# Light *and* Heat: An Exterior Lighting Metering Study Using Both Light and Temperature Loggers

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## ABSTRACT

This paper presents the methodology and results of a residential exterior lighting metering study conducted by KEMA on behalf of Southern California Edison that utilized both light and temperature loggers. We present background information about metering studies that have estimated residential lighting usage in the past and then discuss sampling, instrumentation, implementation, data cleaning, analysis and results. The focus of the paper is on methodology, rather than results, in order to provide guidance to other researchers hoping to conduct future exterior lighting metering studies.

Metering studies present numerous challenges. Usage varies widely across applications, and upstream programs lack customer contact information, necessitating carefully constructed sample frames. Meters must be installed in a manner that minimizes light contamination (and temperature contamination). Once the data are collected they require significant cleaning and analysis. Beyond the considerable challenges of an interior metering study, exterior metering presents problems of its own. Because natural light is less controlled, avoiding light contamination and cleaning data can pose serious problems. Most lighting loggers are susceptible to water damage, and thus cannot be placed in locations that are subject to precipitation or irrigation. While there are significant challenges associated with metering exterior lighting, the use of temperature loggers allows access to fixtures that cannot be metered by traditional light loggers. This study was a step in the process of measuring hours of operation for exterior lighting, but future studies will need to refine the estimates further with a larger sample. Additionally, while this study validated temperature loggers as a methodology, future studies should directly compare measurements from light and temperature loggers.

## Introduction

Estimating energy savings requires an estimate of the hours of operation for both the standard equipment and the efficient equipment. Metering and self-report surveys are the two primary methods for estimating hours of operation for equipment. Metering studies are the more reliable and valid method for estimating hours of operation of lighting equipment, but metering studies are challenging and costly. Metering studies to assess hours of operation of exterior lighting are even more difficult because of additional challenges related to light contamination and instrumentation.

This paper presents the methodology used by KEMA to conduct an exterior lighting metering study on behalf of Southern California Edison and the results of the study. Because the hours of operation of exterior lighting are expected to be dependent on geographic variation in hours of daylight and other factors, and because there are significant challenges in conducting an exterior metering study, this paper will focus on the methodology used, challenges overcome and challenges that remain, rather than specific metering data results. Specifically, we will explain the use of both temperature loggers and light loggers for exterior metering. While installation of temperature loggers and interpretation of temperature loggers' data present new challenges, the use of temperature loggers allows researchers to monitor exterior fixtures that would otherwise be difficult or impossible to meter.

## Background

Lighting presents one of the major sources of potential for improved energy efficiency due to a combination of a relatively high share of residential electricity use and the wide availability of efficient replacements. Lighting consumes approximately 22% of a household's electricity (KEMA-Xenergy 2004). CFLs, linear fluorescents and other efficient technologies offer energy savings of roughly 75% with only a small premium on purchase price in many cases and longer life than standard incandescents.

Outdoor lighting represents about 15% of the total residential lighting load (Heschong Mahone Group 1999) and presents a substantial opportunity for energy efficiency because of high energy usage per lamp and lower aesthetic barriers. Exterior lighting is often high wattage in order to illuminate large areas, provide bright light from a small number of lamps or provide security. These lights are often left on for long periods of time because of photosensors and timers that dictate long hours of use during the night. There also may be lower barriers to adoption of efficient exterior lighting because the lamp itself is less visible, and precise technical requirements, such as color temperature and start-up time, may be less stringent.

Quantifying savings associated with efficient lighting requires quantification of the hours of operation. Hours of operation can be estimated based on reports from users, which is relatively easy to collect, or based on metering, which is much more difficult and costly to collect. Comparisons of the two suggest that the self-report method tends to overstate the hours of operation, and thus the energy savings, compared to metering. Vine and Fielding, in a review of residential lighting metering studies to assess best practices, recommend combining metering with self report survey work in order to use metering data to calibrate larger survey samples (Vine and Fielding 2005).

Metering studies present numerous challenges, including study design, implementation and funding, all of which are interrelated. Different applications for lighting, such as room type and fixture type, tend to have different hours of operation (as well as wattages), so that a comprehensive understanding of lighting behavior requires statistically valid estimates in many categories; even a single estimator requires appropriate weighting and distribution to be reliable. Often, CFL programs use upstream buy-downs and evaluators have no contact information for end users, which presents an additional challenge in constructing the sample frame. Once an appropriate sampling scheme has been created, there are significant challenges in collecting the metering data. The process for implementing the metering portion of a study requires recruitment of participants, lamp selection, meter installation and meter removal. Meters must be installed in a manner that minimizes light contamination (and temperature contamination) as problems with the installation can cause problems with data cleaning, or even lead to the data being unusable. Once the data are collected they require significant cleaning and analysis. Implementing all of these steps successfully requires significant cost, which is a challenge in and of itself.

Beyond the considerable challenges of an interior metering study, exterior metering presents problems of its own. Because natural light is less controlled, avoiding light contamination and cleaning data can pose serious problems. Most lighting loggers are susceptible to water damage, and thus cannot be placed in locations that are subject to precipitation or irrigation.

There have been numerous metering studies conducted in the past, but because of variation in lighting usage, metering studies from other areas of the country are not applicable to California. Geographic variation in hours of daylight is the most significant factor, but Vine and Fielding suggest other possible demographic, economic, and cultural factors, as well as differences in building stock, program and market characteristics (Vine and Fielding 2005).

While there have been numerous residential interior lighting metering studies in California, few direct empirical data exist regarding exterior lighting usage. For most interior lighting estimates in California the results of the "CFL Metering Study" are used (KEMA 2005). KEMA installed loggers on as many fixtures with CFLs as was possible in 369 homes across California's IOU territories. Lighting usage was monitored for between six months and one year on a total of 891 fixtures. KEMA only monitored interior CFLs, and hours of operation for exterior lighting were taken from the "Lighting Efficiency Technology Report Volume I: California Baseline" (HMG 1999). HMG performed a meta-analysis of data from three other studies, two from Southern California Edison, and one from Tacoma Public Utilities (TPU), which included exterior lighting. TPU had led a study of seven utilities in Washington and Oregon for the Bonneville Power Administration that included 2641 fixtures in 161 homes monitored for between 4 and 12 months. HMG notes that, while there was a large sample with a long monitoring period, the sample was not even representative of Northwest housing stock, and certainly not California housing stock. Thus, the data to support hours of operation of exterior lighting were outdated and not even gathered in California. KEMA and SCE endeavored to take a small step to address the lack of data with this project, with the hope of testing a methodology that could be used in future exterior lighting studies.

## Design

To ensure that the metering study results were as useful and robust as possible, the sampling needed to have appropriate coverage of various categories. The sample had to be stratified to contain

- urban, suburban and rural usage in various parts of SCE's territory;
- both CFLs and incandescents;
- various control types (on/off switch, photo sensor, photo sensor with motion detector, timer); and
- various location types (walkway, patio, landscape and entry).

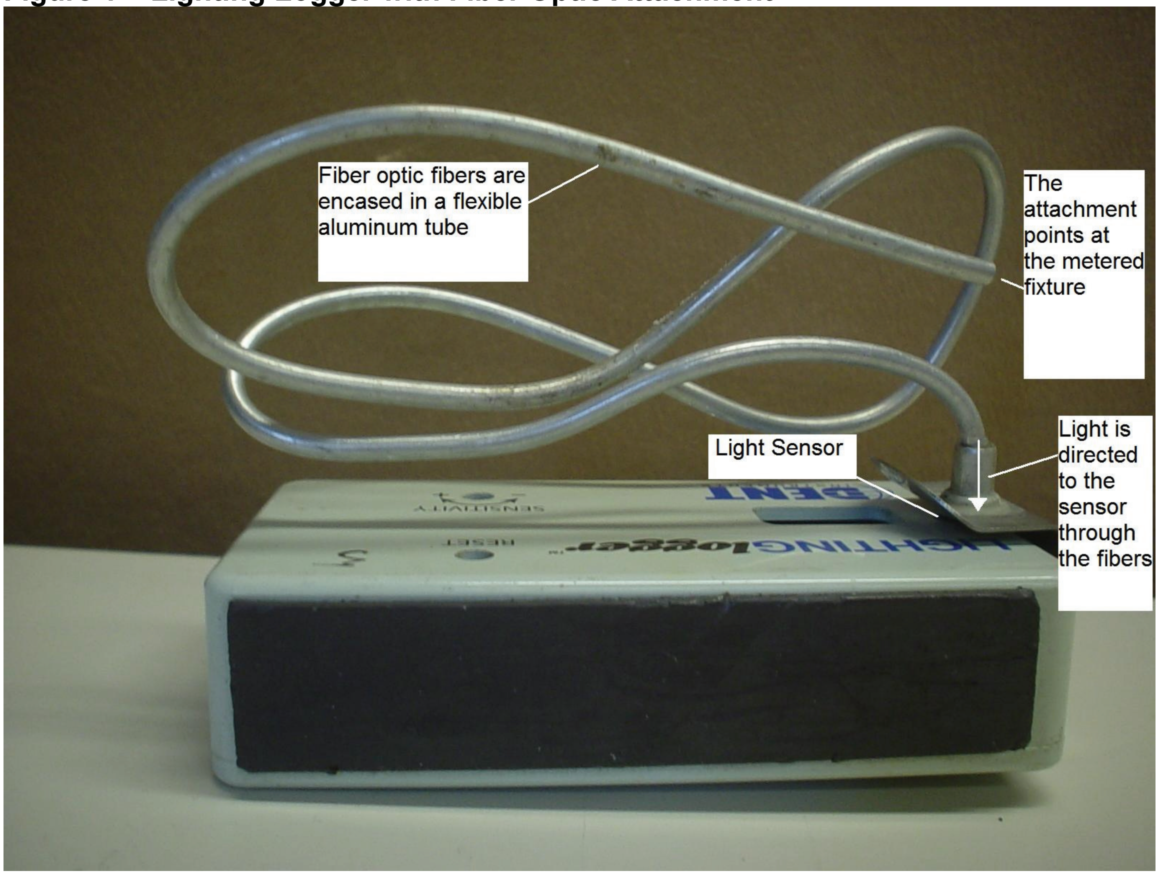
Zip codes were assigned to five categories: non-rural Los Angeles county west of Interstate 5; non-rural San Bernardino, and Riverside Counties and Los Angeles County east of Interstate 5; Orange County; all other non-rural areas; and rural areas. The metering sample also needed to be spread out to cover seasonal variation in lighting usage. We drew a random sample of zip codes from which we recruited 124 sites. We screened to ensure each site had exterior fixtures, and that there would be sufficient breadth of lamp, location and control types in the sample.

Sites were recruited in two waves by Itron through their computer-assisted telephone interviewing facility. The first wave was recruited in conjunction with the 2004-05 Single Family Energy Efficiency Rebate Program evaluation, and survey respondents were asked to participate in the study for an additional incentive. The second wave of recruitment was conducted exclusively for this study.

## Instrumentation

KEMA used two types of loggers for the project, DENT SmartLogger lighting loggers and HOBO Pro v2 temperature loggers with two exterior temperature leads. KEMA has used lighting loggers extensively in past lighting monitoring projects. While the devices perform reliably in interior conditions, there was concern about the possibility of daylight interference for exterior applications. Two measures were taken to address this issue. The first was the use of fiber optic attachments for the light loggers. These attachments can be bent to point directly at the fixture and transmit the light (via fiber optics) to the sensor. When field staff had difficulty adjusting the logger to pick up only light from the fixture, a fiber optic attachment often solved the problem. Figure 1 shows a lighting logger with the fiber optic attachment attached.

**Figure 1 – Lighting Logger with Fiber Optic Attachment**




When the fiber optic attachment was not enough to solve the problem, field staff turned to the temperature loggers. In some cases, the design of the fixture made installing a light logger extremely challenging, and the temperature logger provided an alternative approach. The temperature leads were six feet long, so the logger could be positioned at a distance from the fixture with only the small lead placed near the lamp. Also, unlike the light loggers, the temperature loggers were waterproof, making it possible to install them in exposed locations where they might be exposed to rain and landscape applications where irrigation was an issue.

Because temperature loggers had not previously been used in lighting metering studies, this study deployed them only on a limited basis as proof-of-concept. The loggers have two temperature leads and record a data series for each lead. We posited that by measuring both the temperature near the lamp and the ambient temperature, the temperature differential could be used to determine when the light was on. The approach was tested on a limited basis with two loggers before we committed to purchasing additional loggers for the study.

One of the limitations of the temperature loggers was in data storage capacity. Unlike light loggers, which only record on-off events, temperature loggers are set to record the temperature at specified time intervals, which requires much more device memory. The temperature loggers can record almost 22,000 observations before running out of memory. The period of time for which observations could be recorded depended on the frequency of the observations. Short intervals would give better data resolution, but at the expense of shortening the metering period. Longer intervals risked missing short on/off cycles. In the end, we opted for 5-minute intervals, yielding 74 days worth of data. This was not enough to cover the full planned 3-month deployment for the loggers between downloads, but provided acceptable resolution. The deployment periods were not adjusted (since temperature loggers were a minority of total loggers) resulting in data gaps between the first and second monitoring periods. These gaps were addressed during the analysis when we seasonalized the data to yield monthly and annual average usage estimates.

Temperature loggers can experience interference similar to the daylight interference experienced by light loggers. Thermal interference occurs when one or both temperature leads are in direct sunlight for part of the day, heating up them up relative to the ambient air temperature. While many fixtures are sheltered from direct sunlight, and careful installation can mitigate this problem in exposed locations, care must nonetheless be taken in analysis.

The temperature loggers used for the study were also more expensive than the light loggers used. This factor could be significant for future studies contemplating mass deployment of temperature loggers.

A final issue discovered with the temperature loggers was that in a disappointingly high percent of loggers one or both of the temperature leads failed to record temperatures correctly, for at least some range of temperatures. In some cases a lead recorded -139 degrees Fahrenheit for the entire period; for others, the device would fail to record the correct temperature when the temperature rose above or fell below a certain threshold. This was a clear equipment quality control issue. For future purchases, we recommend testing the devices at a range of temperatures prior to deployment.

## Implementation

We installed light or temperature loggers on approximately two exterior fixtures at each of the 124 sites. If there were more than two exterior fixtures at a site, loggers were placed first based on the control type for which the site was recruited (e.g. a site that was specifically recruited because it had a motion sensor). Subsequent loggers were distributed to achieve an approximately equal distribution of entry, patio, landscape and walkway lighting.

Approximately three months after the initial installation, sites were revisited to conduct an initial data download and verify the quality of data. Field staff removed the loggers, downloaded and viewed the data. They reviewed the data to determine if there were any problems with the logger, such as positioning or if the logger was picking up daylight interference. If necessary, the sensitivity of the logger was readjusted and the logger was reinstalled.

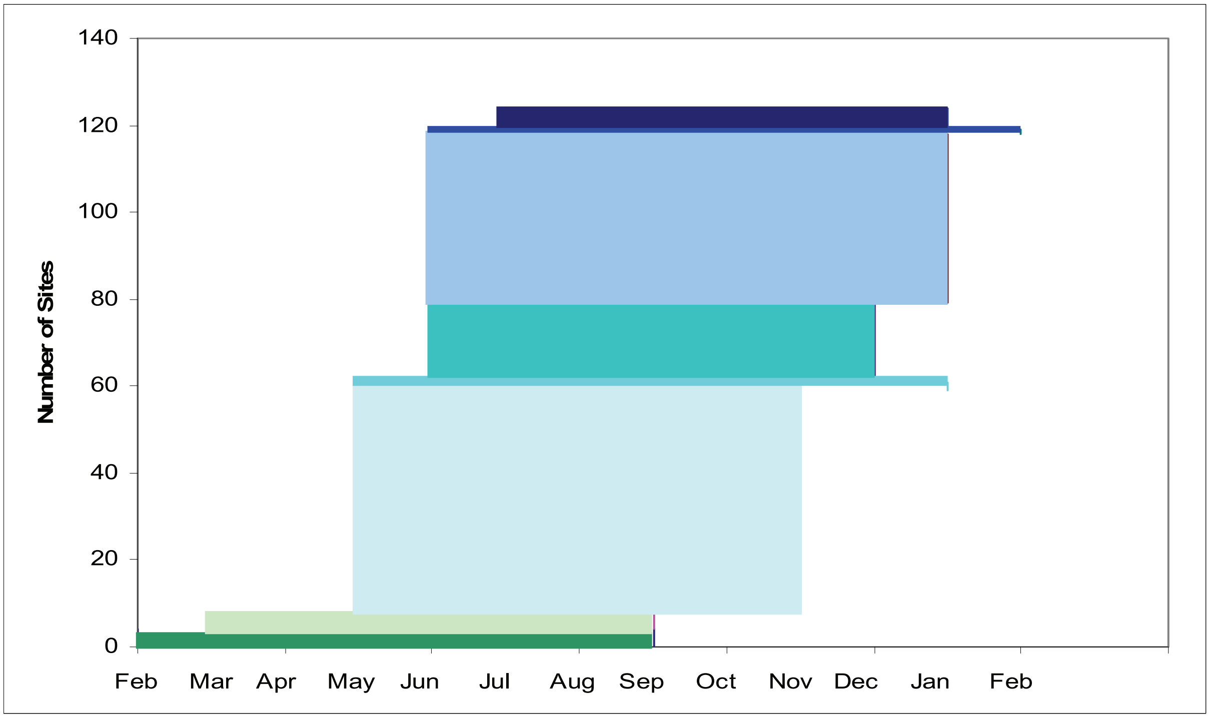
The original work plan called for removing loggers after six months, which would have resulted in all the loggers being retrieved by early November. In November, we decided to extend the metering period for the meters that were still in place in order to represent winter usage more accurately. With the participants' permission, metering was extended for up to two months.

Participants were given the option of removing both light and temperature loggers and returning them by mail (in a self-addressed, postage-paid, padded envelope provided by KEMA), or having an auditor come to remove the device. The majority of participants returned the loggers by mail.

Loggers were installed and removed on a staggered schedule: The first loggers were installed in February 2007, and the last loggers were removed in February 2008. With the extension of the metering period, some loggers were left in place as long as eight months.

Figure 2 shows the final timing of the rolling installations, with the timing and duration of the installations shown on the horizontal dimension and the number of sites shown in the vertical dimension.

**Figure 2 – Metering Schedule**




## Inventory and Survey

During our first visit to each site, in addition to installing light loggers on fixtures, we also captured a detailed inventory of exterior lighting and interviewed residents regarding fixtures with CFLs. For every exterior fixture at each site, field staff recorded the location, mount, lamp base, wattage, lamp type, control type, and self-reported hours of use or timer settings. For CFL fixtures, residents gave reasons for satisfaction or dissatisfaction with the bulb, and were asked to recall what lamp type was there before the CFL, whether controls were used before, and if so, whether the use of controls was changed after the CFL installation.

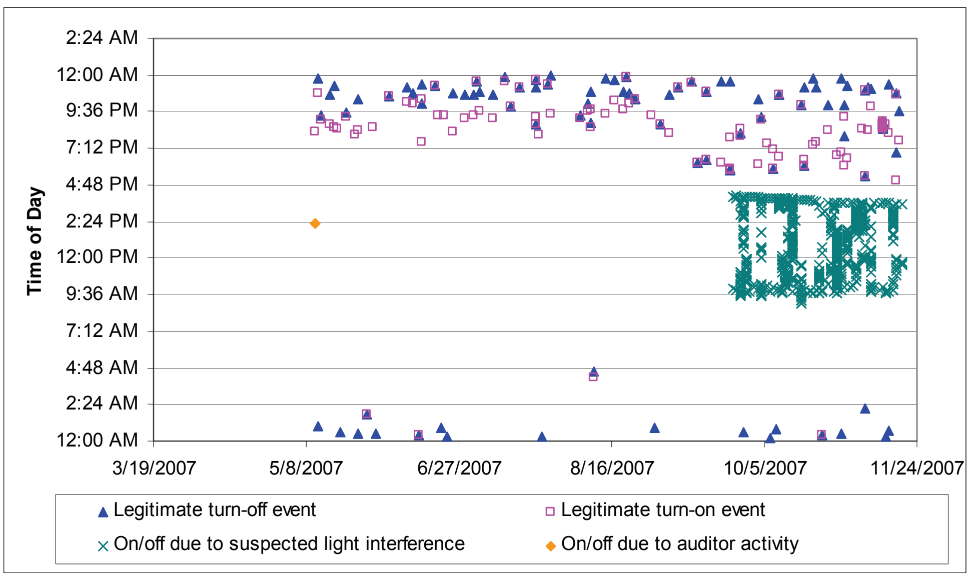
## Data Cleaning

Once the data were collected, the cleaning of the data began. The science of cleaning the data demands a healthy dose of art as well, and requires a significant amount of analysis. Analysts looked for issues such as breaks in usage patterns, daylight interference, and agreement with homeowner-reported usage. For temperature loggers, an analyst developed algorithms to translate temperature differentials into on/off periods.

Light logger data were cleaned to distinguish light contamination and instrumentation problems from actual usage. Loggers that recorded a break in the usage pattern were flagged for additional review. In many cases, the break coincided with the date that an auditor downloaded the first three months of data and reinstalled the logger. In some instances, auditor notes indicate that the logger was recalibrated at the download visit. In most cases this resulted in more accurate data for the second metering period, but in a few cases the auditor, in an effort to screen out daylight, reduced the sensitivity too far to accurately record usage. Marked changes in usage occurring between auditor visits were examined carefully and attributed either to the logger becoming displaced, or to actual changes in usage.

Daylight interference occurred if the auditor was unable to adjust the logger sensitivity to screen out daylight completely. Loggers with light interference were identified through a review of graphed on/off data. Daytime on-offs that occurred day after day during the same time period were deemed to be due to light interference. In many cases, the recorded light interference began or ended with an auditor visit. For other fixtures, daylight interference began or ended independent of any action by the auditor, possible due to the interaction of the angle of the sun with physical obstructions such as porch supports or roof overhangs. Daytime on-offs that were not regular (did not occur on the vast majority of days and/or did not occur in the same time window) were deemed to be legitimate fixture usage. **Error! Reference source not found.** shows an example of light interference.

**Figure 3 - Example of Lighting Interference**

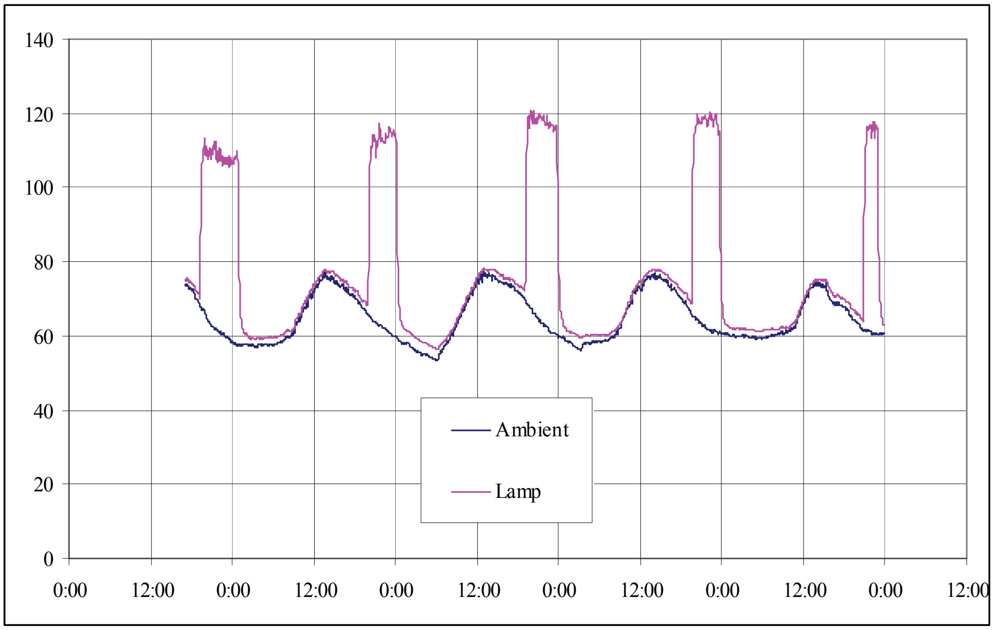



Many fixtures recorded little or no use. Because a data log of a fixture that was not used is indistinguishable from the results of a failed or misplaced logger, these results were compared with hours of use reported by the homeowner. While self-reports are often inaccurate, homeowner responses were useful predictors for dividing fixtures into very low usage (never/almost never and less than 1 hour per day responses) and very high use (more than 6 hours per day). For loggers showing few or no turn-ons, the data were retained when the logged data roughly agreed with the homeowner report. When the data disagreed with the homeowner report for these loggers, the data was not included in the analysis. For loggers that recorded significant usage, homeowner reported usage was not used to evaluate the data.

The temperature loggers required a completely different analysis approach. The data from temperature loggers reflects both temperature changes due to waste heat from the fixture and the changes in the ambient temperature, which can easily vary by 40 degrees over a 24-hour period. The metering protocol called for one of the logger's two temperature probes to be used to measure the ambient temperature, while the other measured temperature near the lamp(s). It was expected that changes in the temperature differential between the two probes would provide a clear picture of when the light was on.

In some cases, the temperature differential is high, more than 100 degrees, making the data easy to analyze. In other cases, the temperature lead for the fixture had to be installed outside the fixture enclosure, or the bulb was a low-watt (and low-temperature) CFL. In a few cases, the temperature differential was as low as 5 degrees, which was much harder to pull out from the noise of the ambient temperature variation. The pattern of usage was nevertheless apparent from a graphical analysis. These fixtures required additional time and care to separate usage from the noise.  Figure 4 shows an example of temperature logger data.

**Figure 4 - Example of Temperature Logger Data**




For some of the temperature loggers, one or both leads were in direct sunlight for part of the day. This resulted in a marked temperature increase for that lead. This was identified and screened out similarly to daylight interference: the events occurred during daylight hours, and they repeated daily for some period of time. In cases where both loggers were affected, the temperature spike was typically staggered, with the sun hitting first one, then the other, with a marked time lag.

Because the temperature loggers recorded temperatures at 5-minute intervals, the usage data are not as precise as the light loggers, which recorded the exact times the light was turned on or off. In translating the temperature data into the on/off status of the fixture, each 5-minute period was determined to be on or off, based on the temperature differential. This resulted in "lumpy" usage estimates compared to the light loggers: for a 15 minute period, the temperature logger would show that the light was either 0 percent, 33 percent, 67 percent, or 100 percent on, while the light logger data could translate into any percentage of the 15-minute period. Pre-testing showed that on periods missed because the temperature had not yet ramped up generally were offset by off periods for which the bulb had not yet cooled off.

The "lumpiness" of the data was an issue in the few cases where temperature loggers were used on motion sensor fixtures. This was done only where light loggers could not be used (e.g. because they would be exposed to water from rain or irrigation). Because motion-sensor fixtures are often only on for a minute or two, the bulb temperature often did not have a chance to climb to its maximum. Temperature loggers only recorded at five minute intervals, which had the potential to miss some turn-ons entirely, while overestimating the length of others (particularly when a series of on-offs kept the temperature elevated for a longer period, which would show up as a single turn-on with a temperature logger). The temperature loggers only approximate motion sensor usage, and while the data were deemed sufficiently accurate for this analysis, for future studies, we do not recommend the use of temperature loggers for motion sensor fixtures if it is possible to use a light logger.

A number of temperature loggers experienced a failure of one of the temperature leads. When the surveying lead monitored the fixture, the data could be analyzed, with difficulty, based on the temperature gradient (with steep gradients coinciding with a turn-on or turn-off event). When the surviving lead measured only ambient temperature, the data were unusable.

## Interpretation

Once the data were cleaned, they were converted into a SAS data set and we developed household, fixture and bulb weights. The household weights were simply relative population weights to reflect the stratified sample design. The fixture weight was a combination of (1) control type and location relative weights to reflect what we believed to be a close approximation of the underlying exterior fixture distribution[1] and (2) a simple weight for each fixture that represented the number of fixtures covered by the logger/control. The bulb weight was simply a weight to reflect the number of bulbs per fixture covered by the logger/control.

In order to generate a dataset containing monthly and annual data, the following regression analysis was performed. First, an 8760 hourly shell was constructed for each logger and then merged with the actual hourly data for each logger. Second, daily hours of daylight were merged with the 8760 data for each logger. The loggers were assigned 1 of 3 locations (San Joaquin Valley, Ventura-Santa Barbara, and the Los Angeles Basin) so that geographic differences could be taken into account. Third, individual logger regression models were estimated. The dependent variable was hourly percent on. The independent variables included weekday indicator, weekend indicator, hourly indicators from 1 to 23, and daily hours of daylight. Note that the hours of daylight variable was set to zero from 9:00 pm to 5:00 am as well as 9:00 am to 4:00 pm. Also, separate daylight hour slope terms were estimated for 6:00 – 8:00 am and 5:00 - 7:00 pm. Fourth, the estimated hourly usage by logger from the regression analysis was employed to fill-in missing actual logger usage data. The full 8760 usage profile (actual as well as fill-in predicted) was used to estimate the monthly hourly average values by day type.

For timers where we did not meter but instead collected survey data based on observed settings and respondent self-report, we developed the same set of variables described above for metered fixtures. We extrapolated the timer setting data, which was collected for winter (based on observed settings on-site during meter installation) and summer (based on respondent self-report) across the full year.

## Results and Outstanding Issues

We found that the overall mean usage is 2.8 hours per day, with motion sensors accounting for the smallest usage at an average of 0.5 hours per day and timers the highest usage at an average of 5.2 hours per day. Results by control type are shown in Table 1. By location, the average ranged from 1.1 hours in patio areas to 4.0 hours in walkways. Summer months averaged 2.5 hours, whereas winter months saw longer use, peaking at 3.2 hours in November and December.

[1] The population distribution was taken from the 2004-2005 Single Family Rebate Program Evaluation CFL on-site survey, which used definitions consistent with the current study. The earlier study specifically targeted homes with at least one CFL (not necessarily exterior), which is a potential source of bias. Nevertheless, we believe that the results are representative, and the benefits of using the study outweigh the risk of bias.

**Table 1 – Average Daily Hours of Use by Control Type and Overall**

| Control Type (and Bulb for Switches) | Sample Size | Mean Daily Hours | Standard Error |
|---|---|---|---|
| Motion Sensor w/ photocell | 57 | 0.5 | 0.2 |
| Photocell only | 11 | 4.4 | 3.1 |
| Switch – CFL | 39 | 1.7 | 0.4 |
| Switch – Non-CFL | 96 | 1.2 | 0.3 |
| Timer | 37 | 5.2 | 0.7 |
| Overall | 246[a] | 2.8 | 0.4 |

[a] Includes six fixtures for which control type was not recorded.

There were a couple of surprising results that we are still trying to understand. The hours of operation for the photocell-only lamps were much lower than we were expecting. This may be due to the mischaracterization of these bulbs as photocell only, when in reality, there were switch controls that were utilized. Also, because we expected little variation in the operation, these fixtures were under-sampled, and there may be some small sample effects.

Another surprising results was that for switched fixtures, we found that CFLs were used more hours per day than incandescent lamps. This may be due to snap-back, in which people are less vigilant about turning off their lights because the lights are more efficient. It may also be due to the users knowing that the most effective uses of CFLs are in high use applications and leading them to install CFLs in higher usage sockets. Over all control types, however, there was no statistical difference in usage between CFLs and incandescents.

## Conclusion

Lighting represents a significant portion of residential energy use, as well as a significant portion of energy efficiency potential. Unfortunately, there is little data about the usage of residential exterior lighting in California. This is partially due to significant challenges associated with gathering and analyzing these data. We have presented here the methodology and results of an exterior metering study that attempts to mitigate those challenges by supplementing the use of light loggers with the use of temperature loggers. Hopefully, this example will help other researchers design and conduct additional work to understand exterior lighting usage better in the future.

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