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Energy Savings Lifetimes and Persistence:

Practices, Issues and Data

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This technical brief explains the concepts of energy savings lifetimes and savings persistence and discusses how program administrators use these factors to calculate savings for efficiency measures, programs and portfolios. Savings lifetime is the length of time that one or more energy efficiency measures or activities save energy, and savings persistence is the change in savings throughout the functional life of a given efficiency measure or activity. Savings lifetimes are essential for assessing the lifecycle benefits and cost effectiveness of efficiency activities and for forecasting loads in resource planning. The brief also provides estimates of savings lifetimes derived from a national collection of costs and savings for electric efficiency programs and portfolios.

Lifetimes and persistence of energy savings are overlapping topics. However, the energy efficiency industry primarily has focused more on quantifying the lifetimes of savings and less on estimating savings persistence (or degradation) over the savings lifetime. The two issues are interrelated in practice because, where compelling data exist, savings persistence often is integrated into estimates of the lifetimes of energy savings for a given efficiency activity.

In the first section of the brief, we present information on common practices and issues associated with savings lifetimes as well as typical values for lifetimes for programs, market sectors and portfolios. We then cover similar topics about persistence. We also discuss opportunities for standardization and identify areas for further research. New research may be needed for certain measures before reaching conclusions about the significance of persistence in estimating lifetime efficiency benefits, including avoided generating capacity costs, delivery infrastructure costs, fuel use and emissions.

Introduction

In 2012, utility customers funded more than $7 billion of energy efficiency programs (CEE 2014). These programs typically use incentives, technical assistance, marketing, or other messaging to persuade people to invest in reducing electricity and natural gas use. The primary reason for pursuing energy efficiency as a utility-sector resource is the long-term stream of benefits to the utility (e.g., avoided energy and capacity costs), to participating consumers (e.g., reduced energy costs), and to society at large (e.g., avoided emissions and avoided adverse health impacts). In most cases, if the savings from efficiency actions only lasted a few years, efficiency would not be a cost-effective investment. Thus understanding how long measures, programs and portfolios last (lifetimes)—and the degree to which savings change over time (persistence)—is critical to estimating the benefits of efficiency, calculating cost effectiveness and prioritizing long-term versus short-term efficiency actions.[1]

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[1] Measure lifetimes can also be a component in calculations of performance incentives for contractors and program administrators. For example, the California Public Utilities Commission ties performance incentives in part to achievement of cumulative savings goals based upon lifetime savings. Other states (e.g., MA, CT) use total benefits as a performance metric for program administrator incentives. Measure lifetimes also play a role in certain screening tools used in designing efficiency programs, such as setting incentive levels for customer rebates.

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For utility resource planners, grid operators and state energy agencies, quantifying savings reliably is important for forecasting energy use and determining what resources are needed to meet projected loads. Estimates of measure lifetimes are also essential for assessing whether measures or programs are saving energy in a cost-effective manner. The lifetimes and persistence of savings for measures, programs, and portfolios are therefore key values for characterizing and assessing energy efficiency as a resource.

Savings Lifetime

In this section, we (1) define savings lifetime; (2) report on savings lifetime values and ranges for programs, market sectors and portfolios; and (3) discuss possible reasons that lifetimes vary in each of these categories and across program administrators.

Definition and Relevance of Measure Life

Energy and demand savings for a measure are typically estimated for one or more spans of time: (1) the first year; (2) a specified time horizon such as 10 years; or (3) the life of the measure. A commonly used approach in the industry (and in this brief) is to characterize measure lifetime as the Effective Useful Life (EUL) of a measure:

> ***Effective Useful Life*** *is the median length of time (in years) that an energy efficiency measure is functional* (SEE Action 2012a; Northeast Energy Efficiency Partnerships 2011; CPUC 1992)*.*

In this brief, we use the term measure lifetime, which is synonymous with EUL. Conceptually, the lifetime of an efficiency measure[2] is a function of:

- Technical Equipment Life: average number of years that a measure can operate, and
- Measure Persistence:[3] the time that an energy-consuming measure actually lasts taking into account business turnover, early retirement of installed equipment, and other reasons that measures might be removed, damaged or discontinued (SEE Action 2012a).

This definition of measure life is widely used with only minor variations (see Appendix A for a comparison of definitions among selected states, regions and national efforts). However, the methods for estimating measure lifetimes—and the actual lifetime values for similar efficiency measures—vary among program administrators, state utility commissions, and the consultant studies that often provide measure lifetime estimates.[4]

What happens to energy savings (and emissions avoidance) at the end of the measure lifetime is another consideration that affects the lasting impact of efficiency measures or programs. Program administrators

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[2] Program or portfolio savings lifetimes are the lifetimes of the measures installed by participating consumers in a program (or portfolio of programs), weighted by the energy savings attributed to each measure.

[3] Savings persistence technically is distinct from, but closely related to, measure persistence. Savings persistence is the change in savings over time as a result of technical or operational/behavioral factors, while measure persistence is more applicable to the physical presence and operability of the measure. As will be discussed, a common practice is to integrate savings persistence, as well as measure persistence and equipment life, into the calculation of measure lifetimes.

[4] For example, technical measure life or equipment life usually is defined as the median number of years that a measure is installed or initiated and is operational. Less commonly, it is defined as the mean number of years to failure. Median value means the time at which half of the measures are removed from service or are otherwise no longer operating as assumed, and half remain operating as assumed.

make a range of assumptions from zero savings (assuming that the end use then reverts to baseline efficiency) to partial or full continuation of savings (assuming that efficient equipment and systems are most likely to be replaced with equipment or practices either equivalent to the more efficient measure or at least more efficient than the original end use). Further research is required to make recommendations by measure type, for specific program applications, and for specific objectives such as resource planning or calculating program administrator incentives.

Reported Lifetimes for Programs, Market Sectors and Portfolios

In annual efficiency program reports collected for the Lawrence Berkeley National Laboratory (LBNL) Demand-Side Management (DSM) Program Database,[5] program administrators provide information that can be used to determine the lifetimes for about 30% of the program years in the database.[6] Table 1 shows the range in lifetimes at the portfolio and sector level (e.g., residential; commercial, industrial and agricultural (C&I); low income) along with the sample size (i.e., number of years of program data).[7]

Table 1. National- and sector-level lifetimes for energy efficiency programs

Sector	Simple Average (years)	1st Quartile (years)	Median (years)	3rd Quartile (years)	Number of program years of data used to derive lifetime
National/Portfolio	13	9	12	15	1,647
Commercial & Industrial	12	10	13	15	813
Residential	13	7	11	16	608
Low Income	13	8	12	16	93

Note: The interquartile range is the middle 50% of values.
Source: LBNL DSM Program Database 2014

Table 1 provides program lifetimes at the sector and portfolio level that were either: (1) calculated by dividing lifetime savings reported by the program administrator by reported first-year savings, or (2) reported directly by the program administrator.[8]

At the portfolio level, the average and median[9] values converge at about 12 to 13 years. Regional breakdowns are not shown in this table. The regional medians and averages are about the same as the national portfolio-level average lifetime—12 to 13 years in the Northeast, South, Midwest and West.

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[5] The LBNL DSM Program Database contains more than 5,900 program years of data, collected from 34 states in which efficiency program data are routinely reported at the program level. LBNL counts the data points in terms of program years. For example, a program administered and operated over three years would generate three program years of data. To date, the collected data include spending and impacts data for electricity and natural gas programs from 2009 to 2013. LBNL created a national program typology (Hoffman et al. 2013) in order to classify programs in a standardized fashion by target markets, program design and efficiency actions.

[6] Some programs have no savings. For many other programs, program administrators do not supply sufficient information to report or derive a program lifetime.

[7] As discussed in the persistence section of this brief, program administrators generally assume that 100% of first year savings of the efficiency measures, programs and portfolios are generated each year during their lifetime—i.e., no reduction in savings occurs over that period.

[8] Many program administrators do not report the exact method they use to establish program lifetimes, and practices vary widely. In some cases, LBNL has little or no independent knowledge of the exact method employed by the program administrator. For this reason, when both values are available, we use the calculated values.

Figure 1 depicts the lifetimes at the portfolio or "all-sectors" level and for each market sector and illustrates the difference between average and median values in various sectors.

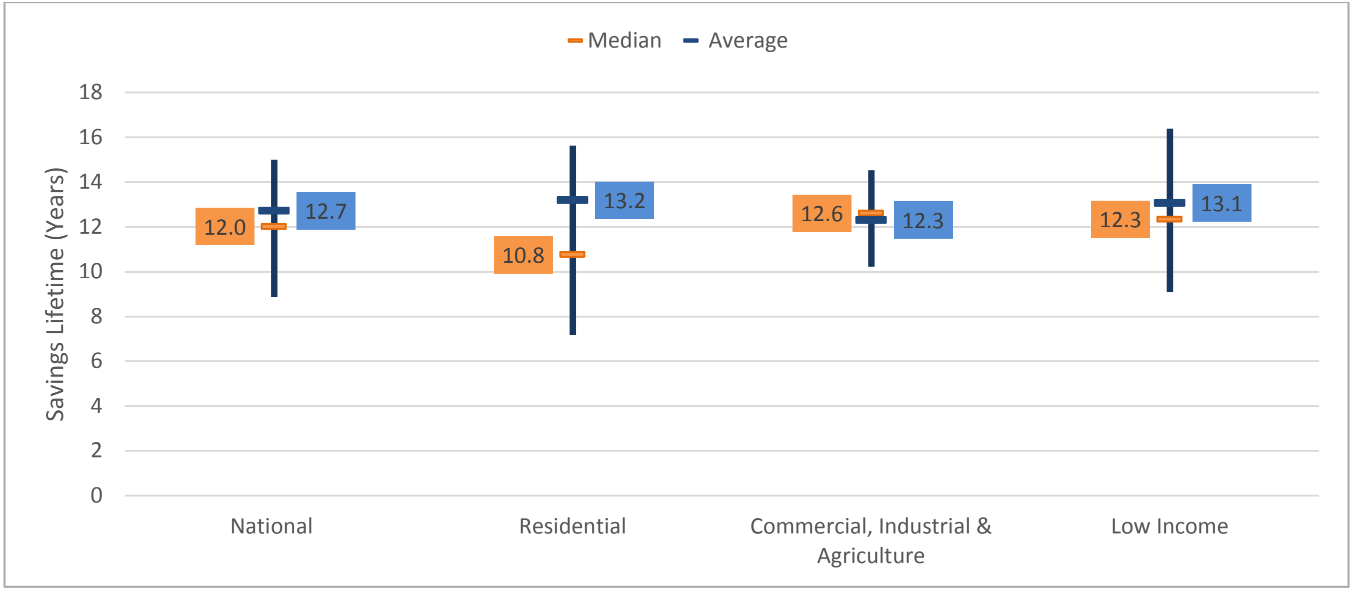

Figure 1. National- and sector-level lifetimes for programs: medians (orange labels and horizontal bars), averages (blue labels and horizontal bars) and interquartile ranges (blue vertical bars)

Note: The interquartile range is the middle 50% of values.
Source: LBNL DSM Program Database 2014

At a national level, median values for program lifetimes in aggregate and across market sectors are quite similar, with a range of 11 to 12 years (see Figure 1). The average lifetimes are slightly different, with a somewhat greater difference in the residential sector.

Table 2 shows the differences between median and average program lifetimes, directly reported or derived, for common types of efficiency programs.

As Table 2 indicates, savings lifetimes may vary significantly within a program category, even within the interquartile range by 30% to 50%, and more widely across the full range of values. Wider ranges can be observed for programs that include a combination of short-lived and long-lived measures. In general, programs that rely heavily upon lighting, and others that largely promote shorter-lived measures, such as residential consumer product rebates and small commercial direct-install programs, have shorter lifetimes and averages below the median. Programs that promote shell measures and heating, ventilating and air-conditioning equipment (residential new construction and custom programs in commercial and industrial markets) tend toward longer lifetimes.

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[9] Medians are the exact middle of a range of values. Thus, half of the collected or derived lifetime values are above the median and half are below. For this brief, we assembled the calculated or derived lifetimes for all portfolios and programs of a specified type and took the middle value.

Table 2. Lifetimes for various types of efficiency programs

Program Type	Simple Average (years)	1st Quartile (years)	Median (years)	3rd Quartile (years)	Number of program years used to derive values
CI: Custom	12	10	13	15	256
CI: MUSH & Govt.	12	10	12	14	157
CI: New Construction	15	14	15	16	70
CI: Prescriptive	12	10	13	15	184
CI: Small Commercial	11	10	12	13	133
CI: All Other Commercial, Industrial and Agricultural	13	12	13	15	20
R: Low Income	12	9	12	15	133
R: Behavior/Normative Feedback (HERs)[10]	1	1	1	1	17
R: Consumer Product Rebate/Lighting	7	6	7	7	89
R: Multi Family	11	9	11	14	81
R: New Construction	25	14	18	20	107
R: Prescriptive	14	10	15	18	104
R: Whole Home Upgrade/Retrofit	15	11	15	17	136
R: All Other Residential	13	8	9	15	8

Notes: CI signifies commercial, agricultural and industrial programs; R, residential programs; MUSH is Municipalities, Universities, Schools and Hospitals. Many behavioral or normative feedback programs in this period were pilots for which no savings were claimed; all others had an assumed measure lifetime of one year. Values are rounded to the nearest integer.
Source: LBNL DSM Program Database 2014

Figure 2 illustrates the ranges, medians, and averages for a subset of the more common types of efficiency programs—for example, commercial, industrial and agricultural (CI) custom and prescriptive rebate programs, small commercial rebate programs, low-income programs, residential (R) consumer product rebates and residential new construction programs.

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[10] These LBNL estimates are based on annual efficiency program reports to regulators and similar documents and therefore are inherently backward looking. Khawaja and Stewart (2014) presented more up-to-date estimates for normative behavior programs of the type identified in the table.

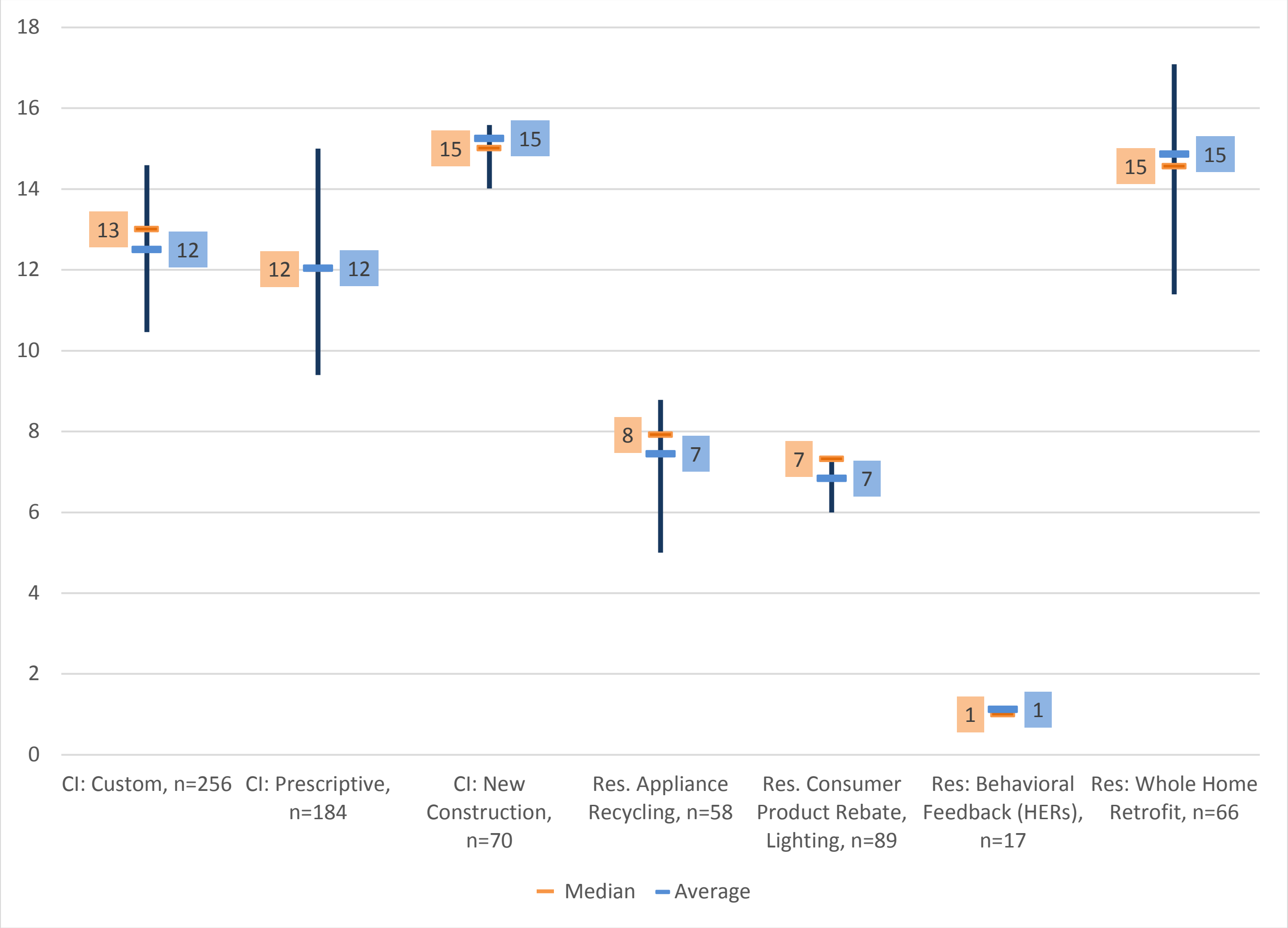

Figure 2. Reported lifetimes for select types of efficiency programs: medians (orange horizontal bars and labels), averages (blue horizontal bars and labels) and interquartile ranges (blue vertical bars)

Source: LBNL DSM Program Database 2014

Again, Figure 2 shows that administrator-reported savings lifetimes for a particular program type can vary widely. For example, savings lifetimes range from five to nine years for the middle 50% of measure lifetimes for residential appliance recycling programs.

Program administrators may change assumed lifetimes as new information comes in, especially for newer measures or program types. For example, behavioral feedback programs grew rapidly in size and geographic coverage over the past several years. These programs save enough by comparing a household's energy use with that of similar households and suggesting ways of curbing energy use, both through behavioral changes such as turning off lights and through installing measures such as more efficient lighting. Nearly all program administrators who claimed energy savings from these programs during the 2009–2013 time frame assumed a measure or program life of one year.[11] However, in a recent meta-analysis of evaluations of behavioral feedback programs, researchers at Cadmus Group (Khawaja and

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[11] Program administrators used a measure life of one year for these behavioral programs because it was a condition of regulatory approval for a pilot or because the programs were new. In its 2012 guidance on evaluation of behavioral-feedback programs, the State and Local Energy Efficiency Action Network recommended collecting additional years of savings data from randomized control trials before extending savings estimates beyond the first year (SEE Action 2012b).

Stewart 2014) concluded that providing a single year of these home energy reports, or similar messaging, can produce savings that continue for up to six years. Allowing for some decay in those savings each year, they recommend that program administrators use a measure lifetime of 3.9 years.

Sources of Variability in Savings Lifetimes

Lifetimes reported by program administrators for efficiency programs (or a portfolio of programs) may vary for three distinct reasons: (1) variability in measure lifetimes assumed by program administrators for individual measures; (2) different combinations of measures that constitute the program or portfolio; and (3) variability in the design and delivery of efficiency programs.

Variability in Measure Lifetimes

Program administrators often document their methods to derive estimated savings (and lifetimes) for individual measures in a technical reference manual (TRM).[12] TRMs may specify the use of different lifetimes based on different programs, market sectors, climates or operating regimes. TRMs in states and regions that pay particularly close attention to accounting for savings can incorporate policy rules and process guidelines, with detailed rules about what data are needed to include a measure, how frequently updates should occur,[13] and requirements for documenting the underlying data on lifetimes, savings and measure costs. As we discuss below, these factors play a role in influencing variability in measure lifetimes.

Variability in measure lifetime estimates can arise from multiple sources:

- Limits or mandated caps on measure lifetimes at 10 or 15 years (e.g., Texas and Pennsylvania);
- Differences among program administrators in evaluation, measurement and verification (EM&V) approach and level of effort, as well as underlying assumptions and frequency of updating measure lifetimes and savings estimates;
- Differences in the types of efficiency project applications (e.g., retrofit installation vs. replace on burnout vs. new construction, which may have different baselines for lifetimes);
- Differences in geography, building stock and environmental conditions—e.g., water heaters in regions with highly alkaline water have shortened lifetimes (Messenger 2014); icy and snowy conditions can shorten lifetimes for exterior lighting;
- Use of dual or dynamic baselines, as discussed later in this brief;
- Use of different technical reference documents, which may use conservative or more liberal estimates of measure lifetimes; and
- Market sector-specific estimates of operating regimes or operating hours for different markets and facility types (e.g., lighting retrofit in schools versus office buildings with differences in hours of operation and schedule).

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[12] The extent of documentation, frequency of updating, and calibration with impact evaluations and field testing varies among states, regions and program administrators. Some states that are ramping up efficiency programs rely on savings estimates and measure lifetimes provided by program administrators (and their consultants) or rely initially on TRM values derived from nearby states.

[13] In states or regions that place more emphasis on EM&V, the results of EM&V studies of measure and project savings are fed back into the TRM to inform estimates for the next program year or cycle. Some states require that savings and lifetime estimates for certain measures or a certain percentage of measures be re-examined on a regular basis. When adopting or updating measure assumptions in the Pacific Northwest, for example, the Regional Technical Forum often will observe that the assumptions may be outdated soon (e.g., by a forthcoming study or anticipated changes in costs) and set a sunset date that requires the forum to reassess the measure assumptions.

Some of the observed differences in measure (and program) lifetimes could be reduced if there were national or regional technical reference manuals for determining lifetimes and savings persistence values by measure. Often, states do not have the resources to expend much effort on documenting lifetime values for measures. However, if states pooled resources, regional databases of lifetimes could cover the entire United States, or a single national database could be developed with adjustments for regional factors as needed. Pooled resources could better support field studies and periodic updating of lifetime values.

Variability in Efficiency Program and Portfolio Savings Lifetimes Due to Design, Delivery and Policies

Program and portfolio lifetimes may vary from one program administrator to another for reasons related to program design and delivery and state policies:

- *Differences in program implementation over time.* For example, targeting of a C&I program to different market segments or differences in the installation of measures may lead to differences in reported program lifetimes among otherwise similar programs. Differences in market maturity may also lead to differences in reported program lifetimes among otherwise similar programs.
- *Differences in mix of measures adopted by customers across similar programs.* For example, the types of measures installed by C&I customers participating in a prescriptive rebate program may vary as the program matures, which may lead to changes in program lifetimes.
- *Differences in state policies that directly or indirectly influence program offerings.* Lifetimes for similar programs offered by administrators in different states are influenced by state policies, particularly in the area of cost effectiveness. A state that screens programs at the measure level will end up with a different (more limited) measure mix than a state that screens programs at the portfolio level. Similarly, a state with a policy of screening measures with a Societal Cost Test that examines a broad array of benefits is likely to render more measures cost effective compared to a state policy that requires a program administrator to screen measures with a more restrictive test, such as the Ratepayer Impact Measure Test[14] (National Action Plan for Energy Efficiency 2008).

Impacts of Variability in Assumed Program Lifetimes on the Total Cost of Saving a Kilowatt-Hour

Differences in assumptions regarding estimated lifetimes for efficiency programs can have significant impacts on the calculated cost per unit of (lifetime) energy savings and on the amount of emissions avoidance both for actions already implemented and for projections of benefits for future efficiency programs. The cost of saved energy is a valuable metric for screening energy efficiency measures and programs, for designing and planning efficiency program portfolios, and for estimating efficiency impacts on load forecasts. Figure 3 depicts the relative impact of program lifetime estimates on the cost of electricity savings delivered through those types of programs.[15]

Figure 3 shows the range and average for the total cost of saved energy (program administrator costs plus participant costs levelized over the lifetime of the energy savings) using measure lifetime values across our sample of programs. The total cost of saved energy varies substantially based on measure lifetime assumptions, even using only the middle 50% of values for a program measure. For example, cost performance varies by 37% in the case of appliance recycling programs, 30% for multi-family retrofit programs, and 28% for C&I prescriptive measure programs. Using the 3.9-year measure life recommended by Cadmus in its meta-analysis of behavioral feedback program evaluations, the savings-weighted average

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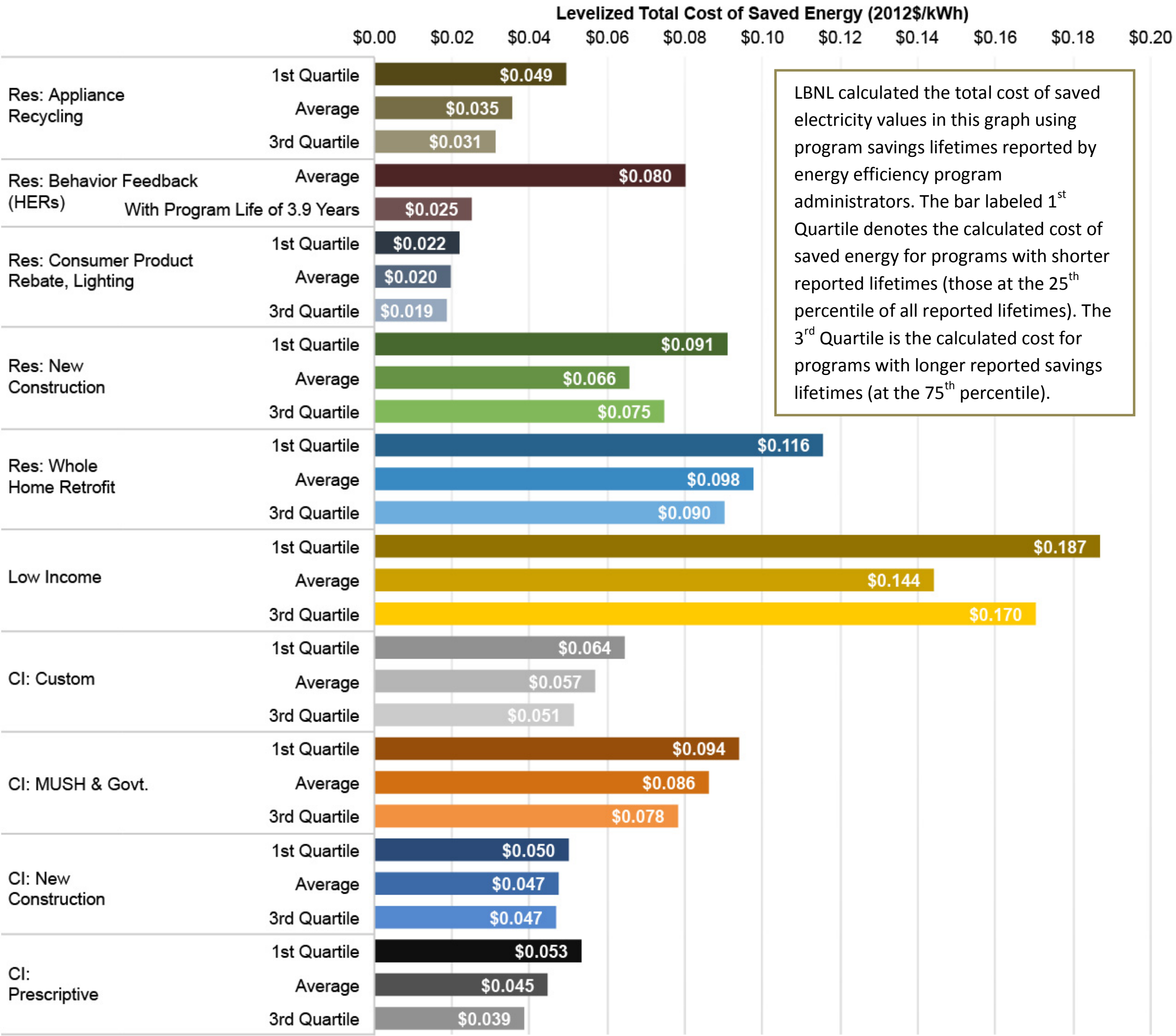
[14] The Ratepayer Impact Measure or RIM test measures the impact of energy efficiency program spending on non-participants in those programs.

[15] Values are available for end-use natural gas savings in the LBNL Database, but the data are more limited than those reported here for electricity.

total cost of saved electricity for those programs would have been $0.025 per kWh, compared to the $0.08 per kWh average based on a one-year measure life.



LBNL calculated the total cost of saved electricity values in this graph using program savings lifetimes reported by energy efficiency program administrators. The bar labeled 1st Quartile denotes the calculated cost of saved energy for programs with shorter reported lifetimes (those at the 25th percentile of all reported lifetimes). The 3rd Quartile is the calculated cost for programs with longer reported savings lifetimes (at the 75th percentile).

Figure 3. The impact of program lifetimes on the levelized total cost of saved energy for select program types

Notes: Home energy reports (HERs) compare a household's energy use with similar households. The MUSH market includes municipalities, universities/colleges, K-12 schools and hospitals. The values reported here for the total cost of saved energy based on average program lifetimes may not agree with other estimates published by LBNL (Hoffman et al. 2015). The illustrative cost of saved energy values in this brief are based strictly upon programs for which energy savings lifetimes were reported directly by the program administrator or could be derived from reported lifetime energy savings, not the full LBNL DSM dataset that includes programs for which savings lifetimes are imputed based on the average for the program type.
Source: LBNL DSM Program Database 2014

Savings Persistence

The performance of an energy efficiency measure usually changes over the lifetime of the measure. The terms "decay" and "degradation" are used to describe the change in measure performance (savings) over time. However, because some efficiency measures may decline in performance at a slower rate than the standard measures that they replace, savings may actually grow over the measure's life. We use the term "savings persistence" to reflect that energy savings may increase or decrease over the life of a measure or program.

Definitions of Savings Persistence

One definition of savings persistence evolved among evaluators and utilities in California and the Northeast in the late 1990s and early 2000s:

> *Savings persistence is the percent change in expected savings due to changed operating hours, human behavior and interaction factors and/or degradation in equipment efficiency* ***relative to the baseline efficiency option*** (emphasis added; Energy & Resource Solutions 2005; California M&V Protocols 2006).

Inclusion of, and accounting for, changes in the baseline conditions (i.e., the end use, installation and operating context prior to taking the efficiency action) in the definition of savings persistence is important. Energy savings are not determined simply by a straight measurement of the performance of the desired equipment or behavior. According to the *SEE Action Impact Evaluation Guide* (SEE Action 2012a), energy savings achieved over time are the difference from baseline performance—the difference in energy performance between pre- and post-treatment. Savings persistence, whether operational or technical, is derived by comparing the degradation in energy performance of standard efficiency equipment, or typical (non-efficiency) consumer behaviors, with the degradation patterns of the program's efficient equipment or behaviors.

> *Therefore, savings are the difference over time between the energy use of the efficient equipment or behavior and the standard equipment or behavior it replaced—with consideration of both baseline and project equipment/behavior degradation in performance (which may be the same).* (SEE Action 2012a)

California's M&V Protocols (2006) put it simply: "Energy efficiency in both standard and high efficiency equipment often decreases over time. The energy savings over time is the difference between these two curves."

Values for savings persistence are developed by either utilizing values published in available resource documents (commonly, another state's TRM) or, less commonly, by conducting surveys of installed equipment several years after installation to determine presence and operational capability of the equipment (Northeast Energy Efficiency Partnerships 2011; Hirsch 2014).

Accounting for Persistence in Efficiency's Resource Value

Administrators and evaluators of energy efficiency programs take different approaches to defining and integrating changes in measure performance into their calculations of efficiency's value in avoiding energy costs or deferring investments in system capacity. In rare cases, savings persistence has been explicitly taken into account as yearly adjustments to assumed annual savings over the life of the efficiency measures. However, in most cases, program administrators neither explicitly nor independently account for savings persistence. Instead, persistence is typically embedded within estimates of measure lifetime. Less commonly, first-year savings are reduced to account for savings changes over the lifetime, as has been done for a small number of measures by Northeast states and by the Regional Technical Forum in the Pacific Northwest (Eckman 2014). California has used both methods for a small number of important measures (Hirsch 2014).[16] These de-ratings of savings lifetimes or annual savings can be part of multiple adjustments based upon lab tests or field experience (e.g., to account for variability in installation quality).

Several factors contribute to the inconsistent treatment of savings persistence across program administrators:

- *Inertia.* It is difficult to justify changes in the calculations of efficiency costs and benefits without sufficient, reliable and compelling findings of a change in those benefits.
- *Cost and difficulty.* Generating persuasive findings often requires tracking measure retention and energy performance over many years, which is expensive, difficult to do properly,[17] and not regarded as a high priority in the competition for near-term evaluation research spending.
- *Impression of modest effect.* Many in the efficiency industry hold the opinion, informed by a few public studies from the late 1990s as well as private sector experience, that (1) substantial changes in savings over the life of most measures, at least due to degradation in equipment efficiency, are rare; and (2) even when degradation of savings is significant, the impacts on cost effectiveness are typically modest because of discounting of measure benefits (Vine et al. 2013).

As a result, studies of savings persistence are uncommon. Savings persistence clearly varies by measure type and application. Thus, the magnitude of its effect on energy savings for a given efficiency action, program, or portfolio may or may not be significant. However, with efficiency portfolios shifting in composition (e.g., more non-equipment focused programs such as behavioral and retro-commissioning programs[18]) and the overall increase in support for efficiency as a significant energy resource, there is increased scrutiny regarding the certainty of savings over time (Skumatz et al. 2009; Vine et al. 2013). Thus, more contemporary and thorough research into savings persistence—and probably more explicit representation in lifetime savings estimation—may be needed for assessing the full value of energy efficiency. The priority and methods for research into savings persistence vary for different types of measures. New or emerging measures, efficiency actions or strategies (e.g., behavioral feedback programs) may warrant near-term field studies. More traditional measures that account for a sizable share of portfolio savings may merit lab-based studies using accelerated aging techniques.[19]

Components of Savings Persistence and Relationship to Measure Benefits

Figure 4 illustrates the relationship among the components of the calculation of efficiency measure resource benefits—measure life, savings persistence and realization factors.

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[16] Some of these measures are nonetheless important. Degradation derates have been applied to CFLs and LEDs—e.g., manufacturers' rated LED life of 25 years or more have been derated to a maximum technical life of 15 years in part because of lumen degradation (Hirsch 2014).

[17] Among these difficulties is acquiring a sufficient sample size for measures, including different applications or settings, to generate statistically significant findings.

[18] Retro-commissioning programs provide incentives or technical assistance to improve how building equipment and systems function together. Retro-commissioning can often identify and address problems in buildings that occurred during design or construction, or address operational problems that have developed throughout the building's life. Retro-commissioning is an effort to improve a building's operations and maintenance to enhance overall building energy performance—e.g., through adjustment of existing building systems, installation of new controls, or deployment of an energy monitoring and management system.

[19] One example of accelerated-aging techniques would be the application of heat in order to speed up degradation or release of gases from plastics or foams. The energy performance of foam insulation in refrigerator walls and doors, for example, may degrade as off gassing occurs in the foam.

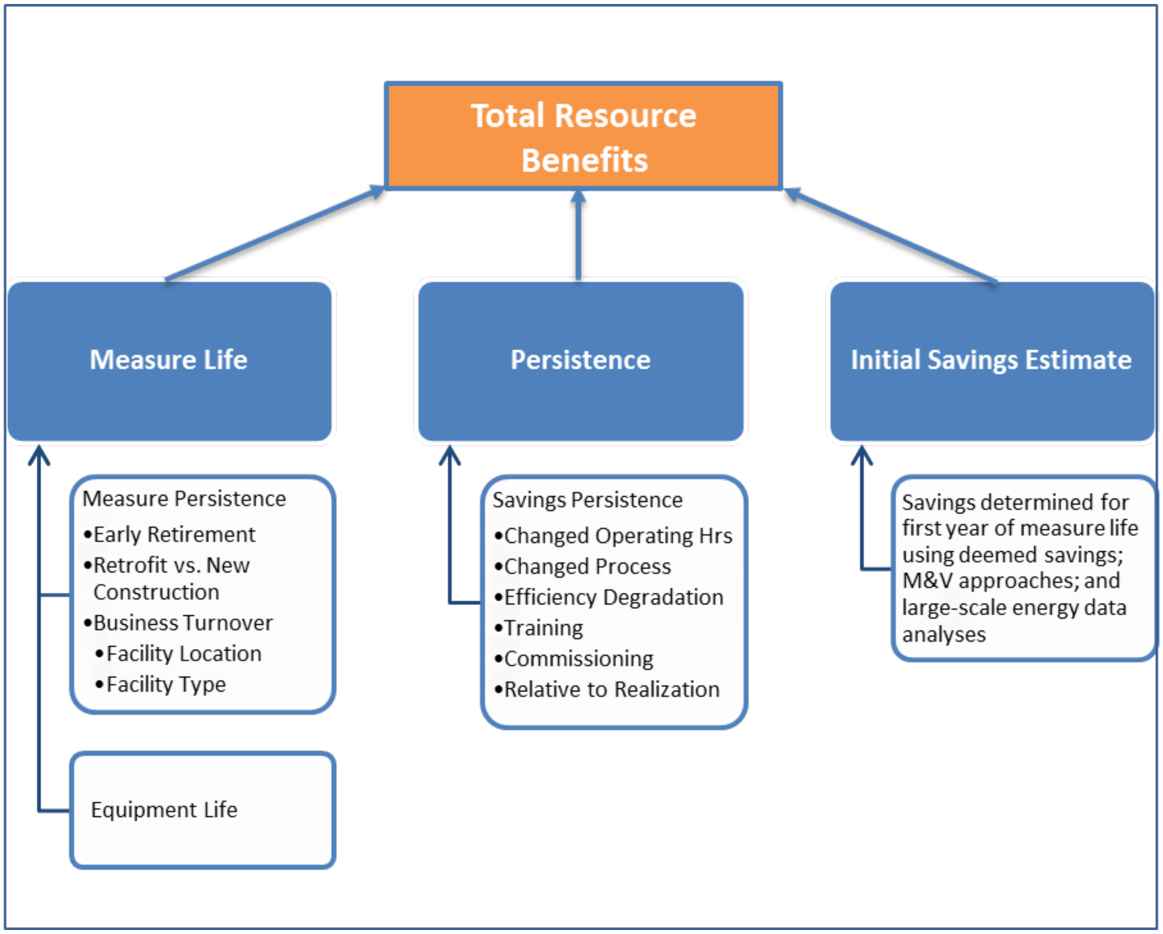

Figure 4. Components of the calculation of resource benefits of an efficiency measure (adapted from Energy & Resource Solutions 2005)

Note: The model illustrated here involves multiplying the lifetime, a savings persistence factor, and initial or first-year savings to calculate lifetime savings for a measure. In common practice, savings persistence is not explicitly used in the calculation but folded into estimated or calculated measure lifetime. Measure lifetime is multiplied by the estimated or calculated first-year savings in order to obtain lifetime savings.

Program administrators tend to treat savings as constant—the measure is in place and delivering savings as assumed for the first year or not. Savings persistence, on the other hand, can be regarded as a series of changes in performance over time. Those changes may be steady year by year, or may increase or decrease nonlinearly over time.

Only a few states and regions have considered or applied formalized definitions of savings persistence. These definitions may cover measure persistence, technical changes in savings for the measure, changes in human interaction with the measure, or changes in the operation of the measure or the facility in which the measure is located (behavioral/operational persistence), and may consider the following scenarios:

- The energy performance of the efficiency measure/behavior changes is relative to a standard measure/behavior;
- The efficiency measure is installed, operated or maintained improperly such that its savings degrades after the first year;

- A measure remains in place but is not used as planned—e.g., an energy management system is turned off by a building operator or a factory that was to run on three shifts drops to a single shift, so loads and savings are reduced, or a room that was an office becomes a conference room;
- The role or function of the measure in a facility or process changes, or its hours or mode of operation changes; and
- A measure is not properly maintained over its lifetime, because it is overridden or goes out of calibration (controls only).

For early replacement and process improvement programs, a dual or dynamic baseline approach may be used. Two levels of savings are estimated over two periods of time in “stair-step” fashion: (1) for the first period, savings are based on an assumed baseline of the previous equipment, system or behavior through the end of the life of the replaced end use, and (2) for the second period, savings are based on an assumed baseline of common practice, building code, or end-use standard for the remaining life of the more efficient measure (see Figure 5).

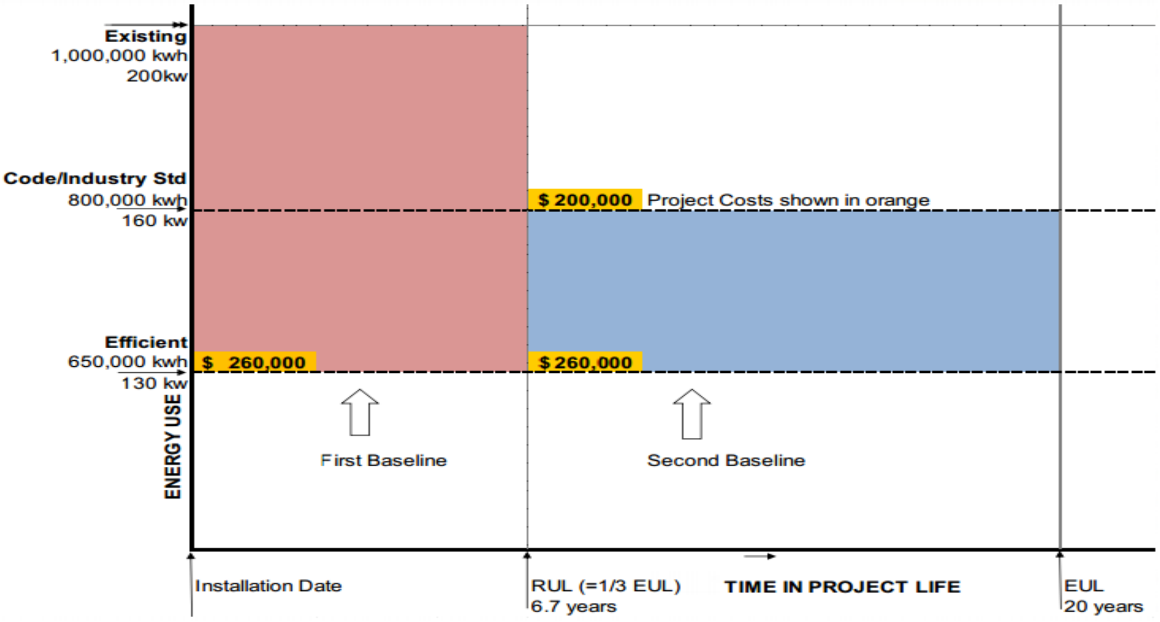

Figure 5. An example of a dual-baseline approach to savings estimation from California

Note: In this example, project savings for an initial period are calculated as the difference between the existing end uses and their more efficient replacements for the remaining useful life (RUL) of the existing end uses, here assumed as 6.7 years. Savings for the rest of the project life are calculated as the difference with either the new code or standard for that end use or common practice at the time. Source: Energy and Environmental Economics (E3) and CPUC 2013

Studies and Applications of Savings Persistence in Calculating Benefits

In the latter 1990s and early 2000s, evaluation advisors to California utility regulators adopted a formal definition of savings persistence and commissioned a unique series of studies of technical performance degradation for common end uses. The studies produced a series of scaling variables called “technical degradation factors” or TDFs. These studies were concerned almost exclusively with technical degradation in savings persistence.

TDFs can be used to account for time- and use-related changes in the technical savings performance of a high-efficiency measure or practice compared to a standard measure or practice. TDFs are expressed as a year-by-year series of ratios to be applied to first-year savings (and other benefits) of a measure for each year of the measure life (see Table 3) using the following formula:[20]

Measure resource benefit = (first–year impact) x (measure lifetime) x (measure TDF for each year of the lifetime)

Table 3 presents technical degradation factors for specific measures selected to emphasize the variability in TDFs. For example, for variable speed drives and dimmable daylighting, technical degradation can reduce savings by 50% and 60%, respectively, within the first seven years of measure life. Conversely, savings for more efficient residential air conditioners and refrigerators can be 3% and 9% higher than standard equipment, respectively. However, these are exceptions. For more than 95% of typical efficiency measures, the TDF studies in California found no statistically significant net change in measure energy performance compared to standard measures (California Energy Efficiency Evaluation Protocols 2006). Based in part upon this work, efficiency industry practitioners have tended to conclude that efficient measures do not degrade significantly faster than existing inefficient measures. For this reason, California eventually dispensed with TDFs and, where data were available and reliable, integrated persistence into estimations of lifetimes or unit energy savings.

Similarly, a small number of studies of savings persistence were conducted for Northeast utilities in the early 1990s, but experts consulted for this brief could not recall recent research on the subject. New studies of degradation factors or savings persistence are uncommon. A relatively recent survey of more than 100 measure lifetime and persistence studies identified few that were contemporary at the time or based upon primary data (Skumatz et al. 2009).

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[20] A few measures have “negative TDFs”—that is, the efficient measure is degrading more slowly or to a lesser degree than the standard measure, resulting in a net relative gain in benefits over time. For example, residential refrigerators can be made more efficient with more efficient compressors. Refrigerator efficiency degrades over time as the composition of the foam insulation in the casing changes and loses its effectiveness. Both standard and efficient refrigerators experience this same 10% loss in efficiency (or gain in load), but the impact of this load change is larger in absolute terms for the standard refrigerator because of its higher load. Similarly, residential air conditioners can be made more efficient by increasing the heat-exchange area with a larger face of condenser coils. Dirt fouls the heat-exchange area by several percent per year. Less of the heat exchange area is fouled in the efficient models with larger coil faces. For a third example, consider a one-inch settling or compaction in R-10 versus R-30 attic insulation over 20 years. Both lose some effectiveness at reducing heat conduction, but the reduction is less for the R-30 versus the R-10 insulation.

Table 3. A sample of technical degradation factors developed for California

YEAR	Residential DX AC	Oversized Evaporative Condenser	Residential Refrigerator	Electric Ballast, T8 lamps	High Efficiency Motors	Adjustable Speed Drive Injection Molding	Wall & Floor Insulation	Dimmable Day-Lighting	Agricultural Pump
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	0.98	1.04	1.00	1.00	0.98	1.00	0.73	1.00
3	1.01	0.96	1.06	1.00	1.00	0.91	1.00	0.61	1.00
4	1.01	0.93	1.07	1.00	1.00	0.74	1.00	0.54	1.00
5	1.02	0.91	1.08	1.00	1.00	0.57	1.00	0.48	1.00
6	1.02	0.89	1.08	1.00	1.00	0.50	1.00	0.43	1.01
7	1.03	0.87	1.09	1.00	1.00	0.48	1.00	0.39	1.01
8	1.03	0.84	1.09	1.00	1.00	0.47	1.00	0.36	1.01
9	1.04	0.82	1.09	1.00	1.00	0.47	1.00	0.33	1.01
10	1.04	0.80	1.09	1.00	1.00	0.47	1.00	0.31	1.01
11	1.05	0.80	1.10	1.00	1.00	0.47	1.00	0.29	1.01
12	1.05	0.80	1.10	1.00	1.00	0.47	1.00	0.27	1.01
13	1.06	0.80	1.10	1.00	1.00	0.47	1.00	0.26	1.01
14	1.07	0.80	1.10	1.00	1.00	0.47	1.00	0.24	1.02
15	1.07	0.80	1.10	1.00	1.00	0.47	1.00	0.23	1.02
16	1.08	0.80	1.10	1.00	1.00	0.47	1.00	0.23	1.02
17	1.09	0.80	1.10	1.00	1.00	0.47	1.00	0.22	1.02
18	1.09	0.80	1.10	1.00	1.00	0.47	1.00	0.21	1.02
19	1.10	0.80	1.10	1.00	1.00	0.47	1.00	0.21	1.02
20	1.10	0.80	1.10	1.00	1.00	0.47	1.00	0.20	1.02

Source: Proctor Engineering, 1999 report for CADMAC; abridged by LBNL to emphasize a range of values.

California evaluation protocols give discretion to regulators to order new persistence studies, stating that:

> *…(t)hese may be needed based upon comments and findings within impact evaluations that discover potential issues with technical degradation, technologies not assessed in the five prior studies, changes in technology for the efficient or standard equipment, or for other reasons. For example, a technical degradation study may be desired for duct sealing which has not been previously studied.*

The protocols set out research standards for establishing both technical degradation factors and behavioral degradation factors but do not specifically require program administrators to use those factors in calculating measure benefits. The spreadsheet calculator used in California to determine cost effectiveness has not explicitly included TDFs (except as embedded in lifetimes) in the calculation of benefits since the 2006-2008 program cycle. Instead, degradation in savings is one of several considerations in de-ratings of either measure lifetime or annual savings but is not typically applied because technical reviewers of the Database for Energy Efficiency Resources have not found “sufficient and reliable” documentation of the effect (Hirsch 2014).

A few jurisdictions do use, or enable the use of, algorithms for calculating measure lifetime with a multiplier for savings persistence. For example, in Hawaii and Vermont, the default persistence value in the lifetime algorithm is 1.0 (i.e., the lifetime is unchanged and 100% of first-year savings is assumed to persist throughout the lifetime in calculations of measure benefits):

> *A value lower than 1.00 will result in a downward adjustment of lifetime savings and total resource benefits. For any measure with a persistence value less than 1.00, the normal measure life…will be reduced to arrive at an 'Effective Useful Life' for the purposes of estimating the TRB (total resource benefits) of a measure or program.*
>
> —Hawaii Energy Technical Reference Manual for Program Year 2012

The rationales for not treating persistence of savings explicitly in efficiency benefit calculations for measures have been compelling. However, administrators and evaluators may want to revisit this issue for certain measures. First, the California studies that reported changes in savings persistence for a small number of measures are dated (i.e., late 1990s), and the universe of potential measures has grown and will continue to evolve. Second, the energy efficiency industry has been moving toward regional technical reference manuals, so the cost of assessing savings persistence may be spread among more program administrators. Third, while discounting of savings in later years may reduce the relevance of persistence for calculating monetized benefits and cost effectiveness, actual energy savings and avoided emissions continue beyond the economic lifetime of the measure. Thus, persistence of savings from certain measures may become more important based on environmental considerations.

Conclusions

Quantifying the lifetime of measures and, by extension, programs and portfolios, is critical to estimating total or lifecycle benefits, calculating cost effectiveness, and prioritizing long-term versus short-term efficiency investments. Estimates of lifetime savings from programs also impact other parts of the utility's business and resource planning: load forecasts, estimation of savings potential, the setting of performance incentives and lost revenue recovery, and avoided emissions estimates. Better understanding and quantification of the variability of savings over time (persistence) also may be important for at least a subset of efficiency actions, measures or programs, including some that are emerging or envisioned as significant sources of savings.

We find that savings lifetimes may vary significantly within a program category—by 30% to 50% even within the interquartile range. This variability is lower when all programs are aggregated across each sector (e.g., for all residential programs) and across all sectors. Some of this variability is justified on technical grounds, such as different mixes of measures among similar programs or different operating conditions in facility types. But savings lifetimes also vary for reasons that may be less accurate or justified, such as different definitions, differing engineering assumptions, or different levels of rigor in evaluation, measurement and verification.

All of these sources of variability flow into values such as the cost of saved energy and may influence screening of measures and programs for cost effectiveness. As Figure 3 illustrates, the cost of saved energy for programs can vary significantly based on different assumed savings lifetimes. For example, cost performance varies across the interquartile range of savings lifetimes by 37% in the case of appliance recycling programs, 30% for multi-family retrofit programs, and 28% for C&I prescriptive measure programs. As another example, changing the measure lifetime of behavioral feedback programs from one year to the 3.9 years recommended in a recent study reduces the cost of saved energy for those programs by nearly 70%.

Some of the observed differences in measure (and program and portfolio) lifetimes could be reduced if there were a nationwide technical reference manual (or more regional versions) that included standardized information on lifetime and savings estimates for specified efficiency measures.

The research for this technical brief indicated that most program administrators have not paid a lot of attention to savings persistence. When they do, they have most commonly integrated savings persistence into estimations of measure lifetime or, more rarely, estimation of annual unit energy savings. For reasons cited in this brief, savings persistence has not been widely regarded as worth the time and effort to quantify its effect. Without more substantial and up-to-date information, we cannot conclude definitively whether savings persistence is a significant factor in the quantification of energy savings.

The need for more research into persistence may become more pressing for a number of reasons:

- Policy makers and regulators may want firmer assurances that energy savings impacts can be counted on for the entire lifetime of efficiency actions.
- The tendency to minimize the importance of persistence, because economic discounting results in modest monetized benefits in later years, ignores the real and continued impact of changes in emissions reductions over, and often beyond, measure lifetimes.
- Persistence may turn out to be a significant issue for a subset of measures that play, or are expected to play, a more prominent role in efficiency portfolios in the future (e.g., behavioral programs, retro-commissioning, new technologies). More up-to-date research is warranted for at least these measure types. Priority should be accorded to measures that:
  - Account for a significant share of overall savings;
  - Have significant behavioral or operational variability over time and in different applications;
  - Represent very different technologies from the baseline or standard measures they replace; or
  - Are at higher risk of degradation in early years.

We therefore recommend additional research into the persistence of savings for certain families of measures:

- *Traditional high-efficiency measures for which savings are not heavily dependent on occupant behavior, but which may account for a significant share of portfolio savings.* These measures (e.g., newer types of lighting fixtures, refrigerators) may be viewed as well understood but are worth periodic re-evaluation—for example, through *in-situ* performance studies or testing under laboratory conditions through accelerated aging techniques.
- *Behavior-based programs.* These program types (e.g., normative or comparative feedback on consumption, online audits) are spreading rapidly and becoming a common feature in many portfolios. A number of studies already have been done or are underway to understand persistence of savings.[21] Thus far, researchers have concentrated on residential normative-messaging programs, but additional research is warranted as these programs are directed at other markets

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[21] See Khawaja and Stewart (2014) for a survey of current evaluations of residential behavior-based programs and estimates of measure lifetime and savings persistence for behavioral programs that rely on normative messaging in the residential sector.

(e.g., small commercial customers) or as program administrators employ other methods for changing consumption patterns.

- *High-efficiency technologies that have a substantial behavioral component.* Controls-based and systems approaches to saving energy (lighting controls, in-home displays, programmable thermostats, retro-commissioning, and C&I building energy management systems) are gaining in usage and may warrant field studies to assess potential changes in savings over time.

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Appendix A. Definitions of Measure Lifetime/EUL

Region/State	Definition of Measure Lifetime or Expected/Effective/Estimated Useful Life (EUL)
Regional Technical Forum (Pacific Northwest)	The median number of years during which at least half the deliveries of a measure are in place and operable, i.e., produce savings. Many factors may affect measure lifetime, including but not limited to delivery method, equipment sizing, maintenance practices, operating conditions and operating hours.
Northeast Energy Efficiency Partnerships	An estimate of the median number of years that efficiency measures installed under a program are still in place and operable.
Public Utilities Commission of Texas	The number of years until 50% of installed measures are still operable and providing savings. Used interchangeably with the term “measure life.” The EUL determines the period of time over which the benefits of the energy efficiency measure are expected to accrue.
California Public Utilities Commission	The estimate of the median number of years that the measures installed under the program are still in place and operable (retained).
SEE Action Evaluation, Measurement, and Verification Working Group	The length of time that a measure is expected to be functional; sometimes referred to as expected useful life. Measure life is a function of equipment life and measure persistence. Equipment life is the number of years that a measure is installed and will operate until failure. Measure persistence takes into account business turnover, early retirement of installed equipment, and other reasons measures might be removed or discontinued.
Uniform Methods Project	The median number of years that a measure is in place and operational after installation. This definition implicitly includes equipment life and measure persistence but not savings persistence. "Equipment life” is the number of years installed equipment will operate before it fails. "Measure persistence” takes into account business turnover, early retirement or failure of the installed equipment, and any other reason the measure would be removed or discontinued.