What Type of CFL User Are You?

Kathleen Gaffney, Miriam Goldberg, Kevin Price, KEMA, Inc., Oakland, CA

ABSTRACT

Wouldn't you think with all the attention they are getting these days, compact fluorescent light bulbs (CFLs) would be flying off the shelves? Lately, in retail stores across the United States, it seems as if they are. But are these CFLs getting installed right away? Or are consumers purchasing them now and storing them for later use? Think about your own home – if you purchased a CFL today, what would you do with it? Would you install it immediately in any applicable fixture? Would you install it selectively because you have concerns about using CFLs in certain fixtures? Or, would you put it on the shelf and wait for your next light bulb to burn out? Or would you wait to replace an existing CFL? Understanding the intentions of a CFL user, along with the current lighting characteristics of their household, is a key component in modeling the time-to-installation for the next CFL they purchase.

This paper will present a methodology to model the relationships among CFL installation, storage, and usage profiles. Understanding these relationships is particularly important as utilities continue to rely on the energy savings from CFLs to solve current resource constraint problems. If CFLs remain uninstalled – sitting on retail shelves or in household closets – while incandescent lamps remain in sockets, CFLs simply cannot conserve energy. The ability to accurately understand CFL usage patterns will help planners and policy makers more effectively target future efficiency efforts and more precisely model energy savings realization.

Introduction

CFLs are a large component of many residential energy efficiency programs across the United States. A key question for such programs is how long it will take a CFL purchased through the program to be installed. Many past studies have addressed this question by simply asking recipients of program CFLs how many of them have been installed. That approach is problematic for certain current CFL programs for several reasons:

1. When CFLs are distributed primarily through upstream programs, there are no lists of customers who purchased CFLs through the programs.
2. Both program-eligible and non-program eligible CFLs are available in the market. Thus, if we call customers at random to inquire about CFL purchase and installation, it can be very difficult to distinguish program from non-program CFLs.
3. CFLs have been sold in packs of multiple bulbs, with several strong promotional periods in recent years. As a result, the average CFL-using home has many CFLs in storage, as well as installed. The in-home storage inventory makes it difficult to obtain good information on the installation of CFLs purchased at a particular time. For instance, did a recently purchased CFL go into storage while a stored one got installed, or was the most recently purchased CFL installed while others remained in storage?
4. The timing of evaluation research is often several months and sometimes years after the CFLs were purchased, making it even more difficult for respondents to accurately report what happened to the CFLs they purchased during program-specific promotional periods.
5. In historically active program areas, the mix of user types, combined with more mature saturation levels, makes it more difficult to understand the dynamics underlying the purchase-installation timeline.

This paper lays out a framework for analyzing the lag between CFL purchase and installation, and the factors that affect this lag. This framework can be used in several ways:

1. Estimating the fraction of CFLs purchased in early and later years of the program that were installed within the program time frame. This fraction is needed to determine the formal credit allowable to the programs for these CFL purchases.
2. Estimating the fractions of program CFLs that will be installed in successive periods after the program's close. In some jurisdictions, program policy does not give credit for post-program installations. However, this analysis of delayed installation is useful for understanding the broader picture of the effects of this and related programs on the market. In other jurisdictions, this type of analysis might be used for assigning long-term credit to a program.
3. Estimating the relationships between prior purchases, storage and installations. Understanding these relationships can help guide future program planning and is fundamental to understanding differences in purchase and installation rate between regions with long-standing CFL promotions and those with relatively new efforts.

In this paper, we describe the modeling framework, lay out the data collection and coding process, and offer some illustrative examples of the analysis.

Modeling Framework

Overview

Our full modeling framework is a system of dynamic models that recognize several quantities as interdependent:

- The number of CFLs purchased in a given period
- The number of CFL installations[†] in that period
- The number of CFLs in storage in the home at the beginning and end of the period
- The number of applicable sockets in the home
- The number of applicable sockets that already have CFLs in them, and the number that do not have CFLs.

The dynamic modeling system will include:

- A model of quarterly purchases, as a function of the number of applicable sockets, number of CFLs in use in the previous quarter, number in storage in the previous quarter, and a measure of the level of promotional efforts.
- A model of CFL installations during the current quarter, as a function of the same variables
- A multi-dimensional diffusion model describing the distribution of user types in the current quarter as a function of the distribution in the prior quarter.

The data used to estimate this system of models are provided by quarterly surveys of random samples of homes.

At this stage in the development of the models, we conduct all of the analysis in terms of average quantities per home. We also recognize that the relationships among these quantities will vary according to the type of CFL user, as described below. Thus, models are estimated separately for each category of CFL user.

[†] Throughout this paper, "installation" refers to the act of placing a CFL into a socket or fixture. The number of CFLs installed in a given period is the number for which the act of installation occurred in that period. We refer to all the CFLs that are in sockets, whether installed in this or a previous period, as the CFLs in use during the period. Installations include both replacements of non-CFLs by CFLs and replacement of old (failed) CFLs by new CFLs.

In this paper we focus on the installation models. The primary installation model estimates how many CFLs will be installed in a defined period of time. For each user type, this number depends only on the number of applicable sockets and the number that had CFLs in them at the end of the previous period. The installation timing model produces an estimate of how many of the CFLs purchased in a given period will be installed in each successive period. This model depends on the total installations in each period, from the primary installation model, as well as the number purchased and in storage in the starting period.

CFL User Types

Conceptually, we distinguish four types of CFL users:

1. **Saturated users**: Have CFLs in all applicable sockets and will replace them with CFLs upon failure.
2. **Transitional users**: Have one or more CFL in use. Will replace all failed bulbs in applicable sockets with CFLs as they move from partial to saturated users.
3. **Partial users**: Have one or more CFL in use. May or may not replace CFLs and other lamps with CFLs upon failure.
4. **Non-users**: Have no CFLs in use.

A challenge for this analysis is that the definition of applicable socket – and therefore of saturation – is somewhat subjective. The definition will evolve over time as users become more comfortable with CFLs and as CFL technologies improve. Moreover, our data on CFL purchase and use come primarily from phone surveys. We therefore have no objective determination of the number of applicable sockets in each home. However, a typical value can be estimated based on recent onsite lighting inventory studies. Below, we describe how we classify users based on their survey responses.

Over time, expected effects of programs include moving non-users to partial users, and moving partial users to transitional or saturated users. Managers of more mature CFL programs are also expecting to increase the installation rate among partial users. These components of the modeling system are not addressed in this paper.

Data Collection

Telephone survey data are being collected from samples of California's residential customers in quarterly waves from June 2008 through August 2009. The sample in each quarter is a random sample of all residential homes, stratified by utility. For upstream programs, it is very difficult for respondents to be able to distinguish between program-eligible and non-program eligible CFLs. We therefore simply use information about CFLs purchased, in use, stored, and installed for the most recent three months. We obtain information both on current quantities used and stored, and those from the previous quarter.

In addition to this information, we also collect information that allows us to classify the respondent's CFL use type. The classification tree below indicates the process.

1. Customers with no CFLs in use or who are unaware of CFLs are classified as **Non-users**.
2. Customers with only CFLs in use and who plan to replace failed CFLs with CFLs, even if additional purchases are necessary, are classified as **Saturated Users**.
3. Most customers have one or more CFL in use, and also have one or more non-CFL in use.
    a. Those who will replace both incandescents and CFLs with CFLs, whether or not additional purchases are necessary, are classified as **Transitional Users**.
    b. All others in this subcategory of unsaturated user are classified as **Partial Users**.

Initially, KEMA believed that it may be possible to differentiate between transitional and partial users by simply asking which type they fell into, providing user type descriptions similar to those described above. However, comparing initial results for these questions with other questions geared at illuminating their intentions, we found several inconsistencies and potential biases. Therefore, we relied instead on the information described in the list above in order to classify the respondent's CFL user type.

Installation Model Specifications

For each respondent, we obtain the information listed in Table 1 for the quarter in which they are surveyed, period t. We also obtain the number in storage S_{t-1} and in use U_{t-1} for the previous quarter. The number of applicable sockets is not reported directly, but is estimated from reported house size variables.[‡]

Table 1 – Model Variables

Variable	Data
S_t	The number of CFLs in storage at the end of period *t*
P_t	The number of CFLs purchased during period *t*
U_t	The number of CFLs in sockets at the end of period *t*
I_t	The number of CFLs installed – i.e., put into sockets – during period *t*
A	The number of sockets where CFLs could be used or are applicable

Primary Installation Model

The Installation Model assumes that there will be a certain rate of replacement of existing CFLs due to failures, and another rate of conversions, or new installations of CFLs in applicable sockets that currently don't have them. Thus, the total number of installations in period t is the replacement rate ρ times the number in use in the prior period, U_{t-1}, plus the conversion rate ν times the remaining number of applicable sockets. The formula is shown below in Equation 1:

Equation 1 – Primary Installation Model

$$I_t = \rho U_{t-1} + \nu\left(A - U_{t-1}\right)$$

A different set of coefficients ρ and ν are estimated for each usage type. For saturated users, we expect the coefficient ρ to be equal to the inverse of the CFL measure life (EUL), expressed in the same units as the time increment t. For example, if the measure life is 7.5 years or 30 quarters, on average 1/30 of the CFLs in use need to be replaced each quarter. For saturated users, by definition, the number in use is equal to the number applicable. Thus, $A-U_{t-1}$ is zero.

For transitional users, we expect the coefficient ρ to be equal to the inverse of the CFL measure life. That is, as for the saturated users, the fraction of CFLs already in use that need to be replaced in each time period is 1/(CFL measure life). Likewise, in each quarter a fraction of applicable sockets that currently have non-CFLs have bulbs that burn out. For the transitional user these non-CFLs are replaced by CFLs. The number of such conversions on failure that occur in each time period is the number of applicable non-CFLs divided by the non-CFL measure life. Thus for transitional users the coefficient ν is the inverse of the incandescent measure life.

For partial users, the failure rates of CFLs and non-CFLs are the same as for saturated and transitional users. However, only a fraction f_c of failed CFLs will be replaced by CFLs, thus the CFL

[‡] As a separate effort, we are collecting detailed lighting inventories and house characteristics for a sample of 1,200 homes. We model applicable sockets based on house size using the inventory data, and apply the results to the survey-reported house size to estimate applicable sockets for the survey samples.

replacement coefficient ρ is expected to be the fraction f_c times the inverse of CFL measure life. Similarly, only a fraction f_n of failed non-CFLs will be replaced by CFLs. Thus, the new installation coefficient ν is expected to be the fraction f_n times the inverse of non-CFL measure life.

For non-users, the failure rate of CFLs is irrelevant because, by definition, they have none in use. The failure rate of non-CFLs remains the same as for all other user types. Similar to the partial user, only a fraction of the non-CFL burnouts will be replaced with CFLs, and the installation coefficient ν is expected to be the fraction f_{n0} times the inverse of non-CFL measure life. However, the non-user fraction f_{n0} is expected to be much lower than the fraction f_{np} for partial users. Ultimately any non-user who installs a CFL becomes a partial (or transitional user). For the sake of this paper's illustration, we will assume a very small f_{n0} for non-users, and will not incorporate the transition from non-user to partial user. Table 2 summarizes the theoretical values of the coefficients for the different user groups.

Table 2 – Theoretical Coefficients of the Primary Installation Model, by User Type

User Type	ρ	ν
Saturated	1 / (CFL EUL)	Not Applicable
Transitional	1 / (CFL EUL)	1 / (non-CFL EUL)
Partial	f_c / (CFL EUL)	f_{np} / (non-CFL EUL)
Non-user	Not Applicable	f_{n0} / (non-CFL EUL)

Installation Timing Model

The Installation Timing Model is based on the expectation that households will not be able to report when they purchased a particular bulb that they installed in the past quarter, or conversely when they installed or will install a particular bulb that they purchased in the past quarter. We simply survey customers on the total numbers purchased, stored, in use, and installed in each quarter.

A key conceptual simplification in this analysis is that we calculate installation timing on the assumption that the oldest bulbs are always used first. While this is not strictly true, it makes sense on average. That is, every time a newer bulb is used before an older one, the use of the newer one shortens the average time to installation, but the deferral of the older one increases that time by a similar amount.

We assume that we have a trajectory of the average numbers of CFL bulbs purchased, stored, in use, and installed during each quarter from the start of a CFL-promoting efficiency program. This trajectory is constructed from the Primary Installation Model above, as well as another Purchase Model, for each usage type. The usage type distribution is also estimated for each quarter, as outlined above.

Starting with any quarter q, we calculate the number of installations I_q during that quarter, using the installation model (Equation 1). We also calculate the number in use U_q at the end of the quarter. The number in use at the end of the quarter q is the number in use at the end of the prior quarter U_{q-1}, minus the number that failed during that quarter (based on the CFL measure life), plus the number of new installations I_q.

We then move to the next quarter, q+1. Starting from the calculated quarter q values I_q and U_q, we calculate the number installed I_{q+1} during quarter q+1 and the number in use U_{q+1} at the end. We proceed forward through time in this way, determining for each quarter from q forward the number installed during that quarter and the number in use at the end of the quarter.

Thus, for any starting program quarter q, we calculate for that quarter and several successive quarters k = q, q+1, q+2, etc.:

- The total number of installations during quarter k, I_k (from the installation model), and
- The total number in use at the end of the quarter U_k (based on the starting number U_{k-1} and the numbers replaced and converted, from the installation model).

Since we know how many were in storage at the start of quarter q, and by assumption we use the oldest CFLs first, we can then calculate how many quarters it takes to exhaust the CFLs that were already in storage before quarter q. We then determine how many CFLs bought in quarter q will be installed in each quarter after the prior storage is exhausted, until the quarter q-purchased CFLs are also exhausted.

Illustrative Results

Data collection and analysis for a current study are still in progress. Results are provided here for illustration only. ***These examples do not necessarily represent any specific estimates for any CFL program.***

Table 3 shows the Estimated Useful Life (EUL) assumptions for both CFL and non-CFL lamps. These values affect the replacement and conversion coefficients used for the installation model (described below).

Table 3 – Assumed Lighting EUL Values[1]

Variable	Value
CFL EUL	30 (quarters)
Non-CFL EUL	4 (quarters)

[1] These examples are for illustrative purposes only and do not necessarily represent specific estimates for any CFL program.

Table 4 consists of the values assumed by KEMA for partial user replacement and both non-user and partial user conversion rates. These are subjective estimates, and will be refined as actual data becomes available. Essentially, these numerical values represent consumer motivation towards replacing CFLs and converting to CFLs for consumers who fall into the partial user and non-user categories.

Table 4 – Assumed Non-user and Partial User Replacement and Conversion Rate Values[1]
Example #1

Variable	Value
Partial user CFL replacement rate f_c	0.3
Partial user non-CFL conversion rate f_{np}	0.2
Non-user non-CFL conversion rate f_{n0}	0.02

[1] These examples are for illustrative purposes only and do not necessarily represent specific estimates for any CFL program.

The replacement and conversion coefficients for the installation model – derived using the above assumed values – are shown in Table 5 below. These values determine the replacement rates, given consumer preferences and estimated useful life.

Table 5 – Derivation of Replacement and Conversion Coefficients[1]
Example #1

User Type	ρ	ρ	ν	ν
Saturated	1 / (CFL EUL)	0.033	0	0.000
Transitional	1 / (CFL EUL)	0.033	1 / (non-CFL EUL)	0.250
Partial	f_c / (CFL EUL)	0.010	f_n / (non-CFL EUL)	0.050
Non-user	0	0.000	f_n / (non-CFL EUL)	0.005

[1] These examples are for illustrative purposes only and do not necessarily represent specific estimates for any CFL program.

In order to illustrate the model, we assume the starting points shown in Table 6 for quarter q among the different user types. As shown, the saturated users have 100 percent of their applicable sockets filled with CFLs, both the partial and transitional users have CFLs in use in half of their applicable sockets, and non-users have no CFLs currently in use. Non-users have one CFL in storage while other user types have four CFLs in storage. Lastly, both saturated and partial users purchased two CFLs during Q_0, transitional users purchased three, and non-users purchased one.

Table 6 – Starting Point of Example Homes
Example #1

User Type	Applicable Sockets (A)	Number of CFLs		
		In Use in Q_0 (U_0)	In storage in Q_0 (S_0)	Purchased in Q_0 (P)
Saturated	28	28	4	2
Transitional	28	14	4	3
Partial	28	14	4	2
Non-user	28	0	1	1

With these assumptions and starting points, we calculate the following for each user type, for each successive quarter starting with quarter q:

- The total number of installations
- The number of these installations filled from storage from pre-q purchases
- The number of these installations filled from CFLs purchased in quarter q

With this information, we are able to calculate the fraction of CFLs from quarter q purchases that are installed in each quarter from q onward, as well as the total number of CFLs in use, on average, for each user type.

The most pertinent information gathered from the model outlined above is the average cumulative fraction of CFL installations of CFLs purchased in quarter Q_0, shown in Figure 1 below. This essentially provides a time-to-installation estimate for each different user type, given the assumed starting point numbers in use, in storage, and applicable from Table 6. When calculated with actual data, and analyzed in conjunction with the relative distribution of user types across a defined geographical area (a utility service territory, for example), the time-to-installation for all Q_0 purchased CFLs can be estimated. The full analysis will take into account that the fractions of customers in each user type will change over time along with the numbers in use and in storage for each user type.

This model allows us to predict the average number of CFLs in use across user types. Shown in Figure 2 (and predicted in the user type descriptions above), the saturated user maintains full saturation over the study modeled timeframe. The transitional user continues to increase the number of installations, never quite reaching the theoretical asymptote of full saturation (after all, a transitional user is no longer transitioning once they have reached full saturation). The partial user increases saturation more slowly than the transitional user, because only a fraction of failed nonCFLs are converted to CFLs, and only a fraction of failed CFLs are replaced by CFLs. Recall that in this example the numbers initially in storage were assumed to be the same for all three of these user types.

For simplicity, this illustration treats each user type as a fixed group with fixed replacement and conversion rates over the time period of the analysis. We do not model the simultaneous process of migration from one group to the next nor of increased conversion and replacement rates within the partial and non-user groups. Thus, the "non-users" in the illustration are households that were non-users in the initial quarter $Q_{0.}$ Strictly speaking, non-users do not have any CFLs in use, and therefore become partial or transitional users immediately after a CFL installation. In this example, the (Q_0) non-users have a very low conversion rate, such that after seven successive quarters they only have 1.1 CFLs installed, on average.

Figure 1 – Average Cumulative Fraction of CFL Installations of CFLs Purchased in Q_0 Over Time, by User Type—Illustrative Example #1

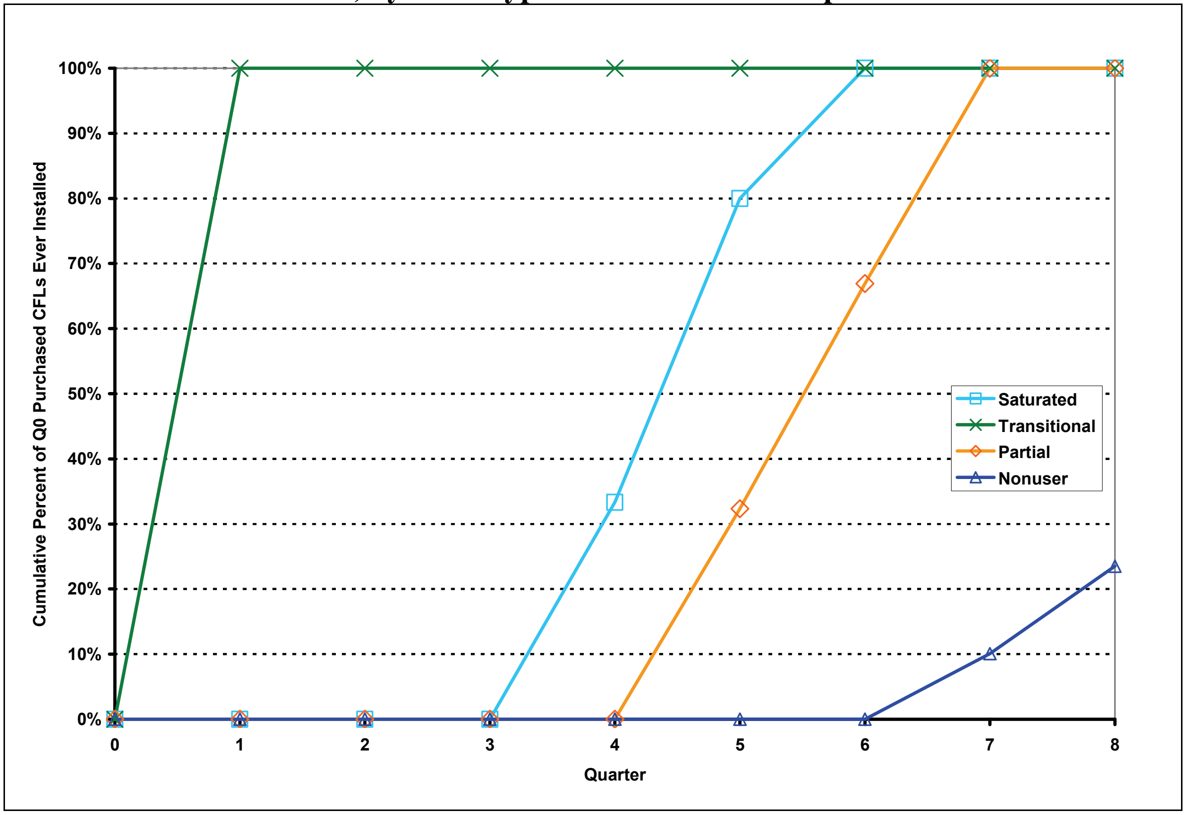
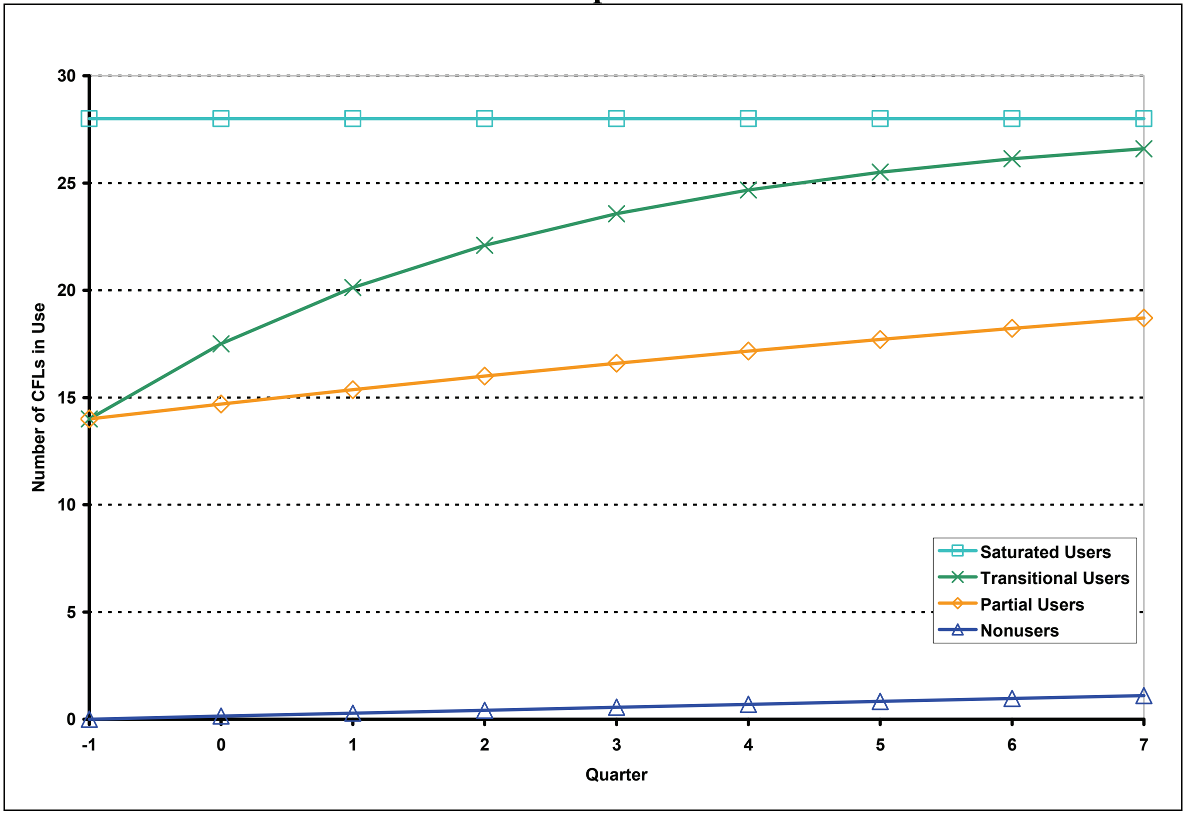


Figure 2 – Estimated Average Number of CFLs in Use Over Time, by User Type—Illustrative Example #1



In order to further demonstrate the responsiveness of the model to variation in survey data – an expected situation resulting from market differences between geographies – the starting point assumptions are changed in order to view another illustrative example.

Table 7 shows the assumed values for the second example. For this case, consumer motivation aspects of this model are shifted. The replacement rate for partial users has increased, while the conversion rates for both partial and non-users have decreased. This affects both coefficients ρ and ν for partial users, and also reduces ν for nonusers, shown in Table 8. Furthermore, the starting point values have been changed in this example, shown in Table 9, below. Numbers initially in storage are assumed to be highest for saturated users, and lower for the transitional, then partial, then nonusers.

Table 7 – Assumed Non-user and Partial User Replacement and Conversion Rate Values Example #2

Variable	Value
Partial user CFL replacement rate f_c	0.4
Partial user non-CFL conversion rate f_{np}	0.1
Non-user non-CFL conversion rate f_{n0}	0.01

Table 8 – Derivation of Replacement and Conversion Coefficients Example #2

User Type	ρ	ρ	ν	ν
Saturated	1 / (CFL EUL)	0.033	0	0.000
Transitional	1 / (CFL EUL)	0.033	1 / (non-CFL EUL)	0.250
Partial	f_c / (CFL EUL)	0.013	f_n / (non-CFL EUL)	0.025
Non-user	0	0.000	f_n / (non-CFL EUL)	0.003

Table 9 – Starting Point of Example Homes Example #2

User Type	Applicable Sockets (A)	Number of CFLs		
		In Use in Q_0 (U_0)	In storage in Q_0 (S_0)	Purchased in Q_0 (P)
Saturated	28	28	7	6
Transitional	28	11	6	3
Partial	28	15	3	1
Non-user	28	0	1	0.5

The outcomes of the above changes in assumed starting point characteristics are represented visually below. As shown in Figure 3, the cumulative fraction of installations of CFLs purchased in Q_0 over time changes significantly depending on the starting points and consumer motivation variables. In general, the installation curve shifts to the right (meaning longer times to full installation) for any of the following:

- Higher initial number in storage (meaning a greater number to be exhausted before the Q0 CFls begin to be installed)
- Higher numbers of CFLs initially in use (meaning fewer replacement opportunities)
- A lower frequency of replacing failed CFLs by CFLs among partial users
- A lower frequency of converting failed nonCFLs to CFLs among partial users and initial nonusers.

The estimated average number of CFLs in use over time, shown in Figure 4, below, does not change as much. This is largely due to the inherent qualities of the different user types. For saturated users, the number in place is essentially fixed. For transitional users, the number of CFLs in use over time depends only on the starting numbers applicable and in use.

For partial users, the rate of increase in the number of CFLs in use depends on the rates of conversion and replacement. The fraction of failed nonCFLs converted to CFLs makes a bigger difference than the rate of replacing failed CFLs with CFLs, since the failure rate is much higher for nonCFLs. For initial nonusers, the conversion rate is assumed to be quite low so that their usage remains near 0.

Figure 3 – Average Cumulative Fraction of CFL Installations of CFLs Purchased in Q_0 Over Time, by User Type—Illustrative Example #2

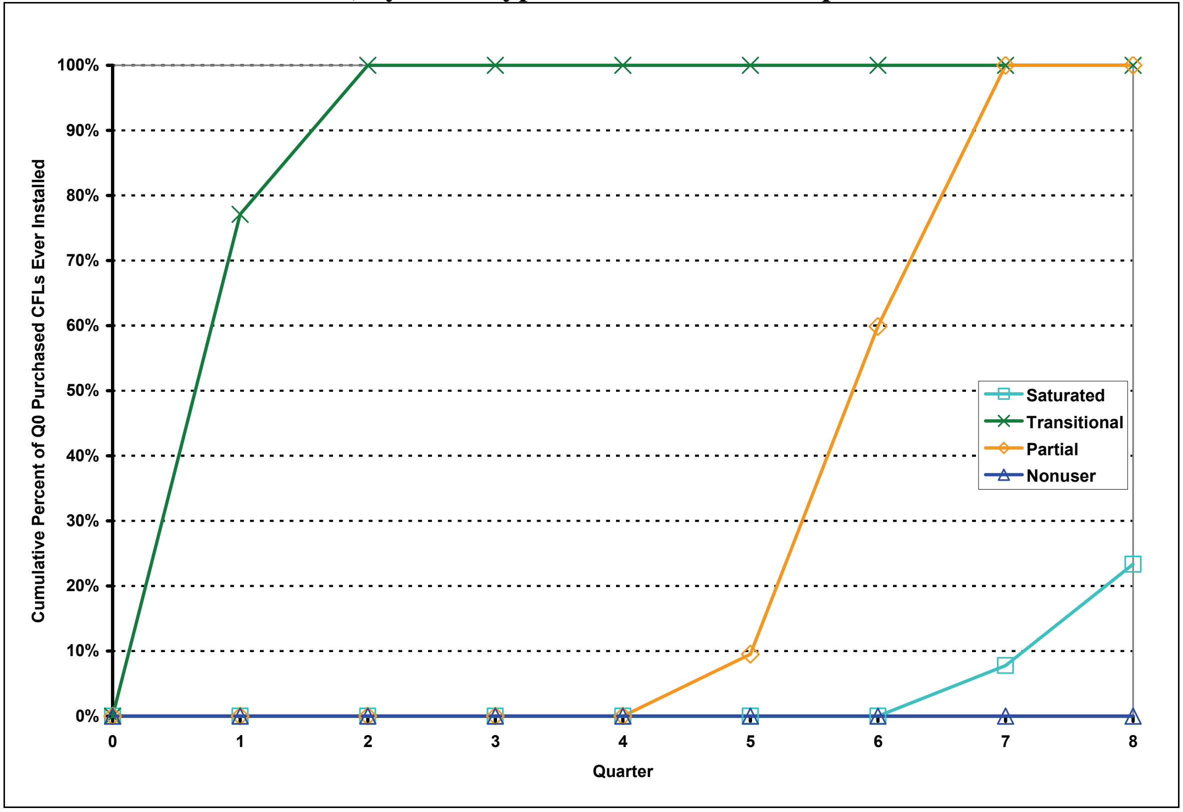
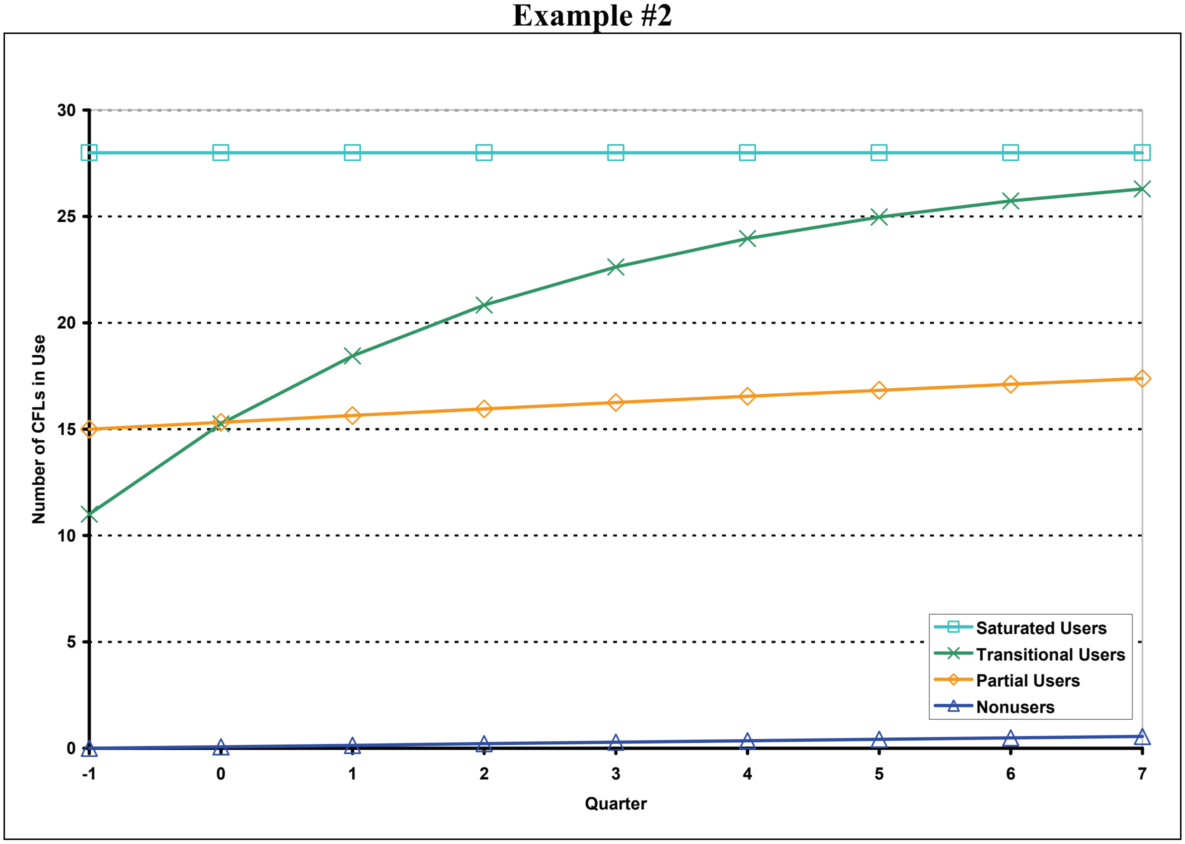


Figure 4 – Estimated Average Number of CFLs in Use Over Time, by User Type—Illustrative Example #2



Conclusions

This paper shows how the trajectory of CFL installation and use over time can be developed from survey data that can be meaningfully provided by household respondents. Households can also be logically classified by user type based on responses to a short survey sequence. The usage and installation patterns over time make sense for each user group and in comparison across user groups.

Promotional programs affect not only CFL purchase but also installation, retention, and replacement of CFLs. As illustrated in this analysis, once a customer has several CFLs in use and in storage, the time to installation for newly purchased CFLs may be several quarters. For newer CFL adopters the time may be much shorter. These differences affect comparisons of between areas with longstanding programs and those with new ones, in terms of purchase as well as installation rates.

Measuring installation rates simply in terms of the total fractions of program bulbs in use within the program period overlooks the dynamic nature of CFL purchase and use, and the full benefits that may be achieved over time. Even where purchase rates have been relatively high, programs have a role in maintaining the commitment of saturated and transitional users, raising the installation rates among partial users, and moving customers to higher levels of commitment.

The full modeling system will be estimated using data at the individual household level, rather than modeling an average home as in the illustrations presented here. Additional features to be considered in the full system include

- Conversion to or from CFL prior to failure
- Transition of homes from one user type to another, and
- CFLs in storage that are expected never to be installed.

Combining the installation models with purchase/storage models and with models for diffusion of user types will provide a rich framework for examining the effects of utility promotions over time.