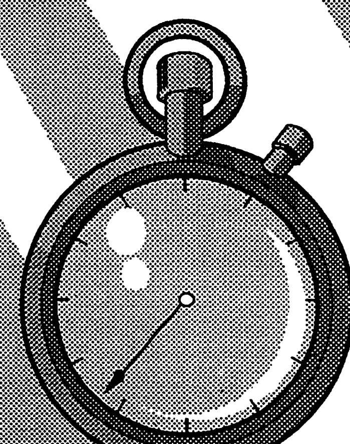
# BONNEVILLE POWER ADMINISTRATION

# MEASURE LIFE STUDY II



☑ *A Program Evaluation Report*

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**U.S. DEPARTMENT OF ENERGY - BONNEVILLE POWER ADMINISTRATION**

# Memorandum

DATE : November 7, 1994

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SUBJECT : Measure Life II Findings

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**Background**

In 1991, Synergic Resources Corporation (SRC) completed a study, Measure Life Study I, for the Bonneville Power Administration (BPA). This study examined longevity of electrical equipment e.g. (lighting) in commercial buildings. The findings revealed that renovations and remodels had significant impacts on the longevity of electrical equipment.

In July, 1994, a second study was completed by SRC under the direction of Bonneville to determine more precisely the effective measure lives of energy conservation measures (ECMs) and similar equipment; estimate equipment removal rates; determine if replaced equipment is more or less efficient; discover if there are any differences between rural and urban remodels/renovations; and estimate whether measure lives used in the Energy Smart Design program are reasonable.

**Methodology**

On-site surveys of 268 retail, office, and grocery buildings throughout Bonneville's service territory were conducted to examine indoor and outdoor lighting, space conditioning, refrigeration, water heating and envelope ECMs. A representative sample (N=178) of Pacific Northwest Non-Residential Survey (PNNonRES) buildings, 58 buildings from the Commercial Incentive Pilot Program (CIPP), and 32 buildings from the Commercial Audit Program (CAP) were utilized. Comparing data on equipment originally installed in these buildings to the results of the site visits for those same buildings several years later, suggests the likely length of time equipment or ECMs might be effective.

Equipment and measure lives were estimated by a number of methodologies depending on the information available. The primary method was a simple weighted average - the length of time like equipment or ECMs were in place, divided by the total ECMs. For instance, if a variable speed drive motor was in place for 6 years, that age was added to the age of other variable speed motors still in place at the time of the survey and divided by the total number of motors. Two motors in place for 6 years results in a weighted average (12 years divided by the number of motors 2) of 6 years.

The weakness of this methodology, as opposed to reported equipment changes or survival analyses, is the market tenure of equipment may be reflected rather than effective measure life. Some of the newer technologies simply have not been in place long enough to fail or be replaced through remodels or renovations. To correct for this and account for real world conditions, the maximum likely measure life is estimated to be twice the weighted average. In the example of the variable speed drives, the effective measure life would be 12 rather than 6 years. Because of this, and other data and analysis problems associated with this methodology, the following results should be regarded as indicative rather than conclusive.

## Findings

Table I shows broad equipment categories for the three business types and their associated measure lives broken out by urban/rural and small/large categories and the three databases.

**Table I**

**Equipment Categories and Measure lives**

| Indoor Lighting | All | PNNonRES | CIPP | CAP | Retail | Grocery | Office | Urban | Rural | Small | Large |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ballast | 10.0 | 10.5 | 8 | 20.5 | 9.5 | 15.6 | 9.8 | 9.6 | 16.3 | 14.4 | 9.7 |
| Bulb | 4.2 | 3.9 | 5.5 | 3.8 | 4.5 | 4.1 | 4.1 | 4.3 | 3.8 | 4.2 | 4.3 |
| Control | 22.9 | 21.8 | 25.3 | | 23.3 | 24.2 | 22.8 | 22.5 | 26.2 | 26.2 | 20 |
| Fixture | 21 | 20.5 | 19.3 | 34.5 | 21.3 | 20.5 | 21.5 | 20.5 | 25 | 24.9 | 18 |
| Reflector | 6.2 | 9.3 | | | | | 5.8 | 5.7 | | | |
| **Outdoor Lighting** | | | | | | | | | | | |
| Ballast | 15.7 | 17.8 | 7.3 | | | | 17.1 | 15.6 | 16 | | |
| Bulb | 6.1 | 6.4 | | | | | | 6.9 | | | |
| Control | 22.7 | 22.8 | 16.1 | 24.4 | 25.2 | 16.2 | 24.1 | 22.6 | 23.9 | 24.2 | 20.8 |
| Fixture | 21.8 | 22.2 | 12.2 | 26.3 | | | | | | | |
| **Equipment** | | | | | | | | | | | |
| Cooling Equipment | 19.9 | 20.4 | 15.2 | 22.0 | 16.6 | 17.8 | 20.8 | 20.2 | 17.9 | 19.5 | 20.3 |
| Cooling Compressor | 15.4 | 15.4 | 16.9 | 15.2 | 9.1 | 13.1 | 18.2 | | 16.6 | 15.4. | |
| Heating Equipment | 18.2 | 17.9 | 17.3 | 24.5 | 13.6 | 19.4 | 20.3 | 18.7 | 14.7 | 20.5 | 18.4 |
| HVAC Controls | 18.5 | 18.8 | 10.4 | | 20.6 | 18.1 | 17.9 | 16.9 | 26.7 | 23.5 | 14.8 |
| Refrigeration | 16.5 | 16.1 | 21.9 | | 14.2 | 19.3 | 19.5 | 16.5 | 20.9 | | |
| Ventilation | 23.4 | 22.9 | | | | | 24.1 | 23.3 | | 27.2 | 22.6 |
| Water Heating | 10.6 | 15 | 8.2 | | 15.2 | 13.2 | 11.6 | 11 | 11.2 | | |
| Cooking | 17.4 | 17.3 | 18 | | 18.8 | 15.6 | 17.9 | 17.5 | | | |
| Motors | 21.7 | 21.2 | | | | | 22.5 | 21.7 | | | |

## Other Findings

- Average building renovation rates for the three business sectors were estimated to be 10% annually compared to 40% found in the Measure Life I study.
- As with the Measure Life I Study, renovations are a major cause of equipment change/removal.
- Equipment/ECM failure is seldom a significant factor influencing equipment change/removal.
- Energy efficiency is a prime motivator for ECM installation.
- Removed equipment most often is disposed of in landfills.
- Building types with the longest and shortest key equipment lifetimes were grocery stores and office buildings, respectively.
- Most of the ECMs reflect measure lifetimes predicted for the Energy Smart Design Program.
- ECMs show similar lifetimes to standard equipment except for ballasts and HVAC controls which have slightly shorter lifetimes for standard equipment.

## Recommendations

For building types with high renovation rates (offices) or low ECM lifetimes, incentive program efforts should be reduced. Conversely, buildings with longer ECM lifetimes (grocery stores) should be targeted for increased conservation activity. Since energy efficiency is a key motivator in equipment replacement, marketing opportunities emphasizing efficiency should be utilized. With the documented high number of renovations and remodels in the commercial sector, this segment should be repeatedly targeted as a market opportunity for increasing energy efficiency.

If you have any comments or questions please call Curtis Hickman at BPA (503) 230-5853.

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# BONNEVILLE POWER ADMINISTRATION
# MEASURE LIFE STUDY II

**Final Report**

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ABSTRACT: MEASURE LIFE STUDY II (MLSII)

This study examines issues surrounding effective measure lifetimes, including renovation rates; maintenance, operation, and replacement practices; and estimated measure lifetimes for broad and specific equipment and ECM categories.

The estimated useful lifetime of energy conservation measures (ECMs) is important for DSM program planning. Although average service life data have been used as ECM lifetime estimates, changes are constantly occurring in commercial buildings -- tenants change, spaces are remodeled/renovated, or the functional use of the space changes -- and these changes may have significant impacts on on-site lifetimes of individual ECMs.

This study used data from an on-site survey of almost 300 buildings (and re-examined data from 300 additional buildings from a previous study) to examine more precisely the effective measure life of ECMs, given the real-world dynamics of the usage and maintenance of commercial buildings. The study concentrated on three particularly important business types -- office, retail, and grocery -- building types with historically significant conservation investment and/or high turnover/remodel potential. The survey examined ECMs in indoor and outdoor lighting, space conditioning, refrigeration, water heating, and envelope.

The analysis provided specific numeric estimates of measure lives that are representative of regional conditions, appropriate for program design and calculation purposes, (including targeting of measures and building types, if appropriate), and useful for modifying regional supply curves. The results of the study showed:

- approximately 10% of buildings in these sectors undergo renovation/ remodel on an annual basis;
- renovation/remodel is a key motivator for removal of some key equipment; however improved efficiency is the driver for lighting and ventilation. Equipment failure is only cited for a few equipment types.
- although the destination of much removed equipment is unknown, little in the responses indicate that much of the equipment goes anywhere other than a landfill, and the equipment is not generally available for reuse.
- most equipment showed lifetimes similar to ESD estimates, with the exception of controls, fixtures, ventilation, and motors, which seemed to indicate longer lifetimes. However, lifetime estimates for large categories of "new", more efficient equipment could not derived because the equipment had not been in the marketplace long enough to experience sufficient failures for the estimation. Some variations based on rural/urban, business type, size of structure, and other factors were noted in the report.

The results pointed out the significant role that renovation and remodeling can have on measure lifetimes, and validated many of the lifetime estimates being used currently. However, the study also pointed out that developing credible lifetime estimates for new equipment is difficult, given the types of program information being collected, and given the shortage of market tenure.

# EXECUTIVE SUMMARY

## EXECUTIVE SUMMARY

### A. INTRODUCTION

The estimated lifetimes of energy conservation measures (ECMs) are crucial inputs to DSM cost effectiveness calculations. Although average service life data have been used as ECM lifetime estimates, changes are constantly occurring in commercial buildings -- tenants change, spaces are remodeled/renovated, or the functional use of the space changes -- and these changes may have significant impacts on the on-site lifetimes of individual ECMs.

This study, the Measure Life Study II (MLS II) used data from an on-site survey of almost 300 buildings (and re-examined information from 300 more) to examine the effective measure life of ECMs, given the real world dynamics of the usage and maintenance of commercial buildings. The study focused on three business types: office, retail, and grocery. These business types were selected because they represent a high portion of commercial sector DSM investment by utilities, because they represent a large fraction of Bonneville's annual acquired kWh from the commercial sector, and because information from Bonneville's Measure Life Study I (MLS I) indicated relatively high renovation or turnover frequency.

The study drew buildings from three Bonneville databases:

- Participants in Bonneville's Commercial Incentives Pilot Program (CIPP). These buildings represent participants in a Bonneville conservation program. Approximately 70 CIPP buildings representing the three sectors of interest (retail, grocery, and office) and the use of this database increases our ability to include program-installed ECMs in the study.

- Buildings selected from Bonneville's Commercial Audit Program (CAP). About 50 buildings from the CAP program were available; these buildings are primarily non-urban type buildings. The use of this database increases the ability to note differences between urban and rural settings.

- Buildings from the Pacific Northwest Non Residential Survey (PNNonRES). Bonneville provided approximately 211 grocery, office, and retail buildings from the PNNonRES survey. This survey includes sample weights and provides a database that can be used to provide a statistically representative of buildings in the BPA region.

The objectives of the study were:

- Gather information about equipment operation and maintenance. Identify the disposition of replaced equipment, and examine the reasons behind equipment and ECM removal. Determine if equipment that gets replaced is replaced with more or less efficient equipment.

- Improve estimates of the impact that remodeling and renovation may have on typical equipment lifetimes. Examine the frequency with which ECMs and equipment are removed before the end of operational lifetimes. Examine differences in remodel and renovation frequency and lifetimes between urban and rural areas, business sectors, and other strata.

- Determine whether the current measure lives used in the Energy Smart Design Program are reasonable.

- Compare the results with MLS I.

The study included two main types of analysis: "measure life" analyses, and "non-measure life" analyses. The non-measure life analysis represented that part of the study dealing with issues related to measure life, but not directly used in estimating measure life. The non-measure life work is discussed first, followed by the results of the measure life work.

## B. RESULTS OF NON-MEASURE LIFE ANALYSES

The non-measure lifetime portion of the analysis concentrated on three issues:

- Maintenance procedures, maintenance frequency and staffing, and observed condition of the equipment

- Reasons for equipment change and removal

- Disposition/disposal of removed equipment

*Maintenance*

- Maintenance frequencies were known about 10-20% of the time, and frequencies were unknown almost half the time. Urban respondents were more likely to know maintenance frequency.

- Maintenance contracts are common for major end-use equipment (heating, water heating) and more common for urban buildings. No maintenance arrangements are commonly reported for smaller equipment (motors, refrigeration). Dedicated maintenance staff were somewhat more common for heating and water heating equipment, but are not generally common.

*Reasons for Change*

- Renovation/remodel was reported as a primary reason for equipment change for specific equipment types. It was cited as a reason for over 50% of changes for motors, HVAC controls, and ventilation (and in combination with building additions, represented more than 50% of the reason for changes in cooling systems). It was cited more frequently as the reason for change for groceries (cooling, HVAC controls, refrigeration, water heat, and outdoor lighting), was responsible for about 40% of urban changes in refrigeration, water heat, heating and cooling; and was a key reason for rural changes in lighting, ventilation, and HVAC controls.

- Energy efficiency was a key reason for changes in the lighting (indoor and outdoor) and ventilation equipment. Specific results showed efficiency as a key motivator for offices (for HVAC controls and lighting); groceries (for heating); and retail (for cooling, ventilation, water heating, and refrigeration); as well as higher reports for rural rather than urban locations.

- Broken equipment was cited as a reason for equipment changed in only limited cases, including cooling and water heating, and to a limited extent, refrigeration.

*Replacement of Efficient Equipment*

- Participant customers (CIPP) appear to have incorporated energy efficiency into their decisions on lighting and some other end-uses. Efficiency as a reason for changing equipment holds even if the old equipment being changed out is classified as efficient in the first place. They seem to be sensitized to energy conservation, noting these reasons more frequently than PNNonRES buildings where remodeling and other factors were more common. For indoor and outdoor lighting, refrigeration, and HVAC controls, the CIPP respondents with previous efficient equipment cited energy efficiency as the primary or secondary rationale for replacement. Note that lighting was also the focus of the CIPP program. However, heating equipment was more likely changed out for reasons more closely related to age of equipment or expansion needs.

*Destination of Disposed Equipment*

- The most common response for the destination of disposed equipment across the equipment categories is generally "don't know". Landfilling is the next most common response, and in particular, landfilling is reported for over half of lighting and water heating equipment. "Other" destinations are also reported frequently for lighting equipment. Landfilling was more commonly reported in urban respondents.

- A small fraction of removed equipment is stored or supplied to secondary markets, mostly heating equipment.

*Renovation/Remodeling Rates*

- Renovation/remodel rates are about 10% per year, with some differences between sectors (offices are higher, groceries lower, rural are lower). Measure lifetime patterns are consistent with and generally reflect renovation rate patterns.

*Comparison to MLS I*

- Common results include the findings that efficiency is a primary motivator for new equipment; failure or high maintenance is seldom cited; and that most removed equipment is landfilled (or sent to an unknown destination) and less frequently is sent to secondary markets.

- Differences between MLS I and MLS II results include greater reporting of maintenance contracts in MLS II; tenant changes and aesthetics are less frequently reported as reasons for change in MLS II; and that renovation/remodel was less frequently cited as a key reason for lighting, heating, and cooling changes than in the MLS I study.

## C. MEASURE LIFETIME RESULTS

The building information was analyzed, using several techniques, to derive estimates of equipment and measure lifetimes.

- Equipment with shorter estimated MLS II lifetimes than assumed program lifetimes largely included equipment that had not yet been in the marketplace long enough to be able to assume that the estimated lifetimes were reliable.[1] The lifetime estimates for these measures (efficient and electronic ballasts, variable speed drives, and economizers) reflected market tenure. However, although full lifetime cannot yet be known, the results do demonstrate that the measures have not experienced widespread early failures thus far.

- Some equipment seemed to display longer lifetimes than assumed for ESD or other programs included heat pumps, unit heaters, and some refrigeration efficiency measures and retrofit.

- The program lifetimes used by Bonneville were generally verified for economizers, time clocks, water to air heat pumps, HVAC controls (deadband thermostats, time clocks, and computer logic EMS), as well as some types of lamps, window treatments, and refrigeration technologies.

## D. IMPLICATIONS FOR ESD

The study has some implications for the design and operation of ESD and other DSM programs.

- Efficiency is a key motivator in equipment replacement, particularly for lighting and ventilation. This may provide Bonneville with intervention opportunities.

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[1]The main analytical method required an assumption that equipment replacements were in a "steady state" -- that there was a mix of original and replacement equipment in the buildings that represented the long-run balance. Although some of the equipment included in the study could reasonably meet that assumption (broad equipment categories like water heating equipment), some of the key measures could not reasonably be assumed to have been in the marketplace long enough to meet this requirement.

- Renovation/remodel is a significant reason for equipment change for several major equipment categories, including cooling, HVAC controls, ventilation, motors, and water heating. Renovation frequency is high in specific sectors, implying some targeting or outreach opportunities.

- Although generally, equipment is seldom replaced because it was broken, this was a key reason for equipment removal in several distinct end uses and business sectors. Developing a method to intervene in these specific types of "emergency" decisionmaking opportunities would likely provide a good opportunity to improve the efficiency of the installed equipment.

Measure lifetimes for ESD were difficult to determine or verify because the equipment incented under the program has not been on the marketplace very long. The analytical assumptions required to provide quantitative estimates (equipment replacements in steady state) could not be readily accepted for key equipment like electronic ballasts, variable speed drives, etc.[2] A few pieces of equipment may warrant assumptions of longer lifetimes than currently used (some heat pumps, unit heaters, and some refrigeration measures).

However, the nature of ESD and other utility programs is to assist in achieving the adoption of new, more efficient equipment more rapidly than would be experience with natural market adoption. This concentration on new and evolving equipment makes it difficult to obtain failure and lifetime information within a timeframe that is timely or useful to program design. For equipment that represents relatively minor engineering changes, the lifetimes of standard equipment may be an approximate metric. However, for equipment that performs a new function, is fairly radically new design, operates significantly differently, or affects behavior, accurate lifetimes beyond quantitative estimates provided by the manufacturer may be difficult to obtain. If the reported laboratory or historical equipment lifetime numbers are used, they should, however, be corrected for the evidence of business turnover.

[2]Although it is difficult to determine whether some of the measures with shorter indicated lifetimes in the MLS II study than program design assumptions actually have shorter lifetimes or just reflect tenure in the marketplace.

Analytical methods require some time lag to allow for sufficient equipment failures, and significant numbers of observations to conduct the estimates. By the time the lifetime estimates are available, the measures will no longer be cutting edge and may no longer be provided an incentive under the program.

## E. RESEARCH ISSUES

Existing DSM program databases do not generally lend themselves to application to measure life studies; this was not their primary purpose. Information consistency varies, the records are incomplete, and some data are unclear in interpretation. Further, the equipment is not marked or stickered once installed on-site, making it difficult to identify or "match" whether equipment noted in program records is still on-site. Therefore, this study relied on analytical approaches that did not require matching. It would be relatively easy in most cases to modify new utility DSM program records to include information needs that would support measure life work, and these data collection changes should be considered for important DSM programs. However, the results of this study show that the results of a one-time audit can provide fairly good information, suitable for estimating measure lifetime for equipment that is "mature" in the marketplace. The method proved less useful for "new", more cutting edge technologies that had not yet cycled in the marketplace.

## F. SUMMARY

This study provides some detailed quantitative and indicative results to measure lifetimes of a wide variety of equipment, as well as information on a number of factors that influence persistence of savings. The study provides findings that can be used to confirm or modify anticipated lifetimes, examined program design and cost-effectiveness calculations, and provide guidance for program and measure targeting/segmentation. As more detailed databases become available, and newer equipment is followed more closely (and has time to gain a failure track record), the measure lifetimes for newer equipment and ECMs will continue to be refined.

# I. INTRODUCTION AND STUDY OBJECTIVES

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## A. INTRODUCTION

The Bonneville Power Administration (BPA) and many utilities across the nation have designed and introduced a wide variety of commercial-sector energy conservation programs. Acquisition from commercial sector energy conservation measures (ECMs) are a primary focus in Bonneville's conservation activities because of the large load represented by the sector.

Calculating the cost-effectiveness of a program or determining the measures that will be provided or subsidized depends on a comparison of the region's ECM cost-effectiveness threshold with the (discounted) calculation of the measure's cost divided by the kWh savings measured over the number of years the measure was estimated to last (or deliver savings). These kinds of calculations are essential to determining the most cost-effective resource mix for the region. The estimated useful lifetime of ECMs is a critical input to program cost-effectiveness calculations.

The major inputs to the calculation of program cost-effectiveness are measure cost, kWh savings, and lifetime. Certainly, the ultimate savings of the program are a function of a broader range of factors, including not only measure retention, but also the performance of the measure, market progression, and other issues. However, this paper focuses on the issue of the effective on-site measure lifetime, and the factors that influence early change-outs.

Utilities have developed data on average service life for typical commercial end-use equipment, and these service life data have been used as estimates of the useful life of individual ECMs. But, recognizing that changes are constantly occurring in commercial and industrial buildings -- tenants change, spaces are remodeled or renovated and/or the functional use of the space changes -- considerable attention has begun to be placed on examining the impact of real-world operating and business conditions on the *in situ* lifetimes of commercial sector energy equipment.

Bonneville early recognized the potential importance of these questions on measure lifetimes and DSM program planning, and has sponsored research on aspects of service lifetimes and related issues since at least 1987. Bonneville studies have examined the test, operational, and effective measure lives of a wide range of ECMs and provided some preliminary downward adjustments in lifetimes to account for on-site conditions.

Bonneville's activities in this area can help assure that appropriate investments are made in the various alternatives available to Bonneville in meeting resource needs. If lifetimes are too long for some measures, utilities may be over-investing in that measure. If the measure does not last as long as planned, the actual cost per kWh delivered rises. In that case, the program may not compare as favorably to investment in other resources in the mix, and Bonneville's program investment levels may not be appropriate.

Bonneville's recent Measure Life Study (MLS I, 1991) was designed to provide indicative information about the extent to which energy using equipment is affected during remodel, renovation, and turnover events in the commercial sector, and to indicate volatile business types and vulnerable measures.

The current follow-on study, Measure Life Study II (MLS II) conducts additional research to examine in greater detail the effective measure lifetime of ECMs and specific energy equipment types, given the real world dynamics of the usage and maintenance of commercial buildings.

## B. OBJECTIVES OF THE STUDY

The scope and objectives of this study are to enhance the work started in MLS I, but to further investigate measure life implications for important business types and to concentrate on providing statistical, quantitative estimates of measure lives for the measures encountered in the study. The study concentrates on three commercial business sectors: retail, grocery, and office. The objectives of the MLS II are:

- Improve estimates of the impact that remodeling and renovation may have on typical equipment lifetimes. Examine the frequency with which ECMs and equipment are removed before the end of operational lifetimes.
- Estimate the frequency of equipment removal from non-participant buildings due to renovation and remodel.
- Determine if equipment that gets replaced is replaced with more or less efficient equipment.
- Examine differences in remodel and renovation frequency between urban and rural areas.
- Determine whether the current measure lives used in the Energy Smart Design Program are reasonable.

MLS I had a broad objective. The study examined renovation rates in all commercial building types, and examined the extent of changes in all end uses due to remodel, renovation, and turnover. This broad mandate necessitated the use of broad equipment categories; limited the number of buildings of each type that could be included in the site visits; and supported only indicative or qualitative results for changes to equipment or ECMs. In addition, few program participant buildings were included.

The MLS II is designed to go beyond the work from the MLS I study in several key ways:

- provide a larger sample for each business type;
- include a larger number of buildings with existing ECMs;
- incorporate a more representative sample;
- derive more representative information about estimated turnover/ renovation/remodel rates; and
- support more quantitative analysis to allow discussion of specific lifetimes of measures and end use equipment.

To support more quantitative and targeted analysis, the data for this study were derived from three sources:

- Participants in Bonneville's Commercial Incentives Pilot Program (CIPP). These buildings represent participants in a Bonneville conservation program. Approximately 70 CIPP buildings representing the three sectors of interest (retail, grocery, and office) and the use of this database increases our ability to include program-installed ECMs in the study.
- Buildings selected from Bonneville's Commercial Audit Program (CAP). About 50 buildings from the CAP program were available; these buildings are primarily non-urban type buildings. The use of this database increases the ability to note differences between urban and rural settings.
- Buildings from the Pacific Northwest Non Residential Survey (PNNonRES). Bonneville provided approximately 211 grocery, office, and retail buildings from the PNNonRES survey. This survey includes sample weights and provides a database that can be used to provide a statistically representative of buildings in the BPA region.

The use of these three databases as the source for the on-site sample provided the possibility to improve previous work in several ways:

- PNNonRES provides buildings from a sample that are representative of the BPA region, so it provides some ability to generalize the impacts beyond the specific sample.

- all the buildings were visited 3 to 5 years ago and a great deal of information was collected.

- use of the databases offers the opportunity to examine changes and lifetimes based on both *program participants (CIPP) and non-participants*,

- the focus on three business types allows larger sample sizes for each sector, and supports greater confidence in the results.

- provided the ability to generalize beyond the geographically limited sample in MLS I (the databases cover a broader area, and the PNNonRES "represents" the region).

- the sample includes non-urban as well as urban buildings, supporting some analysis of the hypothesis that retention may higher in rural areas due to lower remodeling or other effects (CAP enhanced the rural sample).

The focus on three business types (retail, grocery, and office) also allowed larger sample sizes for each sector, and supported greater confidence in the results. These three business categories were selected for several reasons:

- these business types include a large percentage of the commercial sector,

- these business types are the focus of considerable amounts of conservation program investment,

- the ECMs that tend to be installed in these sectors include end-uses that showed volatility in MLS I, and

- MLS I indicated relatively high turnover for several of these business sectors.

Specifically, these three business types were responsible for 55% of the kWh acquired by Bonneville's Energy Smart Design (ESD) program in fiscal year 1993. Offices ranked as the umber one business type, retail was number three, and groceries were number five in terms of acquired kWh (mixed use and commercial hotel/motel/residential-type buildings were second and fourth, respectively). Note that an ability to examine both large and small buildings is also useful, as only 11% of the acquired kWh were from small buildings.

## C. SUMMARY OF APPROACH

Generally, the steps involved in completing the work included:

- refining study objectives;
- devising an appropriate survey instrument, review by interested parties, developing survey procedures, pre-testing, and revising the instrument;
- obtaining and massaging the three databases, and printing over 300 surveys incorporating pre-coded information on installed equipment noted in the last audit;
- scheduling and conducting on-site audits;
- constructing the database, incorporating data labels, and linking with the previous databases; and
- conducting the analysis of the data.

Bonneville supplied the buildings list from three BPA datasets; specifically the PNNonRES (a representative sample of buildings in the area); CAP (Commercial Audit Program, consisting of buildings that include observations in more rural areas); and the CIPP (Commercial Incentives Pilot Program, consisting of participants in a BPA conservation program). A total of 268 buildings were included in the on-site survey.

After the draft on-site survey instrument was developed, it was reviewed by Bonneville and an independent engineer, funded by Bonneville. Databases were linked so equipment and other information from the previous surveys and audits from the three input databases could be transferred directly (electronically) onto the printed survey instruments. The survey instruments were pretested and revised based on the suggestions from the field teams. The survey instruments were constructed to collect higher priority data early in the survey, and the auditors were instructed to make locating the equipment from previous surveys one of the highest priority. Appointments were scheduled with the building managers for on-site surveys. The field teams consisted of experienced engineers/auditors, and each auditor was accompanied on at least one audit by an independent engineer. The survey forms were validated by a lead engineer, and the survey information was keypunched. The database was constructed, tabulations were run to check for invalid information and the database finalized and prepared for analysis.

Several analytical approaches were developed and tested. Based on an assessment of a broad range of considerations, a method based on the age distribution of equipment was used in developing the measure life estimates included in this report.

A summary of the completed surveys by data source, business type, and rural/urban classification is presented in Table I-1 below. This report summarizes the results of the analysis of the MLS II data.

**TABLE I-1:**
**Distribution of MLS II Buildings Data**

| MLS II Data | Number of Buildings | Percentage |
|---|---|---|
| Source Data Set | | |
| PNNonRES | 178 | 66% |
| CIPP | 58 | 22% |
| CAP | 32 | 12% |
| Business Type | | |
| Retail | 88 | 33% |
| Grocery | 45 | 17% |
| Office | 135 | 50% |
| Urban/Rural Indicator | | |
| Rural | 41 | 15% |
| Urban | 227 | 85% |

## D. USE OF AN INDEPENDENT REVIEWER

In order to provide on-going, objective scrutiny to project efforts, Bonneville funded efforts of an independent engineer. The selected engineer, Will Miller, of Criterion, Inc., was retained to assist Bonneville and the consultant team in several ways. His efforts on the project included:

- reviewed and provided comments on the draft survey instrument,
- co-led the on-site training session,
- accompanied each of the on-site engineers on multiple on-site visits to monitor specific staff quality and customer abilities, consistency in filling out surveys, and to identify problems with the survey prior to full implementation,
- provided revisions to the survey instrument to incorporate issues noted during the pilot survey (flow, content, length),
- responded to questions about the specific programs, measures, and programmatic databases used,
- assisted in defining measures, helped determine categories and measure listings included, and provided a ranking of relative measure efficiencies to support "categories" for analysis purposes,
- developed recommendations for analysis activities,
- reviewed and provided comments on the draft report, and
- attended and commented at a meeting reviewing the draft report and methodology.

Mr. Miller's depth of understanding of ECMs, especially in the lighting area, his experience in the conduct of this type of on-site verification audits, his familiarity with the design and on-site implementation of Bonneville's programs, and his background in commercial buildings in the region provided a valuable perspective throughout all stages of this project.

# II. NON-MEASURE LIFETIME ANALYSES

# II. NON-MEASURE LIFETIME ANALYSES

## A. INTRODUCTION

One key emphasis of this study was to gather information that could help provide an understanding of the factors that affect early changed. This part of the study, the portion which was not directly used in estimating measure life, was designated the "non-measure lifetime" analysis. A variety of factors were explored that related to measure retention, decision-making, and disposition and have implications for both program design and evaluation. In particular, this study examined:

- *Reasons for change:* The underlying reasons for removing equipment may provide information to indicate how far from operational lifetimes measures should be assumed to last on-site, and provides information on program design issues. If "looks" are a key change factor for certain equipment in certain business types, that might influence the program design and measure availabilities. If renovation/remodel is a key reasons for changeouts, revisions to the cost-effectiveness calculations may be appropriate for volatile sectors or measures.

- *Disposal of equipment:* The ultimate destination of disposed equipment may shed light on the length of time for which equipment may be able to provide savings. If equipment is put into another location within the building, or if it is sold to a secondary market, the equipment may still have a chance of providing the region with savings, even if it has been removed from the original installation. If removed equipment goes to the landfill, savings are not on-going.

- *Maintenance procedures:* How well equipment is being maintained may be assumed to have a direct impact on the lifetimes of measures. The survey asked questions related to maintenance frequency, observed condition of the equipment, and maintenance staffing/contract arrangements.

The analysis was conducted in two ways.

- First, the information was analyzed using the direct survey responses: that is, for all respondents, the results for the buildings are reported with equal weights (or "unweighted")[1]. This allowed us to examine the behavior of program participants (CIPP) compared to other buildings (PNNonRES and CAP). It also allowed a focus on differences for more rural settings (CAP buildings).

- Then, because the PNNonRES buildings provide a representative sample of buildings in the region, weighted results were also analyzed. Only PNNonRES data could be included in the weighted results, because it is the only one of the datasets designed to be statistically representative of buildings in the region. These results were examined on an "overall" basis, as well as segmented by type of business (retail, grocery, and office), and urban/rural areas.

A summary of the results are presented and discussed in the following sections. The results are based on Tables B-1 through B-4 in Appendix B, which summarize the cross tabulation tables included in that Appendix. Particular attention is paid to the following:

- Destination of Disposed Equipment;
- Equipment Maintenance and Procedures;
- Reasons for Change;
- Differences between CIPP (Participant) and Other Buildings;
- Comparisons to MLS I Results; and
- Implications for Program Planning.

The following sections provide a summary of the results of these analyses. Detailed topic-by-topic information is provided in Appendix B, including detailed discussion of the results, the tables of results, and graphical illustrations of key results. A summary of key results appears at the end of this chapter.

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[1]The use of data from multiple databases selected in different manners would not support developing statistically reliable "weights" to aggregate the data from the datasets to "represent" buildings in the region.

## 1. Equipment Maintenance

*Maintenance Indicators:*

- Based on visual inspection, cooling equipment showed the greatest degree of rust and general dirtiness, followed by HVAC controls. Equipment was generally noted to be dirty or rusty more frequently in rural, rather than urban, buildings.

- Buildings reported a known maintenance frequency approximately 10-20% of the time. However, no equipment maintenance frequency and no specific special conditions were reported for about half of equipment installations. Generally, maintenance frequency was known more often in urban buildings.

*Procedures:*

- Using contracts for equipment maintenance is common for major equipment types. This arrangement is especially common for heating equipment, and water heating systems. Contracted maintenance is also somewhat more common in urban settings.

- No particular maintenance arrangements and no dedicated staff were reported for a significant share of refrigeration and motor equipment. This response is more common in rural locations.

- Dedicated on-site staff devoted to maintaining equipment was seldom used for cooling equipment in this region, but was a more common option for heating and HVAC controls, and for water heating equipment. Using dedicated off-site staff or general staff was not very commonly reported.

## 2. Reasons for Equipment Change

*Changes due to Renovation and Remodeling:*

- The results show that when equipment is removed or changed, renovation and remodeling is given as a primary reasons for over 50% of changes for several key equipment types, including: motors, HVAC controls, and ventilation systems. Generally, renovation and remodeling is given as a reason more frequently in the grocery sector, and is given as the reason significantly more often for cooling, HVAC controls, refrigeration and water heating, and outdoor lighting equipment.

- Renovation and remodeling activity is stated as the reasons for equipment changes in urban locations more frequently than in rural setting for several equipment types, including refrigeration, water heating, cooling and heating equipment. Heating system changes are attributed to renovations about 40% of the time in urban locations. Respondents from rural installations cited renovation activity as the key driver more frequently for lighting systems, ventilation, and HVAC control systems.

*Other Reasons for Equipment Change:*

- Energy efficiency was a key driver for replacement of lighting (both indoor and outdoor) and ventilation equipment.
- The office sector, in particular, noted equipment efficiency as a key factor for HVAC controls and indoor lighting. Groceries noted efficiency as a key driver of equipment changeouts for heating systems.
- The retail sector cited equipment efficiency as a prime reason for equipment removal more frequently than grocery or office buildings for some key equipment categories, including cooling, ventilation, water heating, and refrigeration.
- Broken equipment was a significant reason for change only for a few end-uses, including cooling systems (primarily in offices), water heaters (especially in offices and retail), and refrigeration (exclusively in groceries).
- Rural buildings report concern with energy efficiency as the reason for equipment changeouts more frequently than urban buildings (except for HVAC controls and water heating systems).

## 3. Destination of Disposed Equipment

- Removed equipment is seldom sent to secondary markets or used elsewhere within the building, and only a limited amount of equipment is reported as stored: some indoor lighting equipment in urban locations, some heating systems in rural or retail buildings, and motors in urban installations (generally in offices).

- When heating equipment is removed, retail buildings report storing the equipment. This represents one of the highest responses for equipment storage. A relatively high share of offices report sending removed heating equipment to a secondary market. Groceries landfill this removed equipment.

- Landfilling is the most common destination, with approximately half or more of the removed equipment going to landfills for indoor and outdoor lighting, and for disposed water heaters (which were more often removed because they were broken than other equipment types). Landfilling is more commonly reported from urban buildings.

- Most removed indoor lighting equipment is sent to the landfill (about half), and another 10% is stored. Virtually all of removed outdoor lighting equipment is landfilled.

- For most other end uses, "don't know" is the most common response for the destination of removed equipment.

## 4. Differences between CIPP and Non-Program Buildings

CIPP buildings provided data on program respondents, including information on preferences, procedures, and changes in equipment after program participation. The CIPP responses differed from non-Program buildings in a number of ways.

- *Maintenance:* CIPP buildings were less certain of the maintenance frequency for heating and refrigeration equipment than other buildings, and a higher percent of these buildings were reportedly rusty or dirty. This was also true for ventilation equipment. However, for cooling equipment and water heating equipment, CIPP buildings had higher known maintenance frequencies, but reported formal maintenance arrangements less frequently. Motors were also apparently less maintained in CIPP buildings. There were no patterns of differences for HVAC controls equipment.

- *Reasons for change:* Payback and efficiency rationales were cited by CIPP respondents more frequently than other respondents in describing reasons for changes to equipment, especially for lighting (indoor and outdoor), ventilation, heating, and HVAC controls. Although energy reasons are important, CIPP buildings also cited older equipment as a motivator for change in the cooling and ventilation sectors. One of the key differences was that CIPP participants cited renovation as a reason for change far less frequently than did PNNonRES buildings. Renovation activity was a significant reason for change among PNNonRES buildings.

- *Equipment disposal:* Non-program buildings (PNNonRES) reported sending a greater share of lighting equipment to the landfill than did CIPP buildings, but CIPP respondents reported not knowing the destination more frequently. CIPP respondents reported sending equipment to the landfill in greater percentages than in other buildings for the following equipment: HVAC controls, outdoor lighting, and heating (considerably more frequently, 54% vs. 29%). CIPP buildings reported the destination as "secondary market" less frequently than did PNNonRES buildings.

## 5. Implications for ESD

- The results show that equipment efficiency is a key motivator in equipment replacement for these three sectors. This may provide significant opportunities for intervention by the program with a receptive audience.

- Renovation/remodeling is also a significant reason for equipment removal, depending on equipment type. Coupled with the renovation rate information presented in Chapter II, ESD may wish to target outreach to certain sectors or measures, or refine cost-effectiveness calculations to reflect the degree of changed due to renovation.

- Although dirt and rust was found for some equipment, maintenance contracts or dedicated on-site staff are reported to be relatively common in these three business types, particularly for major equipment categories.

- "Broken" equipment is not a significant factor in equipment replacement except in the case of water heaters and, for groceries, the refrigeration equipment. Generally, chances in equipment appear to be driven by other factors prior to equipment demise. Although limited in number, these cases may provide specific opportunities for program intervention. Programs that wish to impact these end-uses may need to find an effective route for reaching customers who need to make decisions under more "emergency" conditions -- energy efficiency may not be primary on suppliers minds as they deal with customers in this situation.

## 6. Comparison to MLS I Results

- As with MLS I, we find that a large percent of respondents state that energy efficiency of new equipment is a major consideration when considering replacement (80% MLS I).

- Like MLS I, equipment failure or high maintenance costs were not commonly cited, although these were reported as a factor in small offices.

- Maintenance in the commercial sector shows dedicated staff or contract arrangements for a relatively high percent of equipment (between 40-50% for refrigeration and motors; much higher percentages (70-90%) for heating, cooling, ventilation, and HVAC controls systems. This is higher than noted in MLS I.

- MLS I noted that removed equipment is most commonly disposed of in a landfill, and less commonly sold to a secondary market or used in another location. In addition, MLS I noted that a large percentage of respondents did not know the ultimate disposal destination of removed equipment. These conclusions were also found from the analysis in MLS II.

- Tenant changes or aesthetics were reported as reasons for equipment change less frequently in MLS II than in MLS I. However, MLS I focussed on "soft remodels" to a greater extent.

- MLS I found that renovation almost always affected lighting systems, as well as heating, cooling, ventilation, and HVAC controls. MLS II found that renovation/remodel was reported as the primary reason for change in at least 40% of motor, HVAC control and ventilation systems. However, renovation/remodel was cited as the primary driver for indoor lighting, heating, and cooling only about 15% of the time.

- MLS I results reported that equipment being at the end of its life was not a significant factor in equipment replacement decisions for these sectors. MLS II confirmed that finding. MLS II also found that energy efficiency was a prime consideration in new equipment, as did MLS I.

More detailed information, specifically pointing out the results for different datasets and implications generalized to the three business sectors across the region, are provided in Appendix B. The Appendix also includes the specific tables of results and figures illustrating key results across different groups of buildings (urban/rural, etc.).

## 7. Summary of Non-Measure Life Results

Review of the factors affecting lifetimes show the following results:

*Reasons for Change:*

- Renovation, remodeling, and building additions are the most commonly-reported reasons for equipment change for cooling, HVAC controls, ventilation, and motors. These reasons combined account for about 50% or more of changes for all these sectors.

- Efficiency-related considerations are the drivers for indoor and outdoor lighting and ventilation (30-40%); they are somewhat less important in heating and HVAC controls equipment changes (13-18%).

- Broken equipment is a major factor in replacement of cooling and water heating equipment (20% and 59%, respectively).

- Aging equipment and high maintenance costs are prime drivers in the changed of heating equipment.

*Disposal of Equipment:*

- Don't know is the single most commonly reported answer for the destination of all removed equipment except lighting.

- Landfilling is the next most common response regarding destination of equipment, with highest reports from lighting and water heating (43%-89%). Another common response for indoor lighting was "other" (accounting for 29% of responses).

- Heating was the only equipment type with a significant share reporting secondary markets or "storage" as destinations for removed equipment (a total of over 40% of equipment).

*Condition of Equipment:*

- None was the most common response across all end uses, generally reported by over 50% of cases.

- Cooling, HVAC controls, and ventilation equipment were reported in "generally dirty" condition between 21%-24% of the time. Rust was also reported for this and heating equipment between 11-14% of the time.

*Maintenance Staffing:*

- Contract maintenance is the most common arrangement for maintenance for all equipment except refrigeration.

- "None", indicating no obvious signs of rust or dirt, and/or no regular maintenance schedule is most commonly reported for motors and refrigerators. These equipment types typically do not require much ongoing maintenance, with sealed bearings, etc.

- Dedicated on-site staff are not a common arrangement, occurring in 9-12% of the cases for Heating/HVAC control equipment, and water heating.

# III. DERIVING MEASURE LIFE ESTIMATES

# III. DERIVING MEASURE LIFE ESTIMATES

## A. INTRODUCTION

Using field data for calculating measure lifetimes presents some special problems. In the ideal case, data could be collected that would support estimation of lifetimes using a "survival analysis" technique. Survival analysis requires data be known on the type of equipment installed, date of installation, date of removal/failure, and preferably, reason for removal/failure. However, unless the original program was designed with this purpose in mind, it is rare that the data would be sufficient to support the estimation using this technique. Specifically, the problems with implementing this approach include:

- Determining whether the noted equipment (or the program-installed equipment) is still in place is problematic. Only in very rare cases was the equipment labelled with a sticker or other identifier. Nor do program records often include a map or floor plan noting the installation location. For lighting and other equipment it can be difficult to determine *which* equipment was installed as part of the program. In addition, defining a "match" may include not only type of equipment, but for instance, number of fixtures installed. If the count doesn't match, which is program installed equipment, and how should it be counted.

- There can be conflicts between database records and customer-supplied information. For example, the database reports that an economizer was installed, but the customer reports it was never installed and/or the on-site auditor cannot find the equipment. Another example is one in which the customer insists a certain piece of equipment was installed during the program, but the program records indicate otherwise.

- Even in cases where the records, the site inspection, and the customer all indicate that the measure was removed, the date that the measure was removed may not be available. Customers often do not recall the date, or staff that may recall the date may not be available.

- Defining when a measure has "failed" may not be obvious. For the purposes of this study, removal was the type of failure noted. However, we also examined the general condition of the equipment. More complex studies may examine both the presence and continuing performance of the measure (potentially through on-site testing or metering).

- The program participant buildings may install only a subset of the wide range of equipment allowed under programs. This may lead to sample sizes that are too small to support the estimation of lifetimes for particular measures of interest.

- Some measures of interest may have been in the market too short a time to gather a history of enough failures to derive an estimate of lifetime.

Although some program databases are very detailed, the databases used for this study were not specifically designed to support measure retention analysis. The on-site auditors for this project were instructed to give high priority to finding the equipment noted on the survey forms. However, during the preliminary analysis phase, we determined that there seemed to be an unacceptably high percentage of equipment that could not be found on-site. Had the simple assumption been made that all non-matched equipment must have been removed, the analysis would likely have led to short lifetime estimates. In fact, this problem of non-matching could derive from a number of reasons, including: equipment could have been removed due to failure, remodel, renovation or replacement; there may have been original or new database errors; or the equipment was on site but was not located by the auditors. Given the numbers, it did not seem appropriate to assume that all non-matches were attributable to the first reason. In addition, dates for removal were only recalled for about 50% of the equipment changes. Finally, the records for dates for installation of equipment only provided information for the fiscal year of installation, leading to some fuzziness on the age of the equipment.[1]

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[1]The importance of locating this equipment was emphasized to the on-site surveyors, and this was a priority over gathering information on low-priority end-uses or non-equipment information during the on-sites. In addition, the ordering of the end-uses on the survey instrument reflected relative priorities of the end-uses, so if an interviewee terminated the on-site visit prior to completion, information on the highest priority equipment was collected.

The following table reports the percentage of observations for which equipment and ECMs noted on the CIPP, CAP, or PNNonRES databases could be located and matched. In the first set of columns, a strict match was employed; the second set of columns did not require the actual *number* of light fixtures to match. The vast majority of matches were obtained from the PNNonRES database. Matches for CIPP were only obtained for indoor lighting where CIPP data were matched 10.2% of the time under a strict criteria or 60% under the less rigid matching routine.

**TABLE III-1:**
**Percentage of Equipment from CIPP, CAP, and PNNonRES Databases found On-site in MLS II[2]**

| Equipment Type | Type and Number Match | Type Only Match |
|---|---|---|
| Indoor Lighting | 18.2 | 61.1 |
| Outdoor Lighting | 25.6 | 52.0 |
| Water Heating | 49.1 | 72.9 |
| Ventilation | 48.4 | 54.1 |
| Refrigeration | 31.0 | 51.6 |
| HVAC Controls | 63.9 | 63.9 |
| Heating | 27.2 | 42.7 |
| Cooling | 35.4 | 62.0 |
| Cooking | 31.3 | 39.3 |

Logically, the equipment types with the largest matching percentages are water heating, cooling, and HVAC equipment. However, the fact that the "existing" equipment for even these types could only be located 40% to 73% of the time, even under the condition that the correct

[2]The table presents results using two matching criteria: the strict matching requires both detailed type and quantity of equipment noted in the origin data set and the MLS II on-site to match; the less strict matching method requires only detailed equipment types to match.

*number* of pieces of equipment does not need to match, leaves little confidence that the only reason for equipment "non-matches" was that the equipment was removed.

## B. DISCUSSION OF ANALYTICAL METHODS

Several analytical methods were tested for use in this project. Each had strengths and weaknesses. The approaches, and their pros and cons are briefly described below.[3]

- *Survival analysis*: In this method, equipment that was noted to be on-site during the original on-site would either still be there or would be removed, and the percentages and dates of removal would provide the basis for survival analysis. Some of the sample would fail or be replaced by the time of the MLS II equipment surveys; from these failure proportions and dates, expected measure lives could be inferred for different equipment classes. This is a credible analysis method, but the data did not provide high enough quality to support the method. Relying on matches would lead to unreasonably low measure lifetimes, with low credibility. A simpler *matching method* could also be used, where although the specific date of the demise of the equipment was unknown, the window of failure dates would be known and could be used. Again, however, the ability to find or "match" the equipment was low, and the calculations would not provide high reliability estimates of measure lifetimes.

- *Using building ages and equipment change information*: In the absence of good baseline, it may be possible to combine data on equipment and building ages to derive measure lifetimes. By comparing the age of current equipment with the ages of the building, one may infer whether or not original equipment (installed at or near the time of the building's construction) is still in place. In effect, one can perform a survival analysis on the building's original equipment. However, we do not actually know how many equipment failures there have been from building construction to the MLS II survey data. All we know is that at least one failure occurred (the current equipment is not the original equipment) or no failure has occurred (current equipment is the same age as the building). In the case of long-lived equipment, it may be reasonable that in most cases, no more than one change has occurred over a period of 30

[3]Appendix A includes more detailed discussion of these various analytical methods.

or more years. This is an untenable assumption in the case of shorter-lived equipment. However, data needs for this method are fairly limited.

- *Using reported equipment changes*: Survey respondents were asked if an when equipment had been changed. From their responses, it is possible to develop estimates of population rates of equipment change and expected measure life. If the population average rate of equipment change is constant over time, the time between changes can be modeled, and the rate of change calculated as the total number of changes in the equipment class divided by the total time in equipment years that all the equipment was under observation (or a similar analysis can be done for each piece of equipment). Unfortunately, employees do not have perfect recollections, staff may have been ignorant of changes that occurred in the past, and the changes would be increasingly underreported further back in time. The approach hinges on an information tradeoff -- memories of equipment changes are likely to be better for a shorter horizon, but the shorter horizon provides less data on the pattern of equipment failures. An examination of the data showed significant variation in estimated lifetimes within equipment types across subsets of the data, and indicated that reported change data were not compete enough to provide good rate of change estimates.

- *Distribution of equipment ages*: In the absence of a survival sample, the observed distribution of equipment age at the survey date can be used to estimate measure lifetimes. For a survival data set, we would establish a sample of equipment with known ages, and follow it for a period of time, noting the age of equipment when it fails. In the method described here, we take a "snapshot" of the age of all existing equipment at a single point in time. Intuitively, the current equipment age distribution bears some relation to the average lifetime of the equipment. If the average service life to fluorescent bulbs is three times that of incandescent bulbs, it would be surprising if the average age of the current fluorescent bulb population is not higher than the average age of the incandescent bulb population. However, there are pitfalls with this approach. To make inferences about a population's measure life distribution from its age distribution, we must assume that if a member of the population "dies" (i.e., if equipment is taken out of service) it is replaced with a new member of the same population. Given this assumption of a self-replicating population, the population age distribution will converge in distribution to a scaled survival curve. However, there are two problems associated with using this technique for the MLS II analysis. The first is that in some cases, equipment may not be replaced with like equipment. The second, is that this method does not control for the fact that some equipment has not been in the marketplace long and the equipment cannot yet have reached a stable state of replacement. In these cases, the equipment lifetimes will merely reflect the length of time the equipment has been in the market, rather than the ultimate lifetime.

*Selected Analysis Method and Caveats*

In general, the last approach was used for calculating measure lifetimes for this study (unless otherwise noted in the tables or text). The approach allowed the most observations to be used, and did not rely on matching equipment. *However, the results for some measures must be used with judgement. Some equipment, especially newer equipment and more efficient equipment will not fit the assumption of "steady state replacement", and the estimated measure lifetime will only indicate the length of time the equipment or technology has been in the marketplace in this region.*

In particular, the underlying assumption of a self-replicating, or "steady state" population of equipment is more difficult to justify for equipment that is a key focus of analysis -- the types of measures promoted under Bonneville and other utility programs. This is because these measures are typically newer, and on the "cutting edge". The measures will also tend to have smaller numbers of measures found in the field, reducing the chances that the quantitative estimates can be derived. In addition, the length of time that CIPP-installed measures would tend to be in place would be the 8-10 years the program has been operating. Therefore, the estimated lifetimes of measures under this method will tend to reflect the age of the program. Finally, there has been an evolution of ballasts (and potentially other measures) in the marketplace, and the newer versions will tend to demonstrate shorter lifetimes than those that have been in the marketplace longer.

The list of measures that would be expected to have more suspect results because they have not had a full cycle or have only had a short time in the marketplace include key ESD measures including: electronic ballasts, variable speed drives, HVAC controls, efficient magnetic ballasts, and T-8 and other lamps. Results for bulbs are less reliable because they can be replaced with other types of bulbs, and in addition, bulbs are not specifically promoted under the ESD program. For these reasons, the results for these measures should be examined with caution, and it is noted throughout the tables which measures are likely reflecting length of time the measure has been in the marketplace rather than its future, anticipated measure life.

Unfortunately, this list includes many of the key measures included in many conservation programs, including the ESD program. Generating reliable quantitative results for these measures under any estimation method will generally require having a longer history in the marketplace in order to allow measures to fail and to "cycle" to a steady state. However, that does not provide much guidance for programs at the time at which they are designed and implemented. In cases where the measure is a minor engineering modification to an existing technology or piece of equipment that would tend to be operated in generally the same manner, it may be that, in early phases, programs will need to rely on the lifetimes of the standard equipment it replaces. For "new" technology, the options may be few and may be limited to taking laboratory estimates, tempered by information on building remodeling and the noted impacts on the particular types of equipment.

*Informational Results from Other Analytical Methods*

For informational and comparison purposes, some of the results from the less reliable building age, reported equipment change methods, and similar analyses are presented in Table III-2. Although these methods tend to produce less reliable results, this table allows the reader to examine the reasonableness of results from some of these methods, and the apparent directions of bias using alternative methods. However, for the remainder of this study, the results are generally derived from the analysis based on the distribution of equipment ages.

## Table III-2:
## Results from Less Reliable Estimation Methods--For Information Purposes

| | | ALL | RET | GRO | OFC | URB | RUR | PNN | CIPP | CAP |
|---|---|---|---|---|---|---|---|---|---|---|
| IL | Age Dist. | 4.2-22.9 | 4.5-25.3 | 4.1-24.2 | 4.1-22.8 | 4.3-22.5 | 3.8-26.2 | 3.9-21.8 | 5.5-25.3 | 3.8-34.5 |
| | Change | 21.2 | 24.3 | 20.4 | 19.8 | 19.2 | 47.2 | 25.2 | 10.7 | 34.5 |
| | Bldg. Age | 75.1 | 75.0 | 50.7 | 85.6 | 73.7 | 85.6 | 82.5 | 60.0 | 66.1 |
| OL | Age Dist. | 6.1-22.7 | 6.2 | 16.0 | 17-24.1 | 6.9-22.6 | .16-23.9 | 64.9-22.8 | 7.3-16.1 | 24.4-26.3 |
| | Change | 48.1 | 88.8 | 39.7 | 40.3 | 47.8 | 49.1 | 90.1 | 13.9 | 125.0 |
| | Bldg. Age | 79.7 | 94.9 | 52.7 | 85.2 | 79.8 | 79.2 | 95.7 | 50.1 | 80.1 |
| WH | Age Dist. | 10.6 | 15.2 | 13.2 | 11.9 | 11.0 | 11.2 | 15.0 | 8.2 | |
| | Change | 55.6 | 66.7 | 35.8 | 59.7 | 52.6 | 81.1 | 50.6 | 59.1 | 72.1 |
| | Bldg. Age | 58.8 | 67.5 | 39.0 | 62.4 | 57.5 | 69.0 | 58.6 | 58.1 | 62.3 |
| VT | Age Dist. | 23.4 | | | 24.1 | 23.3 | | 22.9 | | |
| | Change | 97.8 | 35.1 | | 128.0 | 104.0 | 65.5 | 90.9 | 62.5 | |
| | Bldg. Age | 94.5 | 158.0 | 69.6 | 87.3 | 92.5 | 109.0 | 92.5 | 110.0 | 98.0 |
| RF | Age Dist. | 16.5 | 14.2 | 19.3 | 19.5 | 16.5 | 20.9 | 16.1 | 21.9 | |
| | Change | 293.0 | 296.0 | 189.0 | | 357.0 | 204.0 | 500.0 | 96.6 | 270.0 |
| | Bldg. Age | 64.5 | 95.7 | 49.3 | 84.8 | 61.5 | 75.2 | 65.9 | 61.3 | 61.0 |
| HV | Age Dist. | 18.5 | 20.6 | 18.1 | 17.9 | 16.9 | 26.7 | 18.8 | 10.4 | |
| | Change | 41.7 | 70.9 | 54.9 | 30.3 | 35.8 | 118.0 | 39.4 | 25.6 | 90.3 |
| | Bldg. Age | 68.4 | 94.3 | 60.8 | 56.1 | 66.3 | 78.6 | 61.8 | 80.3 | 75.8 |
| HT | Age Dist. | 18.2 | 13.6 | 19.4 | 20.3 | 18.7 | 14.7 | 17.9 | 17.3 | 24.5 |
| | Change | 72.0 | 87.9 | 76.5 | 61.9 | 68.6 | 92.9 | 60.1 | 60.9 | 400.0 |
| | Bldg. Age | 64.6 | 66.4 | 55.9 | 66.2 | 64.3 | 66.6 | 66.3 | 68.5 | 51.5 |
| CL | Age Dist. | 19.9 | 16.6 | 17.8 | 20.8 | 20.2 | 17.9 | 20.4 | 15.2 | 22.0 |
| | Change | 64.5 | 111.0 | 69.9 | 52.1 | 58.9 | 123.0 | 56.6 | 41.7 | 327.0 |
| | Bldg. Age | 61.1 | 67.7 | 47.6 | 61.7 | 60.5 | 64.7 | 64.2 | 58.8 | 50.1 |
| CK | Age Dist. | 17.4 | 18.8 | 15.6 | 17.9 | 17.5 | | 17.3 | 18.0 | |
| | Change | | | | | | | | | |
| | Bldg. Age | 85.6 | 100.0 | 80.3 | 78.7 | 76.3 | 154.0 | 83.0 | 101.0 | 78.4 |
| MT | Age Dist. | 21.7 | | | 22.5 | 21.7 | | 21.2 | | |
| | Change | 59.9 | | | 55.4 | 59.9 | | 66.2 | 20.7 | |
| | Bldg. Age | | | | | | | | | |

**KEY:**

**Row Headings:**

IL = Indoor Lighting
OL = Outdoor Lighting
WH = Water Heating
VT = Ventilation
RF = Refrigeration
HV = HVAC Controls
HT = Heating
CL = Cooling
CK = Cooking
MT = Motors

**Column Headings:**

ALL = all observations
RET = Retail sector
GRO = Grocery sector
OFC = Office buildings
URB = Urban
RUR = Rural
PNN = PNNonRES buildings
CIPP = CIPP buildings
CAP = CAP buildings

**Row Headings - Analysis Method:**

Age Dist. = Estimates from age distribution method
Change = Estimates derived using responses to equipment change information questions
Bldg. Age = Estimates using building age information

## C. MEASURE LIFETIME RESULTS - BROAD EQUIPMENT CATEGORIES

### 1. Introduction

Two major types of results are presented in this report:

- Results for broad categories of equipment. Grouping measures increased the observations and support statistical tests of differences between groups of buildings (urban/rural, retail/grocery/office, etc).[4]

- Results for individual equipment and ECMs (which cannot generally be examined for separate subcategories of buildings).

Table III-3 below presents the results of the measure life estimations for a wide range of categories of equipment. Data for a variety of specific equipment types were grouped in order to provide a larger sample size to support higher quality quantitative estimates. Given that at least 20 separate equipment observations are needed for reasonably accurate estimation, in many cases sub-categories did not have enough data and estimates could not be computed.[5] Note that the definitions of how equipment was categorized into efficiency level, as well as how buildings were grouped into urban/rural are included in Appendix C.

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[4]Recall that the measures included under broader equipment types are noted in Appendix C.

[5]Typically, the estimation algorithm experienced convergence problems where applied to smaller subsets of data.

## Table III-3:
## Measure Lifetimes of Broad Equipment Categories

**AGE DISTRIBUTION METHOD**
**(In years, significant differences at 90% confidence noted)**

| | All | PNNonRES | CIPP | CAP | Retail | Grocery | Office | Urban | Rural | Less Effic.(a) | More Effic(a) | Small | Large (1) | ESD Effective |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indoor Lighting | | | | | | | | | | | | | | |
| Ballast | 10.0 | 10.5 | 8.0 | 20.5 ~ | 9.5 | 15.6 ~ | 9.8 | 9.6 | 16.3 | 14.4 *^ | 5.9 *^ | 14.4 * | 9.7 * | 12 |
| Bulb | 4.2 | 3.9 * | 5.5 *^ | 3.8 ~ | 4.5 | 4.1 | 4.1 | 4.3 | 3.8 ~ | 3.1 *^ | 4.4 * | 4.2 | 4.3 | 5 |
| Control | 22.9 | 21.8 | 25.3 | | 23.3 | 24.2 | 22.8 | 22.5 | 26.2 | 23.2 | 20.5 ~ | 26.2 * | 20.0 * | 10-15 |
| Fixture | 21.0 | 20.5 | 19.3 | 34.5 ~ | 21.3 | 20.5 | 21.5 | 20.5 | 25.0 | 19.9 | 21.3 | 24.9 * | 18.0 * | 12-15 |
| Reflector | 6.2 | 9.3 | | | | | 5.8 | 5.7 | | 6.2 | | | | 5-7 |
| Outdoor Lighting | | | | | | | | | | | | | | |
| Ballast | 15.7 | 17.8 | 7.3 ^ | | | | 17.1 ~ | 15.6 | 16.0 | | | | | 12 |
| Bulb | 6.1 | 6.4 | | | | | | 6.9 | | | 5.8 | | | 5 |
| Control | 22.7 | 22.8 | 16.1 | 24.4 | 25.2 | 16.2 *^ | 24.1 | 22.6 | 23.9 | 23.2 | 22.4 | 24.2 | 20.8 | 10-15 |
| Fixture | 21.8 | 22.2 * | 12.2 *^ | 26.3 ~ | 23.6 | 15.9 *^ | 23.3 | 21.6 | 23.2 ~ | 22.1 | 21.8 | 23.0 | 21.0 | 12-15 |
| Cooling Equipment | 19.9 | 20.4 * | 15.2 * | 22.0 | 16.6 | 17.8 | 20.8 | 20.2 | 17.9 | 20.7 | 19.0 | 19.5 | 20.3 | 15 |
| Cooling Compressors | 15.4 | 15.4 | 16.9 ~ | 15.2 | 9.1 * | 13.1 | 18.2 * | | 16.6 | 15.4 | | | | 15 |
| Heating Equipment | 18.2 | 17.9 | 17.3 | 24.5 ^ | 13.6 * | 19.4 | 20.3 * | 18.7 | 14.7 | 19.3 | 18.1 | 20.5 | 16.4 | 15 |
| HVAC Controls | 18.5 | 18.8 | 10.4 *^ | | 20.6 | 18.1 ~ | 17.9 | 16.9 | 26.7 ~ | 24.0 *^ | 12.8 *^ | 23.5 * | 14.8 * | 10-15 |
| Refrigeration | 16.5 | 16.1 | 21.9 | | 14.2 | 19.3 | 19.5 | 16.5 | 20.9 | 18.7 | 16.0 | 15.6,17.1 | 19.4,15.2 | 15 |
| Ventilation | 23.4 | 22.9 | | | | | 24.1 | 23.3 | | 24.7 | 21.6 ~ | 27.2 | 22.6 | 15 |
| Water Heating | 10.6 | 15.0 ^ | 8.2 | | 15.2 | 13.2 ~ | 11.9 | 11.0 | 11.2 | 10.6 | | | | |
| Cooking | 17.4 | 17.3 | 18.0 | | 18.8 | 15.6 | 17.9 | 17.5 | | 21.3 *^ | 13.2 * | | | |
| Motors | 21.7 | 21.2 | | | | | 22.5 | 21.7 | | 21.7 | | | | 15 |

Notes: significance tests at 90% confidence level

^ = significantly different from "all" category
* = significantly different from other entry within category
~ = no confidence interval could be calculated
(1) = large/small categories defined by median of building type
(a) = More and less efficient differences influenced by shorter marketplace tenure for "efficient" equipment
weighted average ESD-effective = 12 years

Both overall results are reported, as well as estimates for specific subsets of the data, including: geographic (urban/non-urban); business type (retail, grocery, and office); source of the original data (PNNonRES, CIPP, CAP); efficient and less efficient equipment; and large vs. small buildings. Differences between point estimates that are significantly different (at the 90% confidence level) are noted on the table.[6]

## 2. Key Results

The key results of this set of estimates follows. Point estimates are provided, but note that significant differences are denoted by symbols in the table.

- **All Category**: This column presents the results of the estimates aggregating all data across building types, database source, etc. The general results compare favorably, in terms of orders of magnitude with lifetimes used by BPA and other utilities. Equipment that are expected *a priori* to last longer in fact showed longer lifetimes (e.g., HVAC-related equipment). In comparing with broad aggregated "effective ESD" lifetimes, similar orders of magnitude are found for much of the equipment, including ballasts, bulbs, reflectors, cooling and heating equipment, HVAC controls, and refrigerators. Those demonstrating longer lifetimes than ESD include controls, fixtures, ventilation, and motors.

- **Database Source**: Generally, the lifetimes for CIPP data show shorter lifetimes, especially for lighting equipment. The vast majority of installations under the CIPP program involved lighting equipment, so these results reflect the fact that the CIPP installations are, in fact, newer installations than the population at large. Note that the small sample size for the CAP program made it difficult to estimate lifetimes for some equipment. PNNonRES, which comes closer to representing the region, rarely had numbers that were significantly different from the "all"

[6]Appendix A contains tables that note the 90% confidence intervals for these point estimates. The subgroup estimates should be treated with some caution, however, since underlying distributional assumptions are more likely to hold across the whole sample than in small subgroups.

category, except in the case of a longer lifetime for waster heating equipment.

- **Business/Building Type**: For several equipment types, notably cooling and heating equipment, office buildings demonstrate significantly longer lifetimes than similar equipment in retail establishments. Groceries showed significantly shorter lifetimes for outdoor lighting equipment. Few other significant patterns between business types were found.

- **Urban/Rural**: The point estimates for the rural buildings are generally longer; however, the relatively few sample points for the rural sites resulted in large confidence intervals. Therefore, none of the differences between urban and rural sites were significantly different.

- **Efficient vs. Less Efficient Equipment**: Generally, more efficient equipment was found to have shorter lifetimes. However, this is very much influenced by the fact that the more efficient equipment had generally been in the marketplace for a shorter period than standard equipment. The weakness of the estimation method used is that it assumes that equipment replacements are in a steady state, an assumption which is not very applicable for this stratification variable.

- **Building Size**: For almost every equipment category, large buildings showed shorter equipment lifetimes (or greater equipment turnover) than smaller buildings (by 5-6 years). Differences were significant for much of the important lighting equipment, as well as HVAC controls.

### 3. General Results

Comparison of the estimates between equipment types show the expected results. Lamps and bulbs have shorter lifetimes (4-6 years) than ballasts, controls, and fixtures (about 20 years) for both indoor and outdoor lighting. Ventilation equipment is long-lived -- on the order of 23 years. Cooling equipment shows an equipment life of approximately 20 years, with compressors showing slightly shorter lifetimes of about 15 years. Refrigeration equipment shows an overall lifetime of about 16-20 years, heating and HVAC controls equipment has a lifetime of approximately 19 years. Cooking equipment and motors are estimated to last about 17 and 22 years, respectively.

## 4. Comparison with Lifetimes Used by Utilities

These general estimates compare favorably with equipment lifetimes used by BPA and other utilities (the ordinal relationship of the results is as expected). Table III-4 shows the useful lifetime assumptions used by Bonneville and various California utilities in designing commercial-sector programs. The last column presents a simple average for these measure lifetimes, assigning equal weights for each of the included lifetimes.[7]

The lifetime estimates commonly used are in the range of 2-5 years for indoor and outdoor lamps (with longer lifetimes for specific equipment like metal halide, high pressure sodium, and compact fluorescent lamps). Fixtures show lifetimes in the neighborhood of 20 years, which matches with the MLS II results shown in Table III-1. Depending on the specific type, utilities use ballast lifetimes of between 6 and 13 years, and the overall estimates from MLS II show a point estimate for all ballasts of 10 years. Lighting controls show wide variations in lifetimes depending on the technology, but the point estimates shown for the category in MLS II are on the longer side of those used by utilities. HVAC equipment ranges in expected lifetimes from approximately 10 years approximately 20 years based on a review of the lifetimes used by BPA and California utilities. The lifetimes shown for MLS II for the broad categories of Heating, Cooling, and Ventilation are, respectively, 18 years, 15-20 years, and 23 years. HVAC controls show an average measure lifetime for all buildings in MLS II of about 18 years; depending on the type of HVAC control technology, other utilities use lifetimes of between 14 and 20 years (except for time clocks, with a 9 year lifetime).

[7]Note that a table with MLS II estimates for the types of detailed measures used by the utilities in program planning is provided later in the report as Table III-8.

# TABLE III-4:
## Useful Lives of Commercial and Industrial Energy Conservation Measures (years)

| Equipment Type and Description | BPA Median | SCE | SDG& | PG&E* | SCG | BPA ESD | AVG |
|---|---|---|---|---|---|---|---|
| LIGHTING | | | | | | | |
| Energy Efficient fluorescent lamp | 5 | 3 | 5 | 6.5 | | 5 | 4.9 |
| Same as above with built-in ballast | 2 | 2 | | | | 2 | 2.0 |
| Energy-efficient ballast | 11 | 12 | 18 | | | 12 | 13.3 |
| Electronic ballast | 3 | 3 | 5 | | | 12 | 5.8 |
| Metal Halide lamp | 10 | 12 | 5 | | | 3 | 7.5 |
| Low-pressure sodium lamp | 5 | 3 | | | | 5 | 4.3 |
| High-presure sodium lamp | 5 | 3 | | | | 5 | 4.3 |
| Parabolic fixture | 20 | 15 | 15 | 20 | | | 17.5 |
| Dimming systems | 20 | 20 | 15 | 20 | | 20 | 19.0 |
| On-off switching | 7 | 20 | | | | 7 | 11.3 |
| Motion sensor | 10 | 15 | 8 | 5 | | 10 | 9.6 |
| Compact fluor. w/detachable ballast | . | | . | | | 12 | 12.0 |
| Energy efficient fixture (fluor, HID, etc) | | | | | | 20 | 20.0 |
| HVAC | | | | | | | |
| Economizer | 11 | 15 | 15 | | | 11 | 13.0 |
| Chiller strainer cycle system | 15 | 15 | | | | 15 | 15.0 |
| Air-to-air packaged heat pump | 10 | 15 | | | | | 12.5 |
| Water-to-air packaged heat pump | 15 | 15 | | | | | 15.0 |
| Ice thermal energy storage | 19 | 20 | 20 | | | 19 | 19.5 |
| Water thermal energy storage | 20 | 20 | 20 | | | 20 | 20.0 |
| Plate type heat pipe recovery system | 14 | 15 | | | 15 | | 14.7 |
| Rotary type heat recovery system | 11 | | | 10 | | | 10.5 |
| Heat recovery from refrig./ condenser | 11 | 15 | | 10 | | | 12.0 |
| Low leakage damper | 9 | 10 | | | | | 9.5 |
| Variable inlet vane VAV | 11 | 10 | 20 | | 15 | | 14.0 |
| Variable pitch fan for cooling tower | 13 | 15 | 10 | | | | 12.7 |
| Make-up air unit for exhaust hood | 10 | 10 | | | | | 10.0 |
| Air destratification fan-paddle type | 10 | 18 | | | | | 14.0 |
| Air destratification fan-high inlet/low discharge | 15 | 18 | | | | | 16.5 |
| Air curtain | 10 | 10 | | | | | 10.0 |
| Deadband thermostat | 13 | 15 | | | | 13 | 13.7 |
| Spot radiant heat | 10 | 15 | | | | 10 | 11.7 |
| Radiant heat (hot water or steam) | | | | | | 25 | 25.0 |
| Unit heaters (electric or gas) | | | | | | 13 | 13.0 |
| Unit heaters (hot water or steam) | | | | | | 20 | 20.0 |
| Valve.actuators (hydraulic) | | | | | | 15 | 15.0 |
| Valve actuators (pneumatic) | | | | | | 20 | 20.0 |
| Valve actuators (self-contained) | | | | | | 10 | 10.0 |
| Air washers | | | | | | 17 | 17.0 |

Average calculated as simple average of measure lifetimes present in table.

| Equipment Type and Description | BPA Median | SCE | SDG& | PG&E* | SCG | BPA ESD | AVG |
|---|---|---|---|---|---|---|---|
| CONTROLS | | | | | | | |
| Computer logic EMS | 13 | 20 | 15 | | | 13 | 15.3 |
| Electronic controls | 11 | 15 | 15 | | | 15 | 14.0 |
| Electric controls | | | | | | 15 | 15.0 |
| Pneumatic controls | | | | | | 20 | 20.0 |
| Time clocks | 10 | 9 | | 5 | | 10 | 8.5 |
| MOTORS, DRIVES, & TRANSFORMERS | | | | | | | |
| Standard electic motor | 15 | 18 | | | | 15 | 16.0 |
| High-efficiency electric motor | 17 | 18 | 17 | 17 | | 17 | 17.2 |
| Variable-speed DC motor | 18 | 20 | | | | 18 | 18.7 |
| Variable-speed drive-solid state | 15 | 15 | | | | 15 | 15.0 |
| Variable speed drive-belt type | 10 | 10 | 10 | | | 10 | 10.0 |
| Efficient AC electric transformer | 15 | 30 | | | | 15 | 20.0 |
| Motor Starters | | | | | | 17 | 17.0 |
| Reciprocating engines | | | | | | 20 | 20.0 |
| Steam turbines | | | | | | 30 | 30.0 |
| DOMESTIC HOT WATER | | | | | | | |
| Heat pump water heater | 10 | 13 | | | | 10 | 11.0 |
| Point-of-use water heater | 12 | 15 | | | | 12 | 13.0 |
| Solar water heater | 15 | 15 | | | | 15 | 15.0 |
| Change electric to gas booster | | | 15 | | | | 15.0 |
| REFRIGERATION | | | | | | | |
| Unequal parallel refrigeration | 14 | 15 | 15 | | | 14 | 14.5 |
| Condenser float head pressure control | 10 | 15 | 15 | | | 10 | 12.5 |
| Auto cleaning system for condenser tubes | 15 | 15 | | | | 15 | 15.0 |
| Hot gas bypass defrost | 10 | 15 | | | | 10 | 11.7 |
| Polyethylene strip curtain | 3 | 10 | | 3 | | 3 | 4.8 |
| Refrigeration case cover | 11 | 15 | | | | 11 | 12.3 |
| BUILDING ENVELOPE | | | | | | | |
| Double glazing | 20 | 20 | | | | 20 | 20.0 |
| Heat mirror | 18 | 20 | | | | 18 | 18.7 |
| Low-emissivity coating | 14 | 15 | | 10 | | 14 | 13.3 |
| Solar shade film (retrofit) | 7 | 5 | 7 | | | 7 | 6.5 |
| Tinted and reflective coating | 14 | 20 | | 10 | | 14 | 14.5 |
| Blanket insulation | | | | | | 24 | 24.0 |
| Molded insulation | | | | | | 20 | 20.0 |
| Air curtain | | | | | | 10 | 10.0 |

Source: Compiled from Bonneville, Utility, and CEC sources.
Note: ESD = Energy Smart Design program.
Note: '(*)' - Two changes made to PG&E information. Measure life of fixture.
20 years for HP-sodium lamp assumed an error, and assigned to parabolic
Also, average of stated measure life of 5,8 assigned to efficient fluorescent lamps

Results for motors, and refrigeration equipment also showed similar results when comparing between broad categories estimated from MLS II and the lifetimes commonly used by BPA and California utilities. Results for refrigeration equipment for MLS II of 16 years was similar to, but slightly longer than the 12-15 year lifetime commonly used. General motor equipment lifetimes for MLS II were approximately 22 years, well within the commonly-used 10 to 30 year range for specific motor equipment.

## 5. MLS II Differences by Subgroups

*MLS II Differences by Urban/Rural*

The results are generally similar across business types, across urban and non-urban locations, and across the datasets (e.g., participants and non-participant buildings). In general, the point estimates of lifetimes for non-urban equipment seem longer than urban installations. Ballasts show almost 7 years longer lifetimes, and indoor lighting controls[8] and fixtures also show shorter lifetimes in urban applications (almost 4 years shorter than the 26 years in rural applications for controls, and 4.5 years shorter than the 25 years shown in rural applications for fixtures). Although the tables show a few patterns in measure lifetimes between urban and non-urban buildings, the differences between the urban and rural groups are not statistically significant.

*MLS II Differences between Participant and Non-participant Buildings*

The CIPP buildings, which represent program participants, showed similar lifetimes for all general equipment categories except:

[8]indoor lighting controls were defined to include mechanical on/off, mechanical/multi-switches, and timer switches.

- Indoor lighting lamps and bulbs lasted an average of 1.5 years longer in CIPP buildings than in the PNNonRES buildings (5.4 years vs. 3.9 years). The CIPP lifetimes were also significantly longer than "all" buildings.

- Outdoor lighting ballast showed significantly shorter lifetimes in CIPP buildings than in any other group (urban/rural or other data sources). The point estimate of measure lifetime for outdoor lighting ballasts for CIPP buildings was between eight and ten years shorter than other installations (7 years vs. 15-18 years in other buildings). Outdoor lighting fixtures also showed significantly shorter lifetimes in CIPP installations than other buildings (about 10 years shorter).

- Cooling equipment had shorter lifetimes in CIPP buildings than in any other subclass, with a measure lifetime about 5 years shorter than other buildings (15 vs. 20 years).

- CAP buildings, showed significantly longer lifetimes for heating equipment -- 24 years vs. the 17-18 years found in other buildings.

- HVAC controls[9] showed significantly shorter lifetimes for CIPP (program participant) buildings than for the PNNonRES buildings (over 8 years shorter than the 19 years found in PNNonRES buildings).

- The results showed that PNNonRES had longer-lived water heating equipment than the average of all buildings visited (a statistically significant result). Although not statistically significant, the difference from CIPP building point estimates is striking.

The overall results show that lifetimes in CIPP installations (our proxy for "participant data") tended to be shorter than the overall lifetimes (and shorter than PNNonRES estimates) for many equipment types, particularly space conditioning and outdoor lighting equipment. However, the results for the important indoor lighting end use are less clear. There are few significant differences, but for the shorter-term measures, indications are that ballasts failed more quickly and bulbs lasted longer than average. Point estimates (although not statistically

[9]HVAC controls include equipment like thermostats (standard and programmable), computer EMS. and deadband thermostats.

significant differences) tended to be longer for the CAP buildings, and similarly in rural buildings.

*MLS II Differences by Type of Business*

Few significant differences were found between building types with the exception of the following:

- Groceries showed significantly shorter measure lifetimes for outdoor lighting controls and fixtures. In each case the estimated measure lifetimes were approximately 16 years, compared to the average 23-25 years shown for the retail and office sectors.

- Retail establishments showed a significantly shorter estimated measure lifetime for key heating and cooling equipment than other business types. This includes cooling compressors with an estimated 9 year lifetime compared to a 15 year average for all building types, or 13 and 18 years respectively for groceries and offices. The heating equipment also shows about a five or six year shorter lifetime in retail buildings.[10]

The results showing differences by subgroups of buildings reflect the influence of a variety of possible factors, including: differences between the behavior of the groups in terms of maintenance, renovation/remodel activity, and other issues; differences in the mix of equipment within the type installed in the buildings; and other factors.

[10] As pointed out by Mr. Fred Gordon, Pacific Energy Associates, Portland, Oregon, it is possible that some of the differences for cooling equipment may be related to differences in types of cooling systems, or in operating hours or other differences between business types. If the latter is the case, the effective savings may be the same, just over greater or fewer years. Therefore, the differences may not be meaningful in savings even if they are statistically significant.

*MLS II Differences based on Efficiency of Equipment*

Included in the table is an indicator of whether the equipment is generally classified high or medium efficiency as opposed to low efficiency equipment (labeled ECM vs. non-ECM). A review of the results of the table tends to indicate that, although similar lifetimes are noted for most of the equipment, higher efficiency equipment shows a shorter lifetime for a few key pieces, including:

- Medium and high efficient ballasts showed significantly shorter lifetimes, and lower efficiency equipment showed much longer lifetimes than average. However, higher efficiency bulbs showed significantly longer lifetimes than non-efficient equipment.
- More efficient HVAC controls showed a shorter lifetime by about 10 years than non-efficient controls, and about 6 years shorter than average. In addition, more efficient ventilation equipment showed shorter lifetimes.
- More efficient cooking equipment exhibited shorter lifetimes.

## 6. Comparison of Lifetime Estimates to MLS I Results

The results reported in MLS I were derived using a different approach and, taken at face value, they could lead to different conclusions than the MLS II results for broad equipment categories. Based on the methodology from MLS I, differences can generally come from two main sources:

- The MLS I estimates are critically dependent on estimates of renovation, hard remodel, and soft remodel rates. In MLS I, these quantitative data were derived from phone survey estimates of annual remodel/renovation rates reported by building designers, architects, and building professionals. These respondents had some difficulty with the MLS I terminology of *hard remodel, soft remodel, and renovation*, and there was considerable suspicion in MLS I that there may have been overlap in these estimates -- that strictly adding the annual turnover rates would lead to overreporting of annual changes. MLS II respondents were only asked about renovation/remodels and were not specifically asked about soft remodels or "tenant improvements" -- the term more widely recognized in the field.

- An overall figure for any changes to equipment associated with the end use was provided in MLS I. Therefore, for example, changes to lamps or bulb types may drive the lighting change information. In addition, the data as reported in the summary tables of MLS I includes *both modifications (a wide variety) and removals*. The MLS II focusses only on removals.

When corrected for these two important definitional factors, the apparent differences between the two studies are reduced, although differences remain. For example, the renovation/remodel rates for MLS II are more comparable to the pure renovation rates from MLS I than to the combination of the separately-reported renovation and remodel rates from MLS I. A more detailed discussion of the comparisons and results is included in Appendix D. The revised results for MLS I are presented in Table III-6.

# TABLE III-5:
# Estimated Renovation Rates, MLS I and MLS II

| | Measure Life I | | | Measure Life II Renovation/Remodel Rates | | | |
|---|---|---|---|---|---|---|---|
| | Reno-vation | Hard Remod | Soft Remod | Weighted | MLE | MLE 90% Confi-dence Interval | |
| All Retail | | | | 9.3% | 8.4% | [ 6.3% | 11.2% ] |
| Large Retail | 8% | 12% | 20% | | | | |
| Small Retail | 9% | 17% | 24% | | | | |
| All Office | | | | 11.5% | 12.0% | [ 9.9% | 14.6% ] |
| Large Office | 6% | 12% | 22% | | | | |
| Small Office | 11% | 16% | 37% | | | | |
| Grocery | 9% | 23% | 17% | 4.1% | 7.4% | [ 4.9% | 11.6% ] |
| Rural | | | | 12.1% | 6.8% | [ 4.5% | 10.6% ] |
| Urban | | | | 7.5% | 10.8% | [ 9.2% | 12.6% ] |
| PNNonRES | | | | | 10.9% | [ 9.0% | 13.1% ] |
| CIPP | | | | | 11.5% | [ 8.5% | 15.9% ] |
| CAP | | | | | 6.5% | [ 4.4% | 9.8% ] |
| All | | | | 9.7% | 10.0% | [ 8.7% | 11.7% ] |

# TABLE III-6:
# Implied Measure Lifetimes for MLS I:
# Revised to Exclude Minor Alterations and Soft Remodels

| MLS I REMOVAL RATES/EQUIPMENT LIFETIMES<br>ALL EQUIPMENT REPLACED | Office Bldgs | | Retail Sector | | Grocer |
|---|---|---|---|---|---|
| | Large | Small | Large | Small | Sector |
| LIGHTING | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 4% | 5% | 4% | 3% | 9% |
| Hard Remodel | 4% | 4% | 5% | 5% | 0% |
| Soft Remodel | 2% | 12% | 20% | 0% | 0% |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 25 | 20 | 25 | 33 | 11 |
| Hard Remodel | 25 | 25 | 20 | 20 | |
| Soft Remodel | 50 | 8 | 5 | | |
| Aggregate Turnover/Implied Lifetime | 10 | 5 | 3 | 13 | 11 |
| HEATING | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 3% | 6% | 6% | 2% | 7% |
| Hard Remodel | 0% | 1% | 0% | 4% | 0% |
| Soft Remodel | 0% | 6% | | | |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 33 | 17 | 17 | 50 | 14 |
| Hard Remodel | | 100 | - | 25 | |
| Soft Remodel | - | 17 | - | - | - |
| Aggregate Turnover/Implied Lifetime | 33 | 8 | 17 | 17 | 14 |
| COOLING | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 1% | 3% | 6% | 1% | 5% |
| Hard Remodel | 0% | 1% | 0% | 1% | 0% |
| Soft Remodel | 3% | 6% | | 0% | |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 100 | 33 | 17 | 100 | 20 |
| Hard Remodel | | 100 | | 100 | - |
| Soft Remodel | 33 | 17 | - | - | - |
| Aggregate Turnover/Implied Lifetime | 25 | 10 | 17 | 50 | 20 |
| HVAC CONTROLS | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 5% | 7% | 6% | 2% | 7% |
| Hard Remodel | 4% | 6% | 6% | 6% | 2% |
| Soft Remodel | 8% | 12% | - | 0% | 0% |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 20 | 14 | 17 | 50 | 14 |
| Hard Remodel | 25 | 17 | 17 | 17 | 50 |
| Soft Remodel | 13 | 8 | - | - | - |
| Aggregate Turnover/Implied Lifetime | 6 | 4 | 8 | 13 | 11 |

| MLS I REMOVAL RATES/EQUIPMENT LIFETIMES<br>ALL OR SOME EQUIPMENT REMOVED OR REPLACED | Office Bldgs | | Retail Sector | | Grocery |
|---|---|---|---|---|---|
| | Large | Small | Large | Small | Sector |
| LIGHTING | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 5% | 9% | 6% | 4% | 9% |
| Hard Remodel | 8% | 10% | 5% | 9% | 6% |
| Soft Remodel | 12% | 12% | 20% | 22% | 9% |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 20 | 11 | 17 | 25 | 11 |
| Hard Remodel | 13 | 10 | 20 | 11 | 17 |
| Soft Remodel | 8 | 8 | 5 | 5 | 11 |
| Aggregate Turnover/Implied Lifetime | 4 | 3 | 3 | 3 | 4 |
| HEATING | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 3% | 7% | 6% | 2% | 7% |
| Hard Remodel | 2% | 1% | 0% | 4% | 2% |
| Soft Remodel | 0% | 6% | | | |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 33 | 14 | 17 | 50 | 14 |
| Hard Remodel | 50 | 100 | - | 25 | 50 |
| Soft Remodel | - | 17 | - | - | - |
| Aggregate Turnover/Implied Lifetime | 20 | 7 | 17 | 17 | 11 |
| COOLING | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 1% | 4% | 8% | 1% | 5% |
| Hard Remodel | 1% | 1% | 2% | 1% | 0% |
| Soft Remodel | 3% | 6% | | 0% | |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 100 | 25 | 13 | 100 | 20 |
| Hard Remodel | 100 | 100 | 50 | 100 | - |
| Soft Remodel | 33 | 17 | - | - | - |
| Aggregate Turnover/Implied Lifetime | 20 | 9 | 10 | 50 | 20 |
| HVAC CONTROLS | | | | | |
| Est. % Removed from (annual rate) | | | | | |
| Renovation | 5% | 8% | 6% | 3% | 7% |
| Hard Remodel | 5% | 6% | 6% | 6% | 2% |
| Soft Remodel | 8% | 18% | - | 0% | 0% |
| Implied Measure Lifetimes from (years) | | | | | |
| Renovation | 20 | 13 | 17 | 33 | 14 |
| Hard Remodel | 20 | 17 | 17 | 17 | 50 |
| Soft Remodel | 13 | 6 | - | - | - |
| Aggregate Turnover/Implied Lifetime | 6 | 3 | 8 | 11 | 11 |

The level of agreement between MLS I and MLS II lifetime estimates varies across equipment categories. For example, lighting equipment shows very different measure lifetimes depending on its category; e.g. obviously, bulbs have shorter lives than fixtures. The renovation rates are not dramatically different from the MLS I estimates for lighting changes from renovation, with slightly longer lifetimes in the retail sector between the two sources, and shorter lifetimes in the grocery sector (although the relative reduction for groceries between the two sources is very different). The results for ballasts (a key lighting component) from MLS II are more similar to the overall change rates from all levels of remodel. Therefore, depending on interpretation, some of the results from MLS I fall generally within the ranges found in MLS II.

The results for HVAC controls are most closely aligned with the figures provided for renovation activity or from hard remodel and renovation activity combined. Implied lifetimes for HVAC controls from all renovation and remodel activity considered in MLS I are considerably shorter than those estimated in MLS II.

The results for heating and cooling equipment changeouts in MLS I were a little sparse, showing many blanks. Recall that the sample was a quota sample with only limited observations in each business type. However, with the exception of some of the high-end lifetimes (100 years), we see magnitudes that are relatively similar, with tend to match more closely when comparing to the "aggregate" change figures.

## D. MEASURE LIFETIME RESULTS - SPECIFIC EQUIPMENT TYPES

### 1. Introduction

Table III-7 below presents the results of the measure life estimations for a variety of specific equipment types and ECMs. In addition, 90% confidence intervals for the point estimates are also provided. The age distribution method used for the calculations requires relatively large sample sizes, so estimates could not be derived for a number of specific ECMs

## Table III-7:
## Estimate Equipment and Measure Lifetimes - MLS II
## Age Distribution Method

| | Measure Lif (In years) | 90% Confidence Interval | | ESD ML | Utility ML Avg. | Utility ML Rang |
|---|---|---|---|---|---|---|
| Indoor Lighting | | | | | | |
| Ballast | 10.0 | 8.7 | 12 0 | | | |
| Std. Magnetic Ballast | 18.5 | 17.5 | 19.5 | | | |
| Efficient Magnetic Ballast* | 8.2 | 6.6 | 9.6 | 12 | 13.3 | (11-18) |
| Electronic Ballast** | 4.6 | 3 8 | 5.1 | 12 | 5.8 | (3-12) |
| Bulb | 4.2 | 3.7 | 4.5 | | | |
| Incandescent | 2.8 | 2.3 | 3.6 | | | |
| Compact Fluorescent | 3.3 | 2.6 | 4.1 | 5 | 4.9 | (3-6.5) |
| Fluorescent | 4.5 | 4.1 | 4 8 | | | |
| Control | 22.9 | 21.8 | 23.9 | | | |
| Mechanical On/Off | 23 2 | 22.4 | 24.1 | 7 | 11.3 | (7-20) |
| Mechanical/Multi Switch | 28.7 | | | | | |
| Timer switching | 22.9 | | | | | |
| Fixture | 21.0 | 20 0 | 21.9 | | | |
| General Lighting | 21.0 | 18 7 | 22.8 | | | |
| Recessed Can | 20.4 | 18.7 | 23.3 | | | |
| Spots/Display | 22.6 | 19.5 | 25.6 | | | |
| Floods | 21.8 | 19.3 | 24.9 | | | |
| Strip Lighting | 22.0 | 20.3 | 25.1 | | | |
| Reflector | 6.2 | 4.3 | 8.8 | | | |
| Outdoor Lighting | | | | | | |
| Ballast | 15.7 | 13.1 | 18.0 | | | |
| Standard Magnetic Ballast | 15.0 | | | | | |
| Bulb | 6.1 | 5.2 | 7.2 | 3.5 | (4.3/7.5) | (3-12) |
| Control | 22.7 | 21.2 | 24.3 | | | |
| Mech. On/Off | 23.8 | 20.6 | 26.2 | | | |
| Photocell On/Off | 18.3 | 16.2 | 19.6 | | | |
| Timer Switching | 26.1 | 23.0 | 28.5 | | | |
| Fixture | 21.8 | 20.4 | 23.3 | | | |
| General Lighting | 19.2 | 17.8 | 21.3 | 20 | | |
| Floods | 20.0 | 18.2 | 22.0 | | | |
| Strip | 27.6 | | | | | |
| Cooling Equipment | 19.9 | 18.6 | 21.3 | | | |
| Central Heat Pump | 17.4 | 14.5 | 19.7 | | 12.5 | |
| Central Packaged | 19.7 | 16.2 | 23.7 | | | |
| Central A/C Unit | 20.8 | 17.0 | 24 0 | | | |
| Chilled Water System | 23.2 | 19.8 | 26.4 | 15 | 15 | (15) |
| Cooling Compressors | 15.4 | 13.3 | 17.0 | | | |

| | Measure Life (In years) | 90% Confidence Interval | | ESD ML | Utility ML Avg. | Utility ML Range |
|---|---|---|---|---|---|---|
| Heating Equipment | 18.2 | 17.1 | 19.7 | | | |
| Central Steam/HW | 24.2 | 18.0 | 28.1 | | | |
| Forced Air Furnace | 25.2 | 16.0 | 26.3 | | | |
| Pkg-Gas Ht/El Cool | 9 9 | 6.1 | 19 8 | | | |
| Pkg-El Ht/Cool | 21.6 | 14.8 | 27.2 | | | |
| Pkg-E heat Pump | 18.6 | 16 8 | 20 3 | | | |
| Unit Heaters | 21.1 | 16.7 | 25.1 | 13, 20 | | |
| Individ. Heat Pumps | 17.5 | | | | | |
| Duct Heater | 21.0 | 18.9 | 24.6 | | | |
| Start/Stop | 13.6 | 9.7 | 18.0 | | | |
| Economizer** | 8.1 | 5.4 | 13.0 | 11.0 | 13.0 | (11-15) |
| HVAC Controls | 18.5 | 16.5 | 20.2 | | | |
| Std. Thermostat | 24.1 | 19.4 | 27.0 | 15-20 | 15-20 | |
| Programmable | 9.0 | 5.5 | 13.2 | 10.0 | 8.5 | (5-10) |
| Computer EMS | 12.7 | 9.0 | 15.6 | 13.0 | 15.3 | (13-20) |
| Dead Band Thermostat | 10.6 | 5.9 | 16.4 | 13.0 | 13.7 | (13-15) |
| Refrigeration | 16.5 | 14.8 | 18.6 | | | |
| Res. Upright | 16.3 | 10.9 | 22.0 | | | |
| Commercial Closed Un | 14.6 | 10.7 | 18.6 | | | |
| Open Vertical | 21.5 | | | | | |
| Open Horizontal | 20.1 | 15.9 | 24.9 | | | |
| Walk In | 19.9 | 16.7 | 22.4 | | | |
| Glass door/cover | 13.7 | 12.4 | 14.7 | 11.0 | 12.3 | (11-15) |
| HE Evap. Fan Motors | 18.8 | 18.3 | 19.3 | | | |
| Floating Head | 18.5 | 10.5 | 27.7 | 10.0 | 12.5 | (10-15) |
| Parallel Unequal | 25.4 | 23.9 | 26.6 | 14.0 | 14.5 | (14-15) |
| Curtains | 11.5 | 10.8 | 12.4 | 3.0 | 4.8 | (3-10) |
| Ventilation | 23.4 | 21.6 | 25.6 | | | |
| Constant Volume | 24.4 | 21.6 | 27.4 | | | |
| Variable Air Volume | 21.7 | | | | 14.0 | (10-18) |
| Water Heating | 10.6 | 9.3 | 12.4 | | | |
| Water Heater Tanks | 11.0 | 9.1 | 13.9 | 10-15 | 10-15 | |
| Cooking | 17.4 | 15.2 | 18.8 | | | |
| Motors | 21.7 | 19.4 | 24.4 | | | |
| Variable Speed Drive** | 6.1 | 3.9 | 13.0 | 10-18 | 10-20 | |
| Non-VSD | 23.4 | 21.8 | 24.9 | ~15 | ~15 | |
| AC Motors | 19.7 | 18.0 | 24.4 | 15? | 20.0 | |
| DC Motors | 26.1 | 23 9 | 28.7 | | | |
| Window Tinting | 10.8 | 7 8 | 14.6 | | | |
| Tinted coatings* | 17.5 | | | 14.0 | 14.5 | (10-20) |
| Low-e coatings* | 10.3 | | | 14.0 | 13.3 | (10-15) |
| Heat mirror* | 5.7 | | | 18.0 | 18.7 | (18-20) |
| All coatings aggregate* | 16.3 | | | | | |
| Double glazing* | 19.0 | | | 20.0 | 20.0 | (20) |

Note: Reported Measure Lives (ML) estimated using age distribution method. Additional equipment and ECMs had small sample sizes that could not support estimation of measure lifetimes. Sample sizes in some cases could not support calculation of confidence intervals for some measures.

(*): These measure lifetimes were calculated with the less reliable "reported rates of change" method.

(**): These measure lifetime estimates more likely represent the length of time this measure has been in the marketplace. Problem of estimation method and the fact that there has not been sufficient time to track failures for newer technologies.

and equipment types. In addition, although the previous "broad category" analysis could examine differences between subgroups, because the estimation needed relatively large sample sizes, the lifetimes could not, in general, be subsetted to show differences between different groups. Note also that for certain measures (indicated by a ** symbol) the measures are too new on the market to be considered in "steady state replacement", and the measure lifetimes estimated via this method likely provide estimates of the length of time the technology has been in the market.

Where available, the table shows the Energy Smart Design Program measure lifetimes, as well as the average measure life and range of measure lives from the Table III-4 showing lifetimes from Bonneville and California utilities. The table shows that lifetimes are longer for some measures, shorter for others.

## 2. Results and Comparison with Lifetimes Used by ESD and Utilities

In many cases, the results of the measure life estimation work confirm the measure lifetimes reported by other utilities, and those used in Bonneville's Energy Smart Design (ESD) program. However, in some cases, the measure lifetimes shown from the MLS II on-site data indicate that the lifetimes used by utilities (and ESD) may need re-evaluation. A summary of the results follows.

- *Lighting Measures:* Efficient magnetic ballasts are estimated to last about 8 years in the field, but utilities and the ESD program assume, respectively, lifetimes of 12 and about 13 years for these measures. Both of these measure lifetimes are significantly higher (at 90% confidence) than the estimated measure lifetimes. Results for **electronic ballasts** also find that there were significantly shorter lifetimes found in the field than those used for planning purposes. The estimated lifetime from MLS II for electronic ballasts is only 4.6 years, with a confidence interval up to about 5 years. This is significantly shorter than the ESD planning number, but somewhat closer to the 5.8 year average derived from the California utilities and BPA information. However, because of analysis method, the results for newer measures like electronic ballasts and efficient magnetic ballasts are better interpreted as years since introduction in the marketplace.

**Compact fluorescent bulbs**, anticipated to last about 2-4.9 years by program designers, show a lifetime of about 3.3 years. This category contains a combination of both built-in ballast measures and separate bulbs, so, although the confidence interval contains neither the two years from one type nor the 5 years for non-built in ballast lamps, the range is reasonable. Lifetimes for **energy efficient fixtures** (from Table III-3, "Effic" column) were estimated to be about 21 years. This is close to the efficient 20 year fixture lifetimes used by ESD. Estimated measure lifetime for **mechanical on-off switches** based on MLS II on-sites was 23 years. This is significantly different than the 7 years assumed for ESD, but is rather close to Southern California Edison's assumed lifetime of 20 years (although 20 years is still shorter than the 90% estimated confidence interval). Too few observations were available to examine motion sensors and a number of other systems.[11]

- *Cooling Equipment:* The results for central **heat pumps**, generally air-to-air heat pumps in our sample, was estimated to be 17.4 years. This is higher than the estimates used by BPA (10 years for air-to-air and 15 years for water-to-air, but no separate ESD estimate) but not considered statistically significantly different for the 15 years used by SCE (the lower bound of the confidence interval is 14.5 years).

- *Heating Equipment:* **Unit heaters**, which were estimated in MLS II to have measure lifetimes of about 21 years, have assumed lifetimes of 13 years in Bonneville's ESD program. This is almost 4 years longer than the lower band of the confidence interval, and 7 years longer than the point estimate. **Individual heat pumps** (largely water-to-air) showed a measure life of 17.5 years (but there was not sufficient information to estimate a confidence interval. This compares fairly closely to the 15 year

[11]Some additional measure lifetimes could be derived from the less reliable "matching" methodology described in Appendix A, although no confidence intervals were derived. For example, measure lifetimes of 7.9 years (based on a "loose" matching definition) was found for metal halide lamps, which is very close to the 7.5 average years for all utilities, but is considerably higher than the ESD assumption of 3 years. Using the "strict" matching method, the estimate is 5.2 years. High pressure sodium lamps were also estimated via this method, deriving an estimated lifetime of 4.8 to 5.1 years (depending on matching criteria). This is close to the 5 years used by BPA ESD, and somewhat longer than the 3 year lifetime assumed by Southern California Edison.

life assumed by Bonneville and SCE programs. **Economizers** showed an in-field measure lifetime of 8.1 years (with 5.4 to 13 years describing the 90% confidence interval). Although the point estimate is lower than the 11 years used by Bonneville for ESD, this does not constitute a statistically significant difference. Nor is the difference significant from the average 13 years computed in the table across utilities. However, it is significantly shorter than the 15 years that SCE and SDG&E use for their programs.

- *HVAC Controls:* The estimated measure lifetimes for **deadband thermostats** from MLS II data was 10.6 years. With a confidence interval that ranges up to 16.4 years, this measure does not show a statistically significant difference from the 13 year estimates used by Bonneville, or the 15 year lifetime used by SCE. The estimated lifetime for **computer logic EMS** controls is 12.7 years. This is very similar to the 13 years assumed for BPA's programs, and is somewhat lower than the 15 and 20 years assumed by SCE and SDG&E, respectively. However, neither difference is statistically significant.[12]

- *Refrigeration:* Measure lifetimes for several refrigeration technologies were estimated. MLS II analysis showed a lifetime of 25.4 years for **unequal parallel** equipment. This is significantly longer than the 14-15 years assumed by Bonneville and other utilities, and falls a full 9 years short of the lower band of the confidence interval. **Floating head** equipment showed a lifetime of 18.5 years (with a confidence interval from 10-28 years). The estimates used by programs (10-15 years) fall within this band. **Case covers** (glass) show a lifetime of about 13.8 years (with a confidence interval ranging from 12.4 to 14.7). This is somewhat longer than the planning estimates of 11 years used by Bonneville, and is slightly shorter than the estimates used by SCE (15 years). **Strip curtains** showed a field lifetime of about 11.5 years (with a range from 10.8 to 12.4). Although significantly longer than the 3 year estimate used by Bonneville, it is somewhat closer to the 10 year estimate used by SCE.

- *Motor Equipment:* **Variable speed drive** motors examined in MLS II showed a lifetime of about 6.1 years (with a confidence interval up to 13 years), which is at least 6 years shorter than the 18-20 years used in

[12]Although the age distribution method could not derive lifetimes for **time clocks**, we obtained estimates from the matching methodology. The estimated lifetime of 10.1 years was relatively close to the 9 and 10 year estimates used by Bonneville and SCE, although it is apparently longer than the 5 years assumed by PG&E.

program planning. However, again VSD motors are new the market place and the six-year estimate more accurately reflects the length of time VSD motors have been in this market. **Non-VSD** motors showed a lifetime of 23.4 years, which is longer than the 15-18 year lifetimes used by Bonneville and California utilities.[13]

- *Hot Water:* No estimates were derived for water heating measures.
- *Building Envelope:* A variety of **window tinting** treatments were found, and the estimated measure lifetime for these treatments was 10.8 years, with a confidence interval from 7.8 years to 14.6 years. This band covers the range of treatment lifetime estimates used by Bonneville and other utilities, including the 10-15 years used for low-e coating (14 years for ESD), the 7 years widely used for solar shade film,and the 10, 14 (ESD), and 20 years estimates used for tinted and reflective coating. Table III-7 presents approximate lifetimes for window treatments using the less reliable method that incorporates responses to reported rates of change. This table again shows longer lifetimes for shadings and treatments, with considerable variation from the aggregate estimates, and from the assumed lifetimes from Bonneville and other utilities. The table also shows an estimated measure lifetime of 19 years from MLS II, which is very comparable to the 20 year estimate used by utilities (including BPA ESD) for planning.

## E. SUMMARY OF RESULTS OF MEASURE LIFETIMES ANALYSIS

Measure life estimates were derived for both broad equipment end-use classes, as well as an assortment of more specific equipment and ECMs. The results supported analysis of comparisons of measure lifetimes between business types, urban and rural installations, as well as a limited comparison of participant/non-participant buildings. The analysis showed that when comparing broad categories of equipment, MLS II derived estimates near those commonly used by Bonneville and other utilities for all major end uses. However, the analysis for broad equipment categories showed some patterns between building subgroups.

[13] Note that some of the same points may be made here that are detailed in Footnote 10.

- Installations in more rural settings generally showed longer lifetimes. Significant results included heating equipment, which tended to last 24 years rather than the 18 years commonly found in urban areas. Estimates of renovation rates for rural and urban buildings, and for the CAP buildings support the conclusion that remodeling cycles in urban areas are shorter, and that measure changeouts may therefore, be more frequent in urban areas. For example, CAP shows shorter lifetimes for heating equipment likely an influence of the rural settings associated with CAP buildings.

- The CIPP buildings, which are comprised of program participants, showed similar lifetimes for broad categories of equipment with the notable exceptions of shorter lifetimes for outdoor ballasts and fixtures (8-10 years shorter on measures with planning lifetimes of 15-20 years). Longer lifetimes were noted for indoor lighting bulbs, and there was some confirmation (although not with statistical significance) of shorter indoor lighting ballast lifetimes. Participants (CIPP buildings) also had significantly shorter lifetimes (15 as opposed to 20 years) for cooling equipment and HVAC controls. The shorter lifetimes for CIPP than PNNonRES for HVAC controls are also likely due to the influence of the fact that the CIPP program was only started 8-10 years ago, and these measures were largely program-installed. Therefore, these measures have generally been in this market only 8-10 years and the estimation results reflect this, and probably not long-term measure life.

- Groceries showed shorter lifetimes for outdoor lighting equipment and tended to have lower renovation/remodel rates.

- Retail buildings showed moderate renovation rates (about 8% per year), but showed significantly shorter lifetimes for key heating and cooling equipment. In some cases the estimates were different enough to potentially have a significant impact on program design -- cooling equipment tended to exhibit lifetimes of 9 years rather than 15-18 years. Heating equipment also showed lifetimes 5-6 years shorter than other building types.

- Efficient equipment tended to demonstrate similar lifetimes as non-efficient equipment except in the case of ballasts (shorter for efficient ballasts), and HVAC controls (shorter lifetimes for efficient measures). The historical problems with some of the early ballasts may be a factor in some of these results.

- Overall renovation rates were about 10% per year. Renovation and remodeling rates are higher in urban locations. Between buildings types, higher remodeling rates were found in the office sector, while groceries exhibited lower renovation rates, although the differences are not statistically significant.

### 1. Results for Specific Measures

The results provide some feedback on the measure lifetimes used in the ESD as well as planning lifetimes used by other utilities. The estimated ranges for broader equipment types were also similar to results commonly used by BPA and other utilities. The sample could not support estimates for a number of other specific equipment types.

### 2. Comparison with Results from MLS I

In addition, the study compared the results obtained from the MLS II analysis with the results from MLS I. Although MLS I did not directly derive quantitative estimates of measure lifetimes for specific equipment, it did infer annual change rates in equipment class from information on estimated renovation/remodel rates and the impacts of building turnover, when it occurs, on equipment. The analysis shows that, when MLS I computations are revised to exclude minor alterations to equipment, the results are generally within the range of the MLS II estimates. In addition, renovation rates from the phone survey sources in MLS I were not unreasonably different from the renovation results shown in MLS II -- however, rates for soft remodel and hard remodel implied more changeovers than the data from MLS II showed. These results showed some variation depending on the end-use equipment under consideration, but the results showed that volatile business types and measure changeouts were generally confirmed. The results indicate that, if similar corrections are made for other business types or for other end-uses, the results may provide appropriate order-of-magnitude indications of volatile sectors or equipment types.

In addition, although one of the analytical approaches developed in MLS II supports derivation of measure lifetimes from one-time-only visits (e.g., it can be used on audit data), the data from MLS I did not find the presence of many ECMs. The data can, to some extent, be used to augment the number of measures when combined with MLS II. However, neither the MLS I data, nor the combination of CIPP and CAP data, could defensibly represent the region to be generalized to represent the region at large because the methods of deriving the samples were significantly different. The PNNonRES sample is the only data that was designed to provide regional representation.

# IV. SUMMARY AND CONCLUSIONS

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## A. INTRODUCTION

Utilities across the nation have developed a wide variety of commercial-sector energy conservation programs. Bonneville early recognized the potential importance that factors related to measure lifetimes -- *"effective"* measure lives vs. laboratory estimates -- play a crucial role in calculations of cost-effectiveness of programs. Annual renovation and remodel expenditures are frequently higher than new construction in the commercial sector. With potentially high renovation and remodel rates in the commercial sector, and with earlier work (MLS I and other studies) that indicates that key equipment are frequently affected by renovation activity, Bonneville commissioned this study to examine the effective measure lifetimes for three business sectors: retail, grocery, and office. These sectors were selected for several reasons. They showed considerable renovation/remodel rates in previous studies (MLS I), and they have historically had significant investment from conservation programs.

Several major topics were analyzed in this study:

- derivation of estimates of renovation rates for the business types and buildings subgroups
- calculation of estimates of measure lifetimes for broad categories, with analysis by subgroups
- estimation of measure lifetimes for specific equipment and comparison to lifetimes used by ESD and other utilities' programs
- analysis of maintenance procedures, reasons for change, and the disposal of removed equipment
- comparison of the results to previous work, particularly to MLS I, and
- implications for Energy Smart Design Program (ESD).

The findings of this study are summarized below.

*Renovation Rate and Measure Life Results*

- Average buildings renovation rates for these three business sectors was estimated at 10% annually. The highest rates were found for offices (12%), followed by retail (8.4%) and groceries (7.4%), although the differentials were not significantly different. These rates were smaller than the combination of the *renovation, hard remodel, and soft remodel* included in MLS I, but are more similar to the reported rates for renovation and hard remodel. This result may be expected, because MLS II concentrated on renovation/remodel.[1] Renovation rates were also lower for rural buildings, although not significantly so.

- The estimated measure lifetimes in the business sectors generally followed the pattern that would be reflected by the higher and lower estimated renovation rates. Groceries tended to have longer lifetimes for key equipment (with some exceptions, for example outdoor lighting). The retail sector showed shorter lifetimes for key heating and cooling equipment. Estimated lifetimes for urban buildings were generally shorter than more rural buildings (also similar to renovation rate estimates).

- Most equipment showed lifetimes similar to ESD or other utility program documentation, with the exception of longer apparent estimated on-site lives for heat pumps, refrigeration ECMs, and a few other measures (as shown in Table IV-1). However, lifetime estimates for numerous categories of "new", efficient equipment could not be derived because the equipment had not been in the marketplace long enough to experience sufficient failures to support estimation. The market tenure results for new equipment do, however, reassure that early failures have not been a problem with much of the new equipment. Some variations based on rural/urban, business type, size of structure, and other factors were noted.

- Estimated lifetimes between efficient and less efficient equipment were generally similar with the exception of shorter lifetimes for efficient ballasts and HVAC controls.

- The left hand column of Table IV-1 shows that the current "market tenure" of the ECMs has been shorter than the expected lifetime. However, it may be worth noting that the lifetimes are on the order of 5-8 years, indicating that the equipment has not experienced widespread early

[1]MLS I found that the three terms were not widely understood in the industry, and this may have contributed to double-counting for some of the estimates.

failures. It will take a few more years before true lifetimes can be measured for many of these technologies.

Results for specific equipment are provided in Table IV-1.

*Maintenance, Reasons for Change, and Equipment Disposal*

- Equipment maintenance showed some patterns and exceptions. The majority of major equipment was reported to be maintained through contract arrangements or dedicated on-site staff, especially for heating, and water heating equipment. Refrigeration and motors tended to report less formal maintenance arrangements. Maintenance frequencies were known in only about 10-20% of cases.

- Contracted maintenance was reported with higher frequency in urban settings (and maintenance frequencies were also reported more often). Equipment in rural settings showed a somewhat higher percentage with dirt or rust.

- Renovation was given as a major reason for equipment changes for several equipment types, including HVAC controls, motors, ventilation systems, cooling, and heating equipment (in urban locations).

  Improving equipment efficiency was a key reason for change for a number of equipment and business types, including HVAC controls and indoor lighting. This was a key motivator for rural buildings and the retail sectors in particular.

- Equipment failure was seldom a significant factor for changes with a few exceptions, including cooling systems (in offices), water heaters (in offices and retail), and refrigeration (in groceries).

- Removed equipment is largely sent to the landfill or to an unknown destination. Little of the equipment is sent to secondary markets or re-used or stored elsewhere in the buildings, with heating equipment as one of the few exceptions.

A summary of these results is presented in Table IV-2.

**TABLE IV-1:**
**Measure Life--Analysis of Differentials, Measure Life Study II**

| Equipment with Shorter Estimated MLS II Lifetimes than Assumed Program Lifetimes | Equipment with Longer Estimated MLS II Lifetimes than Assumed Program Lifetimes | Equipment with No Significant Differences from Assumed Program Lifetimes |
|---|---|---|
| • efficient magnetic ballasts (8 years vs. 12-13 years; ESD= 12 years);***<br><br>• electronic ballasts (4.6 years vs. avg. 5.8 years; ESD= 12 years);***; not significantly different from BPA median or SCE 3-year estimates<br><br>• economizer lifetimes used by BPA and many utilities are not significantly different, but the MLS II estimates (8.1 vs. 11 years for ESD) were significantly shorter than the lifetimes used by SCE and SDG&E (8.1 vs. 15 years);***<br><br>• variable speed drives for motors (at least 6 years shorter than ESD lifetimes of 10-18 years and all utility lifetimes of 18-20 years).***<br><br>NOTES:<br><br>**: This is no longer an ESD measure.<br><br>***: Note that this figure more likely represents the length of time this measure has been in the marketplace. This is a weakness of the estimation method, and also reflects the fact that there has not been sufficient time to track failures on the newer technologies. | • mechanical on-off switches (23 years vs. 7 years, for ESD, 11 years average or 20 years for longest lifetime);**<br><br>• metal halide lamps, using a less reliable estimation method, showed lifetimes of 7.9 years, which is considerably longer than the 3 years used by ESD (although it is close to the 7.5 years assumed by other utilities);**<br><br>• heat pumps showed longer lifetimes than ESD estimates (17.4 years compared to 10 years for ESD, but not different from the SCE figure of 15 years);<br><br>• unit heaters (MLS II showed 21 years compared to ESD estimates of 13 years);**<br><br>• unequal parallel refrigeration equipment (25 years compared to 14 for ESD and 15 years from BPA median and other utilities);<br><br>• case covers (glass) for refrigeration (13.8 years compared to 11 years for ESD and 12.3 average (but the estimate is shorter than planning numbers used by SCE);<br><br>• strip curtains for refrigerators (11.5 years compared to ESD 3 years, utility average 4.8, or SCE's 10 year lifetimes).<br><br>• floating head technology in refrigeration (18.5 vs. 10 ESD, diff.)<br><br>• floating head technology refrigeration not significantly different from utility average lifetimes (18.5 vs. 12.5 average) | • electronic ballasts 4.6, not significantly different from BPA median or SCE 3-year estimates. Shorter than others.<br><br>• economizers (compared to BPA lifetimes); 8 years (11 ESD)<br><br>• window double glazing and window tinting/treatments; (19 vs. 20 ESD; 10.8 chg.; 10-17 vs. 14 pgm.; 16 avg.)<br><br>• compact fluorescent bulbs, (3.3 vs. 2-5 ESD); energy efficient lighting fixtures, (21 vs. 20 ESD); high pressure sodium lamps (lower reliability method (5 yrs vs. ESD 5);<br><br>• time clocks (match) 10.1; 9 ESD (5-10);<br><br>• individual heat pumps (water-to-air); (17.5 vs 15 avg.);<br><br>• deadband thermostats; 10.6 vs. 13 ESD (13-15);<br><br>• computer logic EMS; (12.7 vs. 13 ESD). |

# TABLE IV-2: Summary of Non-Measure Life Results*

**Reasons for Change**

| | Cooking | Cooling | Heating | HVAC Controls | Indoor Lighting | Motors | Outdoor Lighting | Refrigerat<br>ion | Ventilatio<br>n | Water Heating |
|---|---|---|---|---|---|---|---|---|---|---|
| Observations | N=3 | N=40 | N=76 | N=35 | N=280 | N=28 | N=32 | N=7 | N=23 | N=29 |
| New Addition | | 27% | | 39% | 13% | 17% | | | | 21% |
| Renovation/ Remodel | | 24% | 16% | 41% | 14% | 80% | | | 49% | |
| Use Less Energy/Effcny | | | 13% | 18% | 47% | | 32% | | 45% | |
| Payback | | | | | | | 15% | | | |
| Equipment Broken | | 20% | | | | | | | | 59% |
| Equipment Old | | | 29% | | | | 15% | | | |
| More Light | | | | | | | 13% | | | |
| Maintenance/C<br>ost | | | 18% | | | | | | | |

**Disposal**

| | Cooking | Cooling | Heating | HVAC Controls | Indoor Lighting | Motors | Outdoor Lighting | Refrigeration | Ventilation | Water Heating |
|---|---|---|---|---|---|---|---|---|---|---|
| Observations | N=1 | N=33 | N=55 | N=22 | N=206 | N=16 | N=19 | N=5 | N=9 | N=24 |
| Don't Know | | 68% | 40% | 76% | 19% | 73% | | | 99% | 35% |
| Landfill | | 31% | 13% | 21% | 43% | 13% | 89% | | | 61% |
| Stored | | | 20% | | | 13% | | | | |
| Secondary Market | | | 20% | | | | | | | |
| Other | | | | | 29% | | | | | |

**Equipment Condition**

| | Cooking | Cooling | Heating | HVAC Controls | Indoor Lighting | Motors | Outdoor Lighting | Refrigeration | Ventilation | Water Heating |
|---|---|---|---|---|---|---|---|---|---|---|
| Observations | N=0 | N=401 | N=464 | N=164 | N=0 | N=173 | N=0 | N=359 | N=115 | N=201 |
| None (Unknown Maintenance) | | 51% | 61% | 56% | | 73% | | 61% | 54% | 72% |
| Generally Dirty | | 245 | 14% | 21% | | 12% | | 19% | 24% | 15% |
| Rusty | | 11% | 12% | 14% | | | | | | |
| Known Maintenance Frequency | | 10% | 12% | | | 15% | | 19% | 21% | |

**Maintenance Staffing**

| | Cooking | Cooling | Heating | HVAC Controls | Indoor Lighting | Motors | Outdoor Lighting | Refrigeration | Ventilation | Water Heating |
|---|---|---|---|---|---|---|---|---|---|---|
| Observations | N=0 | N=177 | N=177 | N=177 | N=0 | N=177 | N=0 | N=177 | N=177 | N=177 |
| Contract Maintenance | | 63% | 80% | 75% | | 42% | | 38% | | 78% |
| None | | 27% | | 11% | | 50% | | 58% | 62% | |
| Dedicated On-Site | | | 9% | 9% | | | | | 26% | 12% |

* Based on top four responses by end use with 9% or greater response.

- CIPP (participant buildings) are more likely to cite payback or efficiency as the reasons behind equipment changes. Non-program buildings (particularly PNNonRES) reported renovation and remodel as the reason for change with much greater frequency.

- Maintenance by CIPP buildings is less likely to be conducted through formal contracting arrangements, but maintenance frequency was more often known than for other buildings.

- The destination of removed equipment is more commonly landfilling for non-CIPP buildings, but CIPP buildings reported not knowing the ultimate destination (which could be the landfill) more frequently.

## B. COMPARISON TO MLS I RESULTS

The MLS II results supported many of the conclusions of MLS I, but added more quantitative information. However, in other areas, it is clear that the MLS I results need to be used as indicative information only.

- MLS I renovation rates do not differ dramatically from MLS II estimates for renovations and hard remodels. However, the combination of renovation and remodel rates from MLS I are higher than those found in MLS II.

- MLS I annual rates of equipment change are higher than those found for MLS II. If the numbers from MLS I are made compatible -- if the changes are confined to equipment removals or replacements -- the numbers are considerably more similar to the results from MLS II. The results from MLS I, if redefined for compatibility, should provide estimates that can be used for order of magnitude information on equipment turnover and building renovation rates.

- As was found in MLS I, a large percent of respondents report energy efficiency of new equipment is a major consideration in timing and replacement decisions. Also like MLS I, equipment failure and high maintenance costs were not reported as key factors in MLS II.[2] Unlike MLS I (which focused more on "soft remodels"), tenant improvements or aesthetics were not given as a reason for equipment change.

[2]Although MLS I reported that this was a factor in small offices.

- Reported presence of maintenance agreements and dedicated staff arrangements are higher than the indications provided from MLS I.

- As with MLS I, the two most common responses to the destination of removed equipment was the landfill and "don't know".

## C. IMPLICATIONS OF RESULTS FOR ESD AND OTHER PROGRAMS

The MLS II results from this report have direct implications for Bonneville's ESD program and other utility conservation efforts.

- *Cost effectiveness calculation:* An examination of the sensitivity of the payback/cost-effectiveness calculations to the direction and magnitude of changes in lifetime assumptions for particular measures found in this study may be appropriate. (see Table VI-1)

- *Program targeting:* For those measures with significant reductions in measure lifetimes, re-evaluation may be needed before recommending installation of certain equipment types (again, see Table IV-1). In addition, targeting of (or marketing to) certain business types may be appropriate.

Installations in sectors with the high renovation rates (e.g., offices), or with patterns of lower measure lifetimes (e.g., groceries for some measures, or retail for heating/cooling; or larger buildings), may merit reduced outreach efforts, or may need calculation (or measure life) adjustments for determining cost effectiveness of programs or particular conservation investments. Similarly, in considering equipment installations in buildings with lower renovation rates (e.g. groceries), or that demonstrate longer lifetimes (e.g., heating equipment in offices, small buildings or equipment in rural buildings), adjustments in lifetimes or calculation methods may also be warranted.

The study points out some possible opportunities in program design and operation.

- Efficiency is a key motivator in equipment replacement, particularly for the lighting and ventilation end-uses. This may provide Bonneville with intervention opportunities.

- Renovation/remodel is a significant reason for equipment change for major equipment including cooling, HVAC controls, ventilation, motors, and water heating. Renovation frequency is high in specific sectors, implying some targeting or outreach opportunities.

- Equipment is seldom replaced because it was broken. However, developing a method to intervene in these types of "emergency" decisionmaking opportunities may provide a good opportunity to improve the efficiency of the installed equipment.

Some programs may be able to improve overall cost-effectiveness by increasing promotion or outreach to certain sectors and decreasing efforts in other, more volatile sectors. In addition, reaching those sectors or end-uses that report a higher tendency to make decisions under "equipment failure" or emergency conditions may require refinement in program outreach and design.

The results indicate that adjustments to the measure lifetimes assumed in the ESD program may be appropriate, based on the results in MLS II and comparisons with measure lifetimes assumed by other utilities.

## D. IMPLICATIONS FOR MEASURE LIFE STUDIES AND ECM LIFETIMES

In deriving estimates of measure life, analytical methods, like survival analysis, that depend on "matching" equipment, may be difficult to conduct unless the databases include (1) date of installation; (2) detailed information about location and model/type.[3] Periodic follow-up, either through on-sites or phone calls or call-backs, will help identify removal dates.

[3] (including possibly stickers on equipment; instant photos of the equipment on-site; marked-up floor plans; or detailed notations).

If a database of this nature is not available, the results of this study may indicate that a one-time audit can provide fairly good information, suitable for estimating measure lifetimes for equipment that is "mature" in the marketplace. The results of this study tend to validate the lifetimes used for much of the mature equipment.

Measure lifetimes for ESD were difficult to determine or verify because the equipment incented under the program has not been in the marketplace very long. The analytical assumptions required to provide quantitative estimates (equipment replacements in steady state) could not be readily accepted for key equipment like electronic ballasts, variable speed drives, etc.[4] A few pieces of equipment may warrant assumptions of longer lifetimes than currently used (some heat pumps, unit heaters, and some refrigeration measures).

However, the nature of ESD and other utility programs is to assist in achieving the adoption of new, more efficient equipment more rapidly than would be experienced with natural market adoption. This need for lifetime estimates for new and evolving equipment makes it difficult to obtain failure and lifetime information within a timeframe that is immediate enough for program design.

This type of one-time visit will not generally be sufficient to provide measure life estimates for newer equipment--and, unfortunately, it is this "newer" equipment that is generally installed as part of program efforts. Program planners will either need to wait until steady state is reached; or will need to be willing to track items fairly thoroughly for a number of years and then be willing to accept "standard" assumptions (e.g., exponential decay functions) for estimating measure lifetimes.

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[4]Although it is difficult to determine whether some of the measures with shorter lifetimes than program design assumptions actually have shorter lifetimes or just reflect tenure in the marketplace.

In many cases, it may be too soon after market introduction to reliably determine whether newer, efficient equipment displays longer and shorter lifetimes than historical equipment. In determining what assumptions to make for measure lifetimes for ECMs in these types of cases, historical lifetimes may be appropriate as long as the following considerations are taken into account.

- If the measure lifetime estimate incorporates the amount of change out from the impacts of renovation, remodeling, and changes related to functional needs;

- For equipment that represents relatively minor engineering changes, the lifetimes of standard equipment may be an approximate metric. If the technical lifetimes of "old technology" for the same function are similar to the technical lifetimes of the "new technology" (if manufacturers believe that customers will require approximately the same lifetimes for certain end-uses, or if the technology lends itself to similar lifetimes);

- If maintenance and operation procedures are approximately the same complexity, and are understood and followed to approximately the same degree as historical equipment.

However, for equipment that performs a new function, is fairly radically new design, operates significantly differently, or affects behavior, accurate lifetimes beyond quantitative estimates provided by the manufacturer may be difficult to obtain. If the reported laboratory or historical equipment lifetime numbers are used, they should, however, be corrected for the evidence of business turnover.

Unfortunately, analytical methods require some time lag to allow for sufficient equipment failures, and significant numbers of observations to conduct the estimates. By the time the lifetime estimates are available, the measures will no longer be cutting edge and may no longer be providing an incentive under the program.

This study provides some detailed quantitative and some indicative results related to measure lifetimes of a wide variety of equipment, as well as information on a number of factors that influence persistence of savings. The study provides findings that can be used to confirm or modify anticipated lifetimes, examine program design and cost-effectiveness calculations, and provide guidance for program and measure targeting. As more detailed databases become available, and newer equipment is followed more closely (and has time to gain a failure track record), the measure lifetimes for newer equipment and ECMs will continue to be refined.