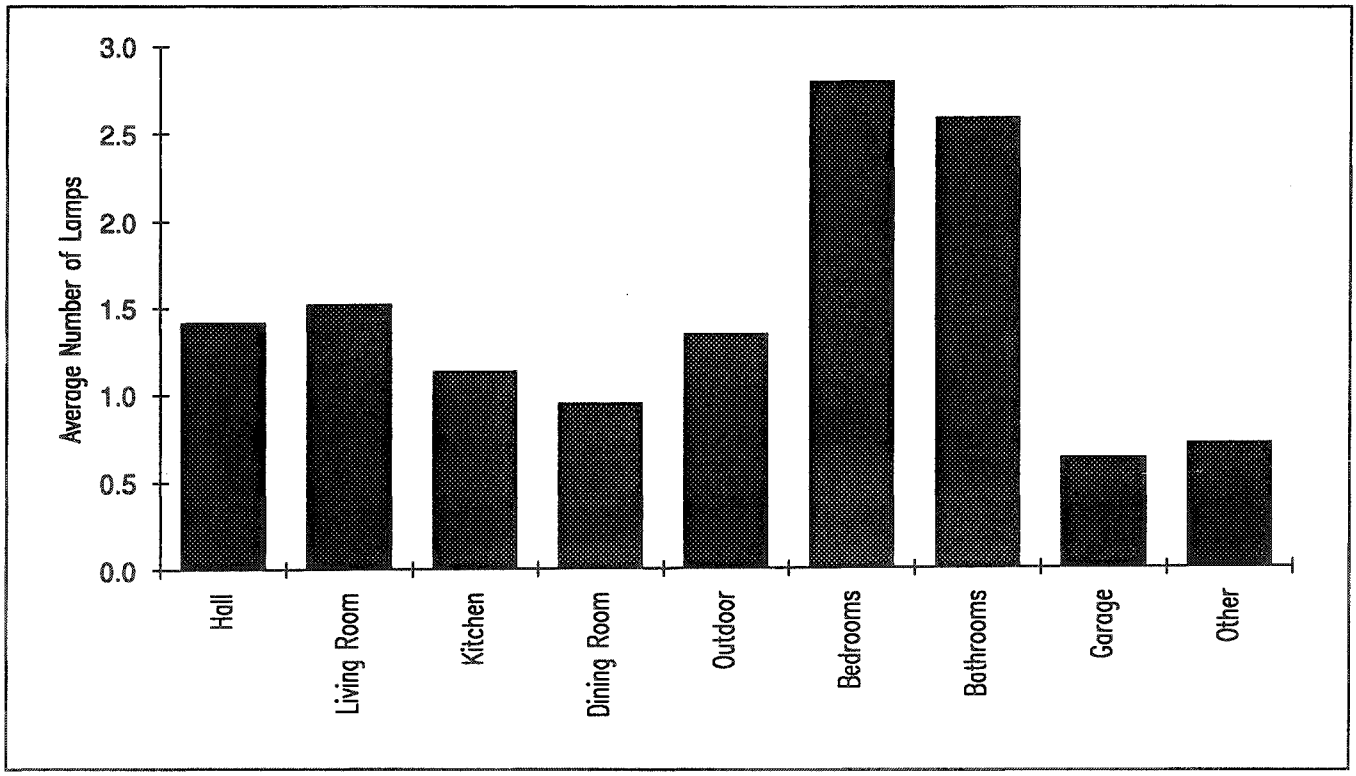

Figure 5. Compact Fluorescent Retrofit Potential (by room)

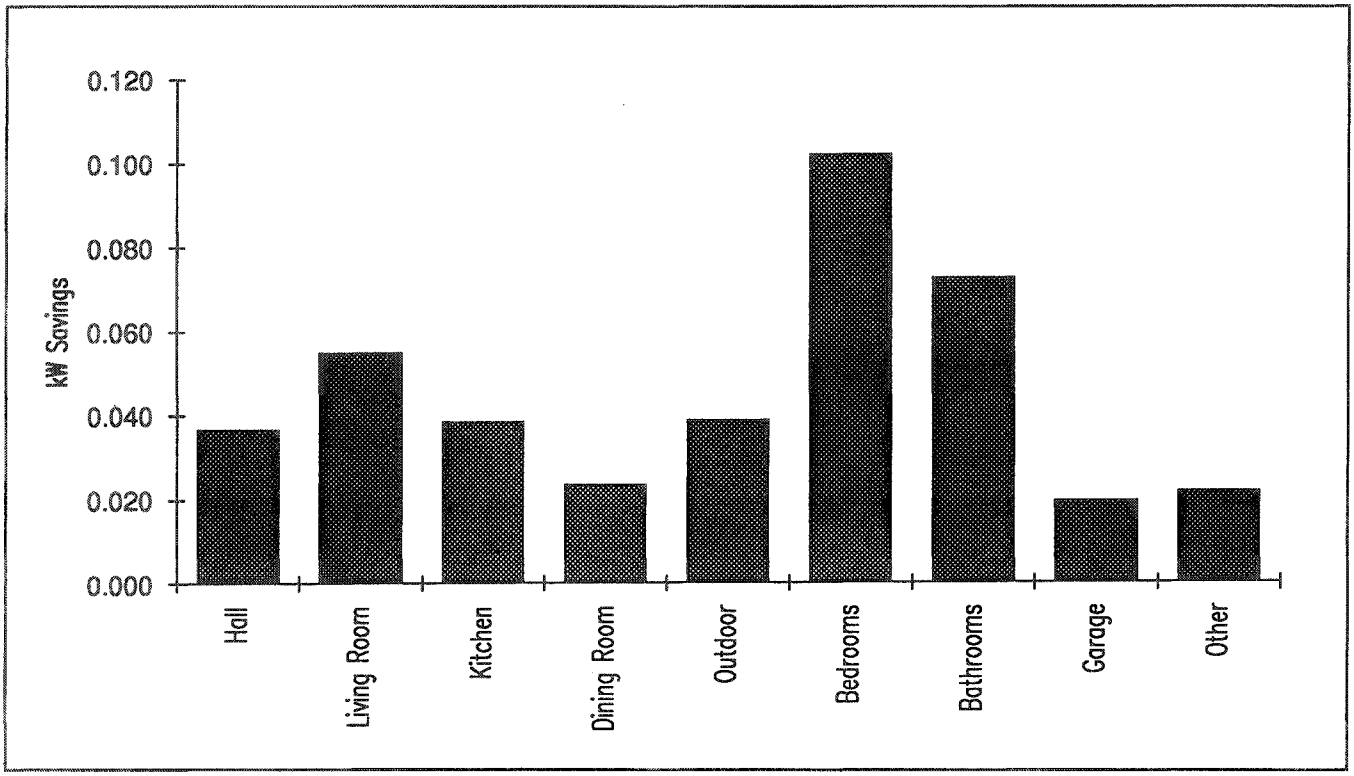

Figure 6. Compact Fluorescent Retrofit Load Reduction Potential (by room)