An Evaluation of Residential CFL Hours-of-Use Methodologies and Estimates:

Recommendations for Evaluators and Program Managers

Edward Vine, Lawrence Berkeley National Laboratory, Berkeley, CA
Diane Fielding, BC Hydro, Vancouver, Canada

ABSTRACT

This paper presents a review of methodologies and results of evaluations examining hours of use (HOU) in compact fluorescent lamps (CFLs). Hours of use is a crucial variable in determining the cost-effectiveness of lighting programs, and there is extensive variation in HOU estimates across methodologies and within a particular methodology. Given the different sources of variation, one must be careful in comparing the results from different studies. However, we are able to recommend a robust methodology that should be used by evaluators of lighting programs, regardless of geography or program delivery type.

1. Introduction

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 generally depended on manufacturers' estimates and/or self-report surveys of residential utility customers. A few studies have relied on data loggers to monitor light usage, providing accurate information on actual operating profiles for various types of lights in a range of residential settings. The monitored data permit program designers to target those lights that are operated longest and thus are most cost-effective to replace with efficient equipment, as well as to calibrate (adjust) estimates based on self-reports. Because of the varying estimates of HOU from different methodologies, there is a need to develop a framework for calculating HOU. For contextual purposes, we first conceptually compare the different data collection and analysis methodologies and then review the results from CFL HOU evaluations. After examining potential sources of variation in HOU estimates, we make recommendations regarding the conduct of future CFL HOU studies of lighting programs. This paper is based on a more extensive study (Vine 2004).

2. Comparison of Data Collection and Analysis Methodologies

Different methodologies may be used in calculating CFL HOU: (1) surveys of residential customers via mail, telephone, or in-person, (2) diaries written by consumers with CFLs, or (3) monitoring of HOU through lighting data loggers. The people surveyed may be from one or more of the following groups: participants in a specific lighting program, non-participants in that program, a specific group (e.g., low income, or high energy users), or a random sample of the population. Accordingly, the results of lighting studies must be viewed with caution, since the findings from these studies may be representative of a particular population, not the general population (and even if they are representative of the general population, they reflect current penetration rates and usage patterns that may change over time and affect HOU) and may not be relevant for future CFL users. Most CFL HOU studies assessed the representativeness of the surveyed group to the general population. Only one study (Carlson et al.

1994) used the diary method, along with other methods. The monitored groups were usually subgroups of the surveyed population (a "nested sample"). Typically, the CFL HOU studies assessed the representativeness of the monitored group to the survey sample and the general population. The following sections briefly discuss some of the concerns associated with each methodology.

2.1. Surveys

Compared to monitoring via data loggers, surveys are relatively inexpensive to conduct and can obtain information from many consumers: e.g. 5,720 households in a BC Hydro mail survey (Synovate 2003), or 7,111 households in a USDOE survey (USDOE/EIA 1996). However, there are many factors (variables) that hinder the ability of survey respondents to accurately estimate lighting hours of use:

- They may not be at home during all of the times that lights are turned on.
- They may not know how other people in the home are using lights.
- Their home is used non-routinely, making it difficult for them to assess the frequency of lighting HOU.
- They may be confused about a particular light/fixture if there are many CFLs involved in the survey.
- They may "bias" their responses: e.g., in order to appear "energy efficient," they may say they rarely use lights (the "conservation ethic"), or say they frequently use the CFLs (the "symbol" of energy efficiency).
- They do not know how often or how long certain lights are used.
- They may be more knowledgeable of particular lights/rooms – those more frequently used, compared to other lights/room that are infrequently used
- Their response may be influenced by the time (season) of the survey: e.g. greater HOU in the winter (when there is less daylight) and less HOU in the summer (when daylight hours are greater)

Some studies have made adjustments for one or more of these factors. Nevertheless, most researchers believe that self-reported data are less reliable than monitored data. As noted below, several studies support this belief when they find that self-reported HOU are higher than monitored data among the same participants.

2.2. Monitoring via data loggers

Lighting loggers are placed near the targeted light fixture and record the time and date the fixture is turned on and off, or the number of HOU per unit of time. Information from lighting loggers allows for the calibration of self-reported operating schedules. The data collected by lighting loggers are considered to be more accurate and consistent than self-reported data, but, due to the cost of monitoring (due to higher upfront investment costs in equipment and labor and costs associated with installing and removing equipment), monitoring data can only be collected for a relatively small group of fixtures and/or homes and for a relatively short period of time (measured in months, not years): e.g., 77 fixtures in 18 homes in a BC Hydro study (Sampson Research 2004b) or 330 loggers and 59 homes in a U.S. study (Xenergy, Inc. 2003). Also, an onsite sample may introduce a different kind of non-response bias, when compared to non-response in phone and mail surveys, especially if participation incentives are used. In addition to small sample size, there are many factors (variables) that affect data monitoring:

- There may be a bias in the selection of lights/fixtures (since not all fixtures can be monitored): e.g., were the selected lights/fixtures used more often than others in the house?[1] It is difficult for a monitoring person to know which particular fixtures are used more than two hours a day, without consulting with the resident who, as noted above, may or may not have this information. Furthermore, some fixtures cannot be monitored for other reasons: (1) light fixtures operating with timers, daylight sensors, or occupancy sensors; (2) areas where excessive humidity would be present (e.g., over the top of cooking surfaces); (3) areas where there is a high risk of theft (e.g., outdoor locations where the logger would be within easy reach); (4) situations where there is an inability to mount the logger (a function of the fixture and/or its location; (5) situations where the fixture cannot accommodate a screw-in CFL due to its size or shape; (6) situations with unsafe wiring or the poor condition of the fixture; and (7) situations where the respondent limits access to certain fixtures for personal reasons (e.g., aesthetics) (Sampson Research 2004b).
- There may be a bias in the selection of households, unless prior research has shown that these households are "average energy users" and representative of the housing stock, rather than high-energy users or energy-efficient households.[2] For a variety of reasons, the monitored sample may be a self-selected sample and, therefore, may not be representative.
- The monitoring may be affected by the time (season) of the survey: e.g. greater HOU in the winter (when there is less daylight) and less HOU in the summer (when daylight hours are greater). As a result, most studies try to make adjustments when extrapolating the data for an entire year, or for averaging.
- When extrapolating data to a season or a year, several factors may affect the extrapolation:
    - Varying amount of daylight during the year
    - Daylight savings time
    - Vacations and/or other periods of seasonal low occupancy

A good monitoring study will plan for these placement and sensitivity issues – e.g., testing and retesting the sensitivity and making adjustments when necessary. Moreover, as part of quality control procedures, one can return to a house periodically to download the logger's data, review the logger's operation (visual examination using graphing software and testing), review data logs onsite, check the sensitivity of the loggers, and identify any anomalous readings and make appropriate adjustments.

---

[1] Some studies have deliberately focused on high-use fixtures – since these are seen as the most promising locations for CFLs.

[2] One study did focus on high-energy users (greater than 12,000 kWh of annual use), since they were seen as potential energy savers (Xenergy 2003). And another study found some differences in the demographic characteristics of respondents who had their lights monitored and those who were surveyed but were not monitored: the monitored households were younger, had higher incomes, owned their home, and were single or had children (Nexus Market Research, Inc. and RLW Analytics, Inc. 2004). But both groups shared many of the general characteristics that differentiated them from the general population.

3. Review of Current Approaches to CFL HOU Evaluations

3.1. Methodology

A literature search was conducted by investigating energy journals, conference proceedings (e.g., the American Council for an Energy-Efficient Economy's Summer Study, and the International Energy Program Evaluation Conference (IEPEC)), and web sites of key energy organizations (e.g., the U.S. Department of Energy (USDOE), the U.S. Environmental Protection Agency (USEPA), the California Measurement and Advisory Committee (CALMAC), the Consortium for Energy Efficiency (CEE), the Northwest Energy Efficiency Alliance (NEEA), the Northeast Energy Efficiency Partnership (NEEP), the New York State Energy Research and Development Authority (NYSERDA), Lawrence Berkeley National Laboratory (LBNL), *Home Energy* Magazine, and the Lighting Research Center (LRC). In addition, a request for CFL hours of use studies was sent to the listserve of the Association for Energy Services Professionals (AESP), members of the IEPEC Planning Committee, and lighting professionals.

3.2. Direct Effects

Direct effects refer to the impacts of a utility's direct program effects, including CFL giveaways or purchases made by a utility-sponsored CFL coupon. Since CFL HOUs vary by data collection method – a common finding as discussed below – the findings have been grouped by data collection method in Table 1.

Table 1. Direct Effects of CFL Programs

Year	CFL Hours per Day (HPD)	Organization	Name of Study	Reference
Monitored data				
1991	2.0	Pacific Power and Light	Unknown	Henson 1992
1992	2.5 2.8 [winter] 2.2 [summer]	Grays Harbor Public Utility District	Compact Fluorescent Maximization Study	Henson 1992
1995	4.6 [3.8 – 5.8]	BC Hydro	Residential Lighting Fixture Monitoring Project	Tamagi and Ireland 1995
1996	2.0	BC Hydro	Baseline Residential Lighting Energy Use Study	Tribwell and Lerman 1996
1996	2.6	Southern California Edison Company, and Pacific Gas & Electric	Residential Appliance Efficiency Incentives Program – Fluorescent Lighting (CFL) Impact Study	Xenergy 1996a
1996	2.7	Southern California Edison Company, and San Diego Gas & Electric	Residential Appliance Efficiency Incentives: Compact Fluorescents Gross Impact Study – 1994 Residential CFL Program	Xenergy 1996b

2004	3.1	New England Lighting Programs	Impact Evaluation of Massachusetts, Rhode Island, and Vermont 2003 Residential Lighting Programs	Nexus Market Research, Inc. and RLW Analytics, Inc. 2004
2004	2.2 [1.7 – 2.8] [3.2 winter]	BC Hydro	Residential Lighting Hours-of-Use Study	Sampson Research 2004b
2005	2.3	California utilities	CFL Metering Study	KEMA 2005
Survey data				
1996	6.7	U.S. DOE/EIA	Residential Lighting Use and Potential Savings Study	USDOE/EIA 1996
1998	5.4	San Diego Gas & Electric Company	1996 Residential Appliance Efficiency Incentives Program – High Efficiency Lighting	SDG&E 1998
2002	4.2	BC Hydro	BC Hydro CCQ Residential Power Smart Initiative	Fielding et al. 2002
2002	4.1 [4.3 for 2nd bulb]	BC Hydro	BC Hydro CCQ Residential Follow-up Survey	Market Facts/MarkTrend 2002
2002	3.3 [3 – 4]	California IOU programs	Evaluation of CFL installation programs	Xenergy 2002b
Estimated/ hybrid data				
1997	2.3	California Energy Commission	Lighting Efficiency Technology Report	Heschong Mahone Group 1997
2002	4 3.5	Wisconsin Division of Energy	Energy Star Labeled Products Program	Mitchell-Jackson and Schauf 2002
2002	2.1 [exterior] 2.2 [interior]	U.S. DOE	National Lighting Inventory	Navigant Consulting 2002
2003	3 [interior] 5 [exterior] 2.8 [interior] 4 [exterior]	Northwest Energy Efficiency Alliance	Residential Lighting programs	Violette et al. 2003
2003	3.0 [2.9 - 3.1]	BC Hydro	REUS	Unpub., cited in Sampson Research 2004b
2003	6.1 [winter] 3.4 [summer]	BC Hydro	Vancouver Island CFL Giveaway	Pollara 2003
2004	4.7	BC Hydro	Evaluation of the Power Smart Residential CFL Program - Phase II – Vancouver Island	Fielding 2004
2004	2.4 [interior] 3.4 [outdoor]	Northwest Energy Efficiency Alliance	Energy Star Residential Lighting	ECONorthwest 2004

*Numbers in brackets are the range, one standard deviation from the mean.

The monitored data ranged from 2.0 HPD to 4.6 HPD. The survey data show self-reported HPD ranging from 3.3 to 6.7. However, these studies came from different regions. The most interesting studies were those that combined different methodologies (e.g., light loggers and surveys) to estimate HPD. The HPD for these studies ranged from 2.1 to 6.1. The variation was reduced if one just looked at interior CFLs (2.2 HPD – 3 HPD). A few studies compared monitored and self-reported data using "nested samples" – a recommended methodological approach, as discussed later in this paper.

3.3. Market Effects

Market effects are defined as the incremental increase in CFL sales that occur as a result of a utility's influence on the supply and demand characteristics for CFLs sold in its service territory (Sampson Research 2004a). Supply-side characteristics include improved availability, accessibility, and the affordability of CFLs. Demand-side characteristics include increased awareness and acceptance of CFL products. By definition, market effects exclude the utility's direct program effects including CFL giveaways or purchases made by a utility-sponsored CFL coupon. BC Hydro has published two reports on market effects (Table 2). However, these HPD data are not based on surveys or monitoring data – they are best guesstimates, as described below.

Table 2. Market Effects of BC Hydro Power Smart Programs

Year	CFL HPD	Organization	Name of Study	Reference
2002	3.5	BC Hydro	Market Effects of BC Hydro's Compact Fluorescent Lamp Initiatives	Gin 2002
2004	4.3	BC Hydro	Residential CFL Initiatives	Sampson Research 2004a

In these reports, it is assumed that direct effects would have longer CFL HOU than for market effects, because of the educational aspects of BC Hydro's CFL promotions that encourage households to install CFLs in high use fixtures (via messaging and education about the most appropriate use of CFLs – through retailers and utility staff). For example, the influence of BC Hydro's programs on participants and retailers allow these households to make better decisions on where to install their CFLs (e.g., in fixtures with the highest hours of use) and how to maximize energy savings (Gin 2002; Sampson Research 2004b; Fielding 2004). At least one study supports this assumption. In an on-site survey of participants in a Vermont CFL program, program participants showed a greater tendency to place CFL fixtures in high use locations (43%) - kitchen, living room and family room - compared to low use locations (32%) - halls and bathrooms) (West Hill Energy & Computing, Inc. 2003). In contrast, nonparticipants were more likely to place CFL fixture in low use locations (32%) than in high use areas (24%).[3]

Thus, above assumption appears reasonable, but more verification is needed. For example, this assumption may be more questionable over time, as market data show that the lighting market is transforming and, therefore, program nonparticipants may becoming more like program participants - informed and educated over time, particularly if consumers installing CFLs continue to come from the

[3] On the other hand, not *all* participants put CFLs in high use areas,

highest education level group and have a high regard for energy efficiency. Unfortunately, no other studies have looked at market estimates of CFL HPD.

3.4. Comparison of Methods

As noted above, self-reported HOU via surveys generally over-report HOUs compared to monitored light usage – whether the focus is on all fixtures/CFLs, or fixture/CFL by room (see below). Four studies have compared the results of monitored light usage with self-reports for the same household members:

- In a recent BC Hydro study, HPD use based on light logger data was 77% of survey estimates (2.2 versus 2.9) (Sampson Research 2004b). On an individual area basis, the largest absolute (either positive or negative) discrepancy between self-reported hours and logged hours occurred for bathrooms, bedrooms, and kitchens/dining rooms (see below).
- In a New England study, HPD use based on light logger data was 81% of on-site survey estimates (2.5 HPD versus 3.1 HPD) and 72% of diary estimates (2.6 HPD versus 3.6) (Carlson et al. 1994). And on-site survey estimates were 72% of telephone survey estimates (2.8 HPD versus 3.0 HPD).
- In another New England study, HPD use based on light logger data was 81% of survey estimates (2.6 versus 3.2) (Nexus Market Research, Inc. and RLW Analytics, Inc. 2004). When differentiated by location of fixtures, the logger data were 84% of survey estimates for interior fixtures and 93% for exterior fixtures. This is not too surprising, since exterior lights are often used for longer periods of time that may make it easier for people to recall in surveys.
- In a recent California study, HPD use based on light logger data was 78% of survey estimates (2.3 versus 2.9) (KEMA 2005). And the correlation between self-reported and monitored HOUR data was 0.44 (a perfect fit would have a correlation coefficient of 1.0).

Thus, based on these studies, monitored estimates are about 77-81% of self-reported estimates, similar to other estimates (68-85%) not discussed in this report (Sampson Research 2004b). Considering that these studies were conducted in different geographical regions, this finding appears to be robust and transferable to most regions in North America.

3.5. HOU by room

House-to-house variations in the number of rooms, and variations in the relative contribution of key rooms/areas (e.g., kitchen/dining, living room, outdoors) to overall house lighting load is a source of variation that will affect the whole house average hours of use estimate. Recent studies, using both survey and monitored data, indicate that exterior lighting use is higher than lighting use in all interior rooms, and the highest use interior areas are the kitchen, living room, and family room.

4. Sources of Variation in HOU Estimates

In Section 2, it was noted that variation in CFL HPD could be attributed to the type of method used to collect lighting data (e.g., surveys versus monitoring). Other possible sources of variation include: variations in socioeconomics, attitudes, and behavior; regional variations in dwelling types; the level of penetration of CFLs; and the timing of adoption of CFLs.

- **Socioeconomic, attitudinal, and behavioral differences**. Possible sources of HPD variation include: differences in number of people in the home (e.g., more people at home will lead to more frequent use of lights); daily lifestyles and schedules (e.g., people who stay at home (such as telecommuters, the elderly, families with young children) will have their lights turned on more often than people who work outside of the home); the number of rooms, how each of the rooms are used, and the frequency of their use; the degree of energy conserving ethic (e.g., less use of wasteful lighting, but maybe more use of efficient lighting); owners versus renters (i.e., people who pay their utility bills versus those who don't); and concerns about home security (e.g., keep both inside and outside lights on). Some studies have been conducted to look at some of these relationships. For instance, monitoring studies have found little or no statistical evidence to support the relationship of hours of use with the number of people occupying the home (BC Hydro 1995; Tacoma 1996; Tribwell 1997). Another study did not find a correlation between lighting energy use and heated floor area or number of occupants (Tribwell 1997). A third study found no correlation between hours of use and type of home or demographic characteristics (Tribwell 1997). And a fourth study (KEMA 2005) found no statistically significant differences in usage by household composition (e.g., households with seniors, households with children, homeowners, and renters). On the other hand, an early BC Hydro monitoring study found that households with 2 adults and 2 children had an average daily usage of 10.6 hours – this was at least 20% higher than all other demographic groups (Tamagi and Ireland 1995).
- **Dwelling types.** Lighting HOU may vary between single detached dwellings and other dwelling types. For example, one study found that HOU estimates for incandescent light fixtures in dining rooms, living rooms, den/study/family/games rooms, and outdoor lighting of single-family detached dwellings were significantly lower than in apartments/condominiums (Sampson Research 2004b). However, another study (KEMA 2005) found no statistically significant differences in usage by dwelling type (e.g., single family versus multifamily).
- **Regional variations.** Since lighting HOU are influenced by dwelling type (see above), regional differences may occur. For example, in one BC Hydro study, the proportion of single-family detached family dwelling to other dwelling types varied between regions, and since hours of use are influenced by dwelling type, these regional variations will affect the estimates of HOU for each region (Sampson Research 2004b).
- **Vintage of CFLs.** Newer CFLs might be used for longer periods of time than older CFLs: a statistically significant difference was reported in one study (KEMA 2005). This finding suggests that people are using the newer CFLs in higher-use fixtures (e.g., in living rooms and kitchens), as newer CFLs are stocked in a wider array of applications, sizes, and color renditions (the older CFLs did not have these attributes and were not placed in these more visible and used areas).
- **Penetration of CFLs.** The increased penetration of CFLs may lead to declining overall average hours-of-use for CFLs. For example, one study found that HOU for homes with at least 4 CFLs in use declined from 5 HPD for the most heavily used CFLs to just over 2 HPD for the fourth most used CFL (Xenergy 2002b). This effect occurs because, as noted in Section 3.3, users that understand which CFL applications are most cost-effective generally install their first CFL(s) in the most heavily used light fixtures, and resort to lesser-used fixtures for subsequent CFL acquisitions. Thus, everything held constant, a residential lighting program that promotes the

adoption of CFLs when the incidence and penetration of the technology is low, should expect higher hours of use than one that promotes adoption once the diffusion (penetration and incidence) of the technology is well established (Sampson Research 2004b). This was confirmed in a second study that showed a decline in average use of CFLs as the number of CFLs installed in the home increased in different lighting programs (Xenergy 2002b; Rasmussen et al. 2002):

- Door-to-Door Giveaway Program: 5.6 hours per day in the first most-used bulb, 3.6 in the second most-used bulb, 2.5 in the third most-used bulb, and 2.0 in all other bulbs.
- Leveraging Other Programs: 4.7 hours per day in the first most-used bulb, 3.2 in the second most-used bulb, 2.5 in the third most-used bulb, and 2.0 in all other bulbs.
- Reduced Price Program: 5.6 hours per day in the first most-used bulb, 3.4 in the second most-used bulb, 2.5 in the third most-used bulb, and 2.0 in all other bulbs.

Thus, HOU assumptions may be overstated if it is assumed that program CFLs are always installed in relatively high-use fixtures.

- **Early adopters versus late adopters of CFLs.** Diffusion theory suggests that the attitudes and characteristics of early adopters of CFL technology will be different than later adopters of the technology. These differences may impact hours of use for CFLs acquired by these respective residential customer groups. For example, households with a high number of high use fixtures will have an incentive to adopt energy saving CFLs sooner than later. If this characteristic was common to early adopters, hours of use estimates for early program participants, everything held constant, would be higher than later participants (Sampson Research 2004b). Similarly, early adopters may have a greater conservation ethic relative to later adopters, contributing to differences in hours of use: they may either use all lighting fixtures less than later adopters, or use CFLs more frequently than late adopters.
- **Use of exterior lights/security lighting.** Typically, outdoor lighting HOU is greater than interior HOU. The Northwest Power Planning Council assumes that an interior fixture operates an average of 3 HPD and an exterior fixture operates an average of 5 HPD (Northwest Power Planning Council 2004). In order to obtain an average HPD, sales data are used: interior CFLs were given a weight of 70 percent and exterior CFLs a weight of 30 percent, to get an average of 3.6 HPD. Also, some of the early HOU studies did not include exterior lighting.
- **Type of CFL program delivery.** It is possible that the type of program delivery may affect CFL HOU (see Section 3.3 on Market Effects). For example, programs that spend resources on education of the consumer and the retailer and provide one-on-one contact may be more effective in influencing consumers in placing CFLs in high-use fixtures, compared to programs that simply have a consumer mail in a rebate coupon, providing little education and information. In the latter programs, one would expect HOU variation, with more people placing CFLs in lower-use areas. One would expect different HOU estimates for the following types of programs (as examples): programs that target CFLs to low-income households (with no experience with CFLs) or seniors (who tend to be home more often), or programs that include retailer advertising targeted to home improvement people (with experience with CFLs). One study of lighting programs in California did not find any statistical differences in HOU among the different lighting programs (Xenergy 2002b; Rasmussen et al. 2002).
- **Takeback.** Most of the studies reported in this report focus on CFL HOU. However, some of the HOU studies were based on all fixtures, including incandescent lights. Are there differences in HOU between CFLs and incandescents? Some have proposed that more efficient and lower

wattage fixtures (like CFLs) will have longer hours of operation, particularly if they are satisfied with the technology – resulting in a "takeback" of energy savings (Heschong Mahone Group 1997). This suggestion was supported in the Tacoma Public Utilities project, where CFLs were use for extended periods of work, night lights, and high energy uses, while incandescents were typically used in low energy use areas and often turned off (Tribwell and Lerman 1996). However, other studies have found no evidence that consumers will use CFLs longer than incandescents (Aspen Systems 1995; Tamagi and Ireland 1995; Sampson Research 2004b).

5. Recommendations for Conducting CFL HOU Studies

This section provides recommendations to improve and enhance the reliability, validity and/or precision of current approaches to estimating HOU for both direct and market impacts.

- Program managers and evaluators should use lighting loggers in combination with one or more other methods for the same group of consumers. There is value in conducting small samples of installed CFL HOU metering to verify self-reported survey data and for developing adjustment or correction factors. As shown in this paper, the correction factor can be derived by taking the ratio of the logged results to self-reported results among the group participating in the logging, and multiplying that ratio times the responses from the overall survey (phone or mail) sample. Because of the variations among households, it is recommended that the metering study extend across a full year and that larger samples be employed.
- Program managers and evaluators should conduct a separate study on market effects of CFLs. This study would be similar to the study for program participants, but would focus on nonparticipants. For example, in addition to conducting a light logging study on a representative, hierarchically nested sub-sample of program participants in a CFL program, another light logging study would be implemented in the same year on a representative, hierarchically nested sub-sample of respondents in the planned market effects surveys in the coming years. This type of study would not be needed where CFL market shares and penetration rates are very high (i.e., participants and nonparticipants would be similar).
- Due to the variation among rooms, both studies of direct and market effects should monitor hours-of-use for CFLs in a representative sample of individual rooms/areas in the home, including exterior lighting.
- Program managers and evaluators should provide sufficient resources for conducting these evaluations, since the measured program success is dependent on the accuracy of CFL HOU. Approximately 5-15% of a CFL program should be spent on evaluation – this budget should be sufficient to implement the above recommendations, as well as to address some of the sources of variation in HOU, so that the level of uncertainty of this valuable resource is reduced.

6. Acknowledgements

We would like to thank the following people for providing information on hours-of-use data and studies: Harley Barnes, Al Bartsch, Ben Bronfman, Rich Brown, Kathleen Gaffney, Susan Haselhorst, Ken Keating, Marty Kushler, Owen Howlett, Judy Jennings, Joe Lopes, John Maxwell, Chris Neme, Ralph Prahl, Steven Rosenstock, Ron Slosberg, David Sumi, Debra Tachibana, Ken Tiedemann, Rick Winch. We also appreciate the time provided by the people interviewed in this project: Jim Nelson, John

Sampson, and Iris Sulyma. Finally, we appreciate the review comments by Robert Wirtshafter and Tami Rasmussen on an earlier version of this paper.

7. References

Aspen Systems Corporation. 1995. *Impact Evaluation of Con Edison's Residential Enlightened Energy Programs: Refrigerator Dealer Incentive Program, Room Air Conditioner Dealer Incentive Program, Residential Submetering Program, Section1, Final Technical Report,* Silver Spring, MD.

Carlson, L., J. Mulligan, and C. Gondek. 1994. "Elements of residential efficient lighting savings," Proceedings of the 1994 ACEEE Summer Study on Energy Efficiency in Buildings, pp. 8:19-27, American Council for an Energy Efficient Economy, Washington, D.C.

ECONorthwest. 2004. *Energy Star Residential Lighting: Market Progress Evaluation Report, No. 2*. Portland, OR.

Fielding, D., I.M. Sulyma and S. Shackerley-Bennett. 2002. *Courtenay-Comox Valley & Quesnel (CCQ) Residential Power Smart Initiative: Evaluation of the CCQ Phase I Roll-out*. BC Hydro, Vancouver, BC.

Fielding, D. 2004. *Evaluation of the Power Smart Residential Compact Fluorescent Lighting Program, Phase II Vancouver Island*. BC Hydro, Vancouver, BC.

Gin, J. 2002. *Market Effects of BC Hydro's Compact Fluorescent Lamp Initiatives*. BC Hydro, Vancouver, BC.

Henson, J. 1992. "Conversions + Conversations = Conservation," *Home Energy*, Nov./Dec. 1992.

Heschong Mahone Group. 1997. *Volume 1 California Baseline: Lighting Efficiency Technology Report [Residential Excerpts Only],* Fair Oaks, CA.

KEMA, Inc. 2005. *CFL Metering Study*, Oakland, CA.

Market Facts/MarkTrend. 2002. *BC Hydro CCQ Residential Follow-up Survey*, Vancouver, BC.

Mitchell-Jackson, J. and D. Schauf. 2002. *Focus on Energy Statewide Evaluation. Energy Star Labeled Products Program. "Evaluation of Deemed Energy Savings Estimates for Energy Star-labeled Products,*" State of Wisconsin, Department of Administration, Division of Energy.

Navigant Consulting, Inc. 2002. *U.S. Lighting Market Characterization. Volume 1: National Lighting Inventory and Energy Consumption Estimate*, U.S. Department of Energy, Washington, DC.

Nexus Market Research, Inc. and RLW Analytics, Inc. 2004. *Impact Evaluation of the Massachusetts, Rhode Island, and Vermont 2003 Residential Lighting Programs*, Cambridge, MA.

Northwest Power Planning Council. 2004. Conservation Resource Database, web site: http://www.nwcouncil.org/comments/default.asp

Pollara. 2003. *Vancouver Island CFL Giveaway: 1-Year Follow-Up*. Vancouver, BC.

Rasmussen, T., K. McElroy, and R. Rubin. 2002. "Mass Deliveries of Compact Fluorescent Lamps (CFLs) as a Response to the Energy Crisis: Evaluation of California's 2001 CFL Programs," Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings, pp. 10:247-258, American Council for an Energy Efficient Economy, Washington, D.C.

Sampson Research. 2004a. *Market Effects of BC Hydro's Residential CFL Initiatives*. Vancouver, BC.

Sampson Research. 2004b. *Residential Lighting Hours-of-Use Study*, Vancouver, BC.

San Diego Gas & Electric Company. 1998. *1996 Residential Appliance Efficiency Incentives Program – High Efficiency Lighting, First Year Load Impact Evaluation*, San Diego, CA.

Synovate. 2003. *BC Hydro 2003 Residential End Use Survey (REUS)*, Vancouver, BC.

Tamagi, W. and S. Ireland. 1995. *Residential Light Fixture Monitoring Project*. BC Hydro, Vancouver, BC.

Tribwell, L. 1997. "Shedding Light on Home Lighting Use," *Home Energy*, January/February edition.

Tribwell, L. and D. Lerman. 1996. "Baseline Residential Lighting Energy Use Study," Final Report to Tacoma Public Utilities and in the *Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings*, pp. 3:153-160, American Council for an Energy Efficient Economy, Washington, D.C.

U.S. Department of Energy/Energy Information Administration. 1996. *Residential Lighting Use and Potential Savings.* Washington, D.C.

Vine, E. 2004. *Review of Estimates of CFL Hours-of-Use*, prepared for BC Hydro, Power Smart Evaluation, Vancouver, BC.

Violette, D., M. Ozog, and K. Cooney. 2003. *Retrospective Assessment of the Northwest Energy Efficiency Alliance*, Summit Blue Consulting, Boulder, CO.

West Hill Energy & Computing, Inc. 2003. *Vermont Residential New Construction 2002: Baseline Construction Practices, Code Compliance, and Energy Efficiency*, Chelsea, VT.

Xenergy, Inc. 1996a. *Residential Appliance Efficiency Incentives Program – Fluorescent Lighting (CFL), 1994 First Year Statewide Load Impact Study*, Oakland, CA.

Xenergy, Inc. 1996b. *Residential Appliance Efficiency Incentives: Compact Fluorescents Gross Impact Study – 1994 Residential CFL Program*, Oakland, CA.

Xenergy, Inc. 2002a. *CFL Market Characterization and Baseline Data*. Portland, OR.

Xenergy, Inc. 2002b. *Phase 4 Market Effects Study of California Residential Lighting and Appliance Program,* Oakland, CA.

Xenergy, Inc. 2003. *NSTAR Residential High Use Program Operating Hours Realization Rate Study*, Burlington, MA.