GROUP A

Residential Insulation Measure Effective Useful Life Study Final Report

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Glossary of terms

Effective Useful Life (EUL) – Effective useful life (EUL) is defined as an estimate of the median number of years that the measures installed under a program are still in place and operable.[1]

Measure – A product whose installation and operation at a customer's premises results in a reduction in the customer's on-site energy use, compared to what would have happened otherwise. [1]

Participant – An individual, household, business, or other utility customer who received a service or financial assistance offered through a particular utility program, set of utility programs, or aspect of a utility program in a given program year.[1]

Performance Degradation – Any overtime savings degradation (or increases compared to standard efficiency operation) that includes both (1) technical operational characteristics of the measures, including operating conditions and product design, and (2) human interaction components and behavioral measures. [1]

Persistence Study – A study to assess changes in net program impacts over time (including retention and degradation).[1]

Precision – The indication of the closeness of agreement among repeated measurements of the same physical quantity. In econometrics, the accuracy of an estimator is measured by the inverse of its variance.[1]

Reliability – When used in energy evaluation refers to the likelihood that the observations can be replicated.[1]

Remaining Useful Life (RUL)- a subjective estimate of the number of remaining years that an item, component, or system is estimated to be able to function by its intended purpose before warranting replacement. The remaining useful life is estimated based on observations or average estimates of similar items, components, systems, or a combination thereof.[2]

Retention (Measure) – The degree to which measures are retained in use after they are installed. [1]

Rigor – The level of expected reliability. The higher the level of rigor, the more confident we are that the results of the evaluation are both accurate and precise, i.e., reliable.[1]

R-Value – A measure of insulation's ability to resist heat traveling through it.[3]

Sample Design – The approach used to select the sample units.[1]

Survival Analysis – Survival analysis is a class of statistical methods for studying the timing of events or time-to-event models. Originally these models were developed for medical research where the time to death was analysed, hence the name survival analysis. These statistical methods are designed to work with time-dependent covariates and censoring. Time-dependent covariates are independent variables whose impacts on the dependent variable vary by not only its occurrence but also its timing. Censored data refers to not knowing when something occurred because it is before your data collection (left-censored) or has yet to occur at the time of data collection (right-censored).[1]

Technical Degradation Factor – A multiplier used to account for time- and use-related change in the energy savings of a high-efficiency measure or practice relative to a standard efficiency measure or practice due to technical operational characteristics of the measures, including operating conditions and product design.[1]

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[1] California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals. April 2006. Appendix B: Glossary of Terms.

[2] PARTNER Engineering & Science Inc. https://www.partneresi.com/resources/glossary/remaining-useful-life-rul/#:~:text=The%20Remaining%20Useful%20Life%20(RUL,intended%20purpose%20before%20warranting%20replacement.

[3] ENERGY STAR®, Recommended Home Insulation R–Values | ENERGY STAR, https://www.energystar.gov/saveathome/seal_insulate/identify_problems_you_want_fix/diy_checks_inspections/insulation_r_values

1 EXECUTIVE SUMMARY

This report presents the findings of the effective useful life (EUL) evaluation study conducted by DNV on behalf of the California Public Utilities Commission (CPUC) for residential wall and ceiling insulation. Insulation was selected for study for the following reasons:

- To support California's decarbonization and savings goals. Reducing heating loads with insulation is a key measure that supports beneficial electrification and decarbonization. Also, it can achieve gas savings but does not burn gas, thereby excluding insulation measures from policy limitations set on ratepayer funded incentives for gas energy efficiency measures (see definition of *Exempt Measures* in Decision 23-04-035[4]).
- Understanding if insulation envelope measures EUL values exceed the existing 20-year EUL assumption[5] that limits the lifecycle benefit accounting of insulation.
- Recent EUL studies only focused on persistence and did not consider performance degradation.
- Strong interest from stakeholders.

An EUL is the estimate of the median number of years that a measure, or energy-efficient technology, installed under a program is still in place and operable. EUL values are critical in reliably estimating the lifetime energy savings that are used for program planning and evaluation activities, and therefore, need to be periodically re-assessed.

1.1 Study background and methods

The residential wall and ceiling insulation measures were selected by the joint staff (CPUC and DNV) as part of a broader residential EUL research effort that includes heating, ventilation, and air conditioning (HVAC), and water heater measures. The current EUL value for residential wall and ceiling insulation measures is capped at 20 years. [6,7] If supported by evidence, the directive under decision D.23-04-035[4] allows the EUL values of wall and ceiling insulation measures to be capped at 30 years instead of the existing 20-year cap.

Under this EUL evaluation study, DNV estimated the EUL values for residential wall insulation and residential ceiling insulation. To arrive at more accurate EUL estimates, DNV conducted on-site inspections of residences that had installed insulation through utility energy programs to estimate how the savings associated with the residential wall and ceiling insulation measures change over time. This is known as performance degradation and can occur due to technical operation characteristics of the insulation itself or due to external unique and human behavioral factors, such as rodents/pest infestation, plumbing leakage, rainwater intrusion/ compaction, fire damage, compaction due to storage, and home renovations. To quantify insulation performance degradation, we collected data at 28 sites that had installed wall insulation from 2006-2007 and at 48 sites that had ceiling insulation installed in that same 2006-07 period. Additionally, we conducted secondary research to understand how performance degradation of insulation occurs due to technical characteristics of insulation itself (natural degradation).

The site data in conjunction with the findings of secondary research on natural degradation informed us on the number of instances the wall and ceiling insulation installed in 2006-2007 had failed or had been removed, either partially or

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[4] Decision 23-04-035. April 6, 2023. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF

[5] Wall Insulation and Ceiling Insulation EUL values are stated in the CPUC Support Tables under EUL IDs "BS-BlowInIns" and "BS-CeilIns" respectively (link to CPUC EUL Support Table: Effective Useful Life and Remaining Useful Life | ETRM (caetrm.com))

[6] Itron. "2004/2005 Statewide Residential Retrofit Single-Family Energy Efficiency Rebate Evaluation." Itron, Inc.

[7] CPUC. cpuc.ca.gov. https://docs.cpuc.ca.gov/published/Final_decision/11474-13.htm

completely, up until 2023. We then used this information to predict the amount of time that passes until 50% of the installed wall and ceiling insulation are still working and providing savings – the wall and ceiling insulation measure EUL values.

1.2 Key findings and recommendations

The key findings from the residential EUL evaluation study are as follows.

Finding 1. Increases to the EUL values for wall and ceiling insulation measures should be considered based on the results of this study.

As presented in Table 1-1, this study developed lower and upper bound EUL estimates for residential wall and residential ceiling insulation measures through analysis of site data. The lower bound estimates were developed assuming that any partial reduction in the observed performance of insulation would be considered a failure, whereas the upper bound estimates ignore the partial reduction and only consider a 100% reduction in insulation performance as a failure. For ceiling insulation, both lower and upper-bound EUL estimates are well above the 30-year cap directed by Decision D.23-04-035.[8] For wall insulation, while the lower bound of EUL is below the 30-year cap, the upper-bound EUL estimate is still above the 30-year cap, and these upper and lower bound results bracket the proposed 30-year EUL.

Table 1-1. EUL results

Residential technology	On-site completed	Lower bound of EUL (years)	Upper bound of EUL (years)	Proposed EUL* (years)
Wall Insulation	28	28	34	30
Ceiling Insulation	48	45	267	30

* Capped at 30 years per Decision 23-04-035.

Recommendation: Update the EUL values for both residential wall and ceiling insulation measures to 30 years.

The EUL values of residential wall and ceiling insulation measures should be updated from the current cap of 20 years to the new 30-year cap. The EUL identifications (ID) of the evaluated wall and ceiling insulation measures in the database for energy efficient resources (DEER) appear as “BS-BlowInIns” and “BS-Cailin’s”, respectively[9]. Notably, the "BS-BlowInIns" DEER EUL ID pertains solely to blown-in wall insulation. Given that our study's site data encompasses both blown-in and batt wall insulation, we recommend expanding the wall insulation EUL results to encompass batt wall insulation, denoted by the "BS-WallIns” EUL ID.

The EUL values for "BS-BlowInIns”, "BS-WallIns," and "BS-CeilIns" should be updated to 30 years.

Finding 2. DNV estimates the savings associated with the residential wall insulation and residential ceiling insulation measures installed in 2006-2007 to reduce by 2.15% and 5.90%, respectively, in 2023.

Based on the data collected on 28 wall insulation measure adopters from 2006-2007, DNV estimates the persistence and therefore, savings associated with the wall insulation measure to reduce by 2.15% in 2023. This estimated reduction is mostly due to wall removal for renovation.

[8] Decision 23-04-035. April 6, 2023. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF

[9] California Electronic Technical Reference Manual (eTRM). Accessed 10/31/2023. https://www.caetrm.com/login/?next=/

For the 48 ceiling insulation measure adopters from 2006-2007, DNV estimates the savings associated with the ceiling insulation measure to reduce by 5.90% in 2023. This estimated reduction is mostly due to pest/fungus damage, long-term storage compression, fire damage, and renovation.

These low degradation values (2% to 6%) and therefore, low reduction in savings associated with wall and ceiling insulation measures, even after 16-17 years of installation, suggest that it would take more than 20 years to observe a 50% degradation of wall and ceiling insulation. Therefore, the current EUL of 20 years is low. Based on the extrapolation of the site findings, DNV expects the EUL values of wall and ceiling insulation measures to be well above the current EUL of 20 years.

Recommendation: DNV has no specific recommendations for this finding.

Finding 3. Insulation degrades minimally on its own and therefore, the performance and associated savings are expected to be minimally reduced over time if exposed to natural conditions only.

DNV, through a review of available literature, found that the performance (i.e., heat-resisting capacity) of wall and ceiling insulation is expected to minimally reduce (heat resisting capacity of 16-17 years old insulation is expected to reduce only by < 0.01% of the heat-resisting capacity of a newly installed insulation) on its own or when subjected to natural temperature and moisture conditions only.

Recommendation: DNV has no specific recommendations for this finding.

Finding 4. The insulation persistence and the associated savings are most commonly reduced due to unique external and human-behavioral factors.

DNV, through site inspections, found that the continued existence and functioning (persistence) and therefore, the associated savings of wall and ceiling insulation measures are most reduced due to the following unique external and human behavioral factors: pest/fungus damage (observed on four sites), renovation (observed on three sites), long term storage (observed on three sites), and fire damage (observed on one site).

DNV conducted data collection on 28 sites that had installed wall insulation during the 2006-2007 program years. DNV did not find any evidence to suggest that the insulating property of the installed wall insulation had changed on its own. For two out of 28 sites, the installed insulation was either partially or fully removed due to renovation, resulting in a reduction in associated retention and therefore, savings.

Similarly, based on on-site inspection of 48 ceiling insulation sites, DNV did not find any evidence to suggest that the insulating property of the installed ceiling insulation had changed on its own. For nine out of 48 sites, the ceiling insulation was either partially or completely removed due to the following unique external and human-behavioral factors: pest/fungus damage on four sites, long term storage on three sites, renovation on one site, and fire damage on one site.

While the number of wall and ceiling insulation failure/removal observation is low, what is important is not the number of failures observed alone, but rather the removal observed relative to the total observations and over a relevant amount of time.

Recommendation: DNV has no specific recommendations for this finding.

2 INTRODUCTION AND STUDY BACKGROUND

This report presents the findings of the EUL evaluation study of residential wall and ceiling insulation measures selected by the joint staff (the CPUC and DNV). DNV conducted an EUL estimation study and investigated the performance degradation of the residential wall and ceiling insulation measures. The measure names and the associated EUL identifications (ID) of the evaluated wall and ceiling insulation measures in the database for energy efficient resources (DEER) are shown in Table 2-1.

Table 2-1. Residential insulation measures evaluated by the EUL study.

Measure name and ID	Technology		EUL ID[10]
Wall Insulation, Residential (SWBE007-02)	Measure	Wall insulation, Residential	BS-BlowInIns
	Baseline	Existing wall, no insulation	N/A*
Ceiling Insulation, Residential (SWBE006-02)	Measure	Wall insulation, Residential	BS-CeilIns
	Baseline	Existing insulation	BS-CeilIns

*N/A = not applicable

The residential insulation EUL study is a part of the larger residential EUL research effort that includes heating, ventilation, and air conditioning (HVAC), and water heater measures. The residential HVAC and water heater measure EUL study is under a different timeline, and that report will be delivered to the CPUC and stakeholders in December 2023.

2.1 Background

The Decision D.23-04-03 issued on April 14, 2023, "directs program administrators to develop comprehensive strategies and associated budgets to incentivize and promote exempt measures," [11] which includes insulation measures. As such, the residential wall and ceiling insulation measures are expected to be more prominently included in California's energy efficiency portfolio in the coming years. To reliably estimate the total system benefit and the cost-effectiveness used for program planning and evaluation activities, it is important to periodically re-assess EUL values of insulation measures.

The current DEER EUL value for residential wall and ceiling insulation measures is capped at 20 years.[12] This cap means that not all the benefits of insulation measures are being considered during measure evaluations, which reduces the assessment of both total system benefit and cost-effectiveness. The decision D.23-04-035 directs "program administrators to immediately begin examining the measure packages of all exempt measures in eTRM[13] and, if supported by evidence, update those measure packages to extend the effective useful life for those measures to up to 30 years." Understanding the EUL of wall and ceiling insulation measures may challenge the 20-year EUL cap that limits the cost-effectiveness of insulation measures and the use of remaining useful life (RUL) for add-on insulation. Additionally, the residential insulation energy efficiency measure, along with other energy efficiency measures, plays a key role in the state's transition to limit greenhouse gas (GHG) emissions and decarbonization. Therefore, there is a strong interest from the stakeholders to understand the EUL of residential wall and ceiling insulation measures.

[10] California Electronic Technical Reference Manual (eTRM). Accessed 10/31/2023. https://www.caetrm.com/login/?next=/
[11] Decision 23-04-035. April 6, 2023. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF
[12] CPUC. cpuc.ca.gov. https://docs.cpuc.ca.gov/published/Final_decision/11474-13.htm
[13] California Electronic Technical Reference Manual (eTRM). Accessed 10/31/2023. https://www.caetrm.com/login/?next=/

2.2 Study objectives

The two primary objectives of this study were to:

1. Revise or verify the DEER EUL values of residential wall and ceiling insulation measures.
2. Quantify performance degradation of residential wall and ceiling insulation measures.

2.3 CPUC EUL study protocol and terms

EULs are defined as the median number of years after installation that the measures installed under a program are still in place and operable—in other words, how long the measure persists.[14] The EUL Evaluation Protocol section of the California Energy Efficiency Evaluation Protocols[17] document outlines three types of EUL evaluation persistence studies: retention, degradation, and EUL analysis studies.

The Protocols define a persistence study as one that "measures change in the net impacts that are achieved through installation/adoption of program-covered measures over time. These changes include retention and performance degradation. The EUL protocol defines retention as the proportion of measures retained in place and that are operable."[15] Performance degradation accounts for both time-related and use-related changes in energy savings over time.

For the wall and ceiling insulation measures, DNV conducted a degradation study to capture the persistence of energy savings over the measures' lifetimes. As defined by the evaluation protocols, "performance degradation studies produce a factor that is a multiplier used to account for both time-related and use-related change in the energy savings of a high-efficiency measure or practice relative to a standard efficiency measure or practice. Degradation studies must designate and clearly describe all the elements that will be analyzed for the degradation factor produced. If only a technical degradation factor is produced or only a behavioral degradation factor is produced for a measure that contains both, this must be clearly noted. If the equipment has both a technical and behavioral degradation factor and one of these is to come from a previous study or another source and the other is being addressed in the Protocol-covered study, both factors must be presented in the report and the analysis must produce a combined factor for that equipment."[16] Table 2-2 summarizes the degradation study protocol methods by rigor level.[17]

Table 2-2. Degradation study protocols

Rigor level	Required protocols for degradation studies
Basic	➢ A literature review for technical degradation studies across a range of engineering-based literature, including but not limited to manufacturer's studies, ASHRAE studies, and laboratory studies ➢ Review of technology assessments such as assessments using simple engineering models for technology components that examine key input variables and uncertainty factors affecting technical degradation ➢ Telephone surveys/interviews with a research design that meets accepted social science behavioral research expectations for behavioral degradation ➢ Basic rigor requires that a 0.70 level of power be planned at the 90% level of confidence with 30% precision.
Enhanced	➢ For technical degradation: field measurement testing ➢ For behavioral degradation: field observations and measurement

[14] California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals. April 2006. Appendix B: Glossary of Terms.

[15] Ibid

[16] Ibid

[17] Ibid

Rigor level	Required protocols for degradation studies
	➢ Enhanced rigor requires that a 0.80 level of power be planned at the 90% level of confidence with 10% precision.

3 METHODOLOGY

The objective of the wall insulation and ceiling insulation EUL evaluation study was to develop EUL estimates as well as to quantify performance degradation over time. This was accomplished by conducting on-site data collection of the oldest available wall and ceiling insulation program participants (from 2006 and 2007), distributed proportionately over climate regions. Details on EUL the degradation analysis methodologies can be found in Section 3.3.

3.1 Sample design

A sample design and data collection memo for the insulation EUL and degradation study were delivered to the CPUC. EUL study generally tracks if an equipment is still in-place and working or not and assigns a binary yes/no (1 or 0) status. Unlike a piece of equipment that may fail or be removed as a unit, insulation may fail or be removed partially. As such, for the insulation EUL study, DNV developed a sample size assuming that the insulation site visits would determine a degradation factor for each project, rather than determining a yes/no retention status. A degradation factor of 0 means no degradation; a degradation factor of 1 means total degradation to highest extent possible, with observed degradation to some, but not all, insulation falling between 0 and 1. Targeting a precision level of 25% with 90% confidence, DNV designed a total on-site sample size of 45 data points for the insulation study. This sample size was designed to meet the basic rigor requirement for degradation studies. DNV completed a total of 48 on-site inspections, which exceeds the sample size designed for a basic rigor degradation study. For additional details, see section 6.

3.2 Data collection

3.2.1 Primary data collection

DNV conducted a total of 48 on-site inspections which included 28 residential wall insulation measure adopters and 48 ceiling insulation measure adopters from the PY2006 and PY2007 programs. The objective of the on-site inspection was to gather information on insulation material retention and wall/ceiling assemblies as well as to document the qualitative impact of insulation via infrared camera photos. While on-site, DNV also conducted interviews with program participants to gather information on pre-existing and installed insulation conditions on-site.

DNV conducted an on-site inspection of wall and ceiling insulation program participants and achieved the following:

- Assessed the extent of the program-installed wall insulation that was in place and if the installed insulation still insulates as well as it did when it was new. If the program installed insulation was not in place or did not insulate properly, we documented when exactly the insulation degraded/was removed and the reason(s) why that was the case.
- Verified/documented the age of program installed insulation.
- Gathered information on the program installed (or new insulation if program-installed insulation was removed) wall and ceiling insulation types (materials, thickness, and R-values), and impacted square footage.
- Material, thickness, dimension information, and material condition for walls and ceilings.
- Gathered ceiling framing information and information on wall framing and spacing.
- Gathered thermal images of walls and ceilings.
- Gathered information on what prompted the replacement of the old/pre-existing insulation.

- Gathered information on the condition and age of old/pre-existing information that was removed/replaced.
- Gathered information on what percent of time is the old insulation removed when installing new insulation.
- Gathered information on if leaks between attics and conditioned space is sealed when the old insulation was removed.

Table 3-1 presents an on-site data summary for the sampled wall and ceiling insulation program participants. A summary of the data collected on-site can be found in Table 8-1 and Table 8-3.

Table 3-1. Summary of insulation program participants

Technology	On-site completed	Tracked total insulated area (ft^2)	Evaluated total insulated area (ft^2)	Percent of insulated area retained
Wall Insulation	28	29,790	29,040	97.48%
Ceiling Insulation	48	55,800	54,669	97.97%

Table 3-2 provides a breakdown of the wall and ceiling insulation sites where the program installed was either all in place and functioning, partially removed, or fully removed.

Table 3-2.Summary of insulation status assessment

Technology	On-site completed	Number of sites where installed insulation was:		
		All in place and functioning	Partially removed	Fully removed
Wall Insulation	28	26	1	1
Ceiling Insulation	48	39	7	2

3.2.2 Secondary research

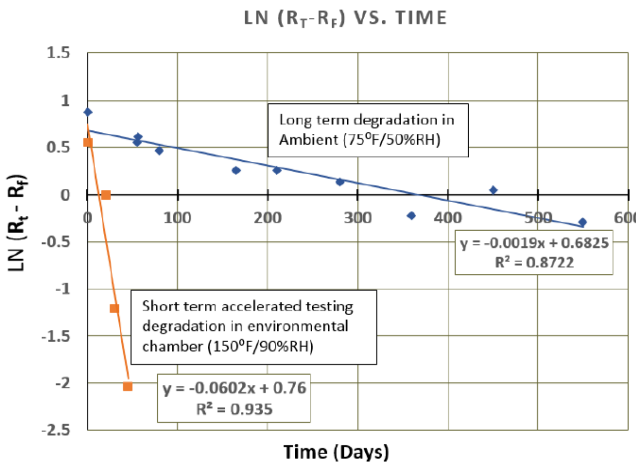
Insulation materials are prone to degradation over time based on environmental and unique external conditions. Degradation can happen either naturally due to prolonged exposure to environmental conditions (temperature and humidity) or due to unique external and human-behavioral factors, such as rodents/pest infestation, plumbing leakage, rainwater intrusion/ compaction, fire damage, compaction due to storage, and home renovations.

A natural degradation study of insulation is costly and requires insulation performance data collection for a prolonged period. As such, DNV relied on existing studies to gather insulation natural performance degradation curves. DNV identified a 2015 U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) study[18] as a reliable source for obtaining insulation natural degradation curves because of the study's relevancy and recency. The ERDC study investigated the long-term performance of five commercially available insulation materials including nonwoven insulation liners, aerogel blankets, closed-cell spray polyurethane foam, extruded polystyrene, and fiberglass batt. The study conducted an accelerated aging experiment by exposing insulating materials to various temperature and humidity conditions for 5 weeks. The accelerated test results were then simulated to estimate the long-term degradation of insulating materials. As shown in Figure 3-1 below, the study presented regression on how the R-value of the insulation changes over time due to long-term exposure to the environment (temperature and humidity). The study concluded that fiberglass and extended polystyrene

[18] U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC). "Prediction of Long-Term Degradation of Insulating Materials." May 2015.

insulations are only slightly affected by natural aging (disintegration and settling/compaction occurring naturally) and retain over 97% of their initial R-values after 30 years. The insulation materials DNV observed during on-site inspections were mostly fiberglass and blow-in cellulose insulation, which is similar to what the insulating materials investigated by the ERDC study, so we applied the natural degradation curve shown in Figure 3-1 to predict the long term natural degradation of the inspected site-specific wall and ceiling insulation.

Figure 3-1. Natural Logarithm of (RT-RF) versus time for polystyrene foam insulation* [19]



*RT is the initial R-value of the insulation, whereas RF is the R-value of insulation at time T.[20]

To understand the degradation due to unique external and human-behavioral factors, such as rodents/pest infestation, plumbing leakage, rainwater intrusion/compaction, compaction due to storage, and home renovations, DNV conducted on-site data collection on a sample of historical wall and ceiling insulation program participants. Site-specific data were used to quantify if and how the program-installed insulation degraded over time.

3.3 Analysis methods

3.3.1 EUL analysis

This section of the report discusses the methods employed to estimate measure persistence to date. A measure's EUL is defined as its median retention time; that is, the time at which half the units of the measure installed during a program year are not retained. To analyze retention, this study employed a method commonly referred to as "survival analysis." The set of techniques referred to as survival analysis is widely employed to analyze data representing the duration between observable events. The tracking and verified data were fed into two models: a non-parametric Kaplan-Meier life test model and a parametric survival analysis, which are briefly explained below.

Survival analysis generally tracks the binary options of "in place" and working or either of the opposites, not in place or not working. Insulation, as a measure, is different from system or fixture measures such as furnaces or lightbulbs that can be characterized in this binary fashion. Insulation is installed across different cavities and surfaces and at different R-values. Unlike a bulb that may fail or be removed as a unit, insulation may fail or be removed partially either in terms of expanse or R-value. Partial failure or removal makes it more difficult to track reliability and incorporate it into the standard survival

[19] U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC). "Prediction of Long-Term Degradation of Insulating Materials." May 2015.
[20] Ibid

analysis. To address this, we will estimate survival curves for multiple scenarios that allow for sites to be considered on a binary basis, either in place and working or not.

Furthermore, an optimal survival analysis has data across a range of ages (time since installation). The age of measures that are still in place is essential to fitting the models as they give information regarding the survival of the population at different points along the survival curve. This allows the model to better choose an optimal distribution and provide estimates with tighter confidence intervals. The data for this analysis all come from program installations that occurred in 2006 or 2007. The installations still in place are approaching the current EUL of 20 years which is good for the analysis. However, we only have the two program years at only one year apart. This provides limited information to the estimate process making the selection of the optimal distribution difficult and the confidence intervals wide.

To address these two issues, we estimate two different scenarios that bracket the underlying survival process (i.e., retention). The rare instances of measure failure (e.g., pest/fungus damage and removal due to renovation) have a date associated with their occurrence. Both scenarios include these failed instances as they exist in the data. As discussed below, the two scenarios differ in how they deal with partial survival at any given site:

- For the most "conservative" scenario, we treat any partial survival as a full-measure failure. That is, if the engineer indicated 10% survival, the model considers it to have failed completely at some point before today. As none of the observed partial survival goes beyond 20%, this is obviously an exaggerated level of survival that offers an absolute lower bound for the EUL.
- At the opposite extreme, we treat all sites with partial survival as fully in place and working under a more "generous" scenario. This provides an upper-bound EUL that only designates full-measure failure if there was complete insulation removal at the site.

These bracket results may be wide and accompanied by wide confidence intervals, but they still may offer sufficient insight to inform a change in the EUL of wall and ceiling insulation.

3.3.2 Kaplan-Meier (non-parametric) estimator

Combining the measure failure data from multiple program years requires a way to take into consideration unknown future events. Put another way, analysts need a method that can handle observations of measures that are installed at the time of the current site visit, but that will experience a removal event at some unknown point in the future (right censoring). Life-test or Kaplan-Meier (KM) survival curves are a simple yet powerful way to summarize unit operation vs. failure over a certain date range. The goal is to estimate a survival curve (i.e., what percent of installed units survive to any given age, plotting % surviving vs age). With the non-parametric approach, that curve is calculated based on the percent of those that survive to a given year who also survive to the next (e.g., of those who survive to year 3, what percent survive to year 4).

If measures have been installed long enough that more than 50% of the measures, or sites, are no longer in place, then a non-parametric approach, such as a KM approach, can offer a characterization of measure retention. The limitation of the non-parametric approaches is that they cannot be projected beyond the limits of the maximum observed elapsed years. In many cases where estimates of measure retention are sought, over 50% of the measures are still surviving in the field, thereby limiting the ability to use KM for the EUL estimate. However, the KM approach is still useful for comparing with the parametric results.

3.3.3 Parametric survival analyses

The parametric analysis allows an estimate of the percent that will survive to longer ages than are yet observable in the data, by assuming the decay in the survival curve follows a particular form. The same data used for the non-parametric KM estimator is used to estimate the parameters of a general form or distribution. With these parameters, we can draw the projected survival rates for higher ages than have yet been observed. We can also calculate the EUL as the age at which 50% of the units will no longer be in place, that is, the median survival time.

For this study, DNV applied a parametric model with a Weibull distribution. The Weibull is broadly used for survival analysis and has a general shape consistent with the way equipment failures tend to happen.

3.3.4 Degradation analysis

To quantify the performance degradation of insulation, DNV considered two different degradations: a) natural degradation due to long-term exposure to the environment (temperature and humidity) and b) degradation due to unique environmental and behavioral factors (e.g., pest infestation, fire damage, compaction due to storage, and home renovations).

As discussed in Section 3.2.2, DNV estimated the natural degradation due to long-term exposure using the degradation curve presented by the ERDC study. DNV compared the program-claimed insulation installation date with the date of the site visit to estimate the number of days. The initial insulation R-value ($R_{program}$) was assumed to be the verified program-claimed R-value. The R-value after natural degradation of the fiberglass and blown-in cellulose insulation found on site was then estimated as:[21]

$$R_{natural} = R_{program} - \exp(-0.019 \times number\ of\ days + 0.068)$$

The long-term natural degradation was then quantified as:

$$Degradation_{natural} = 1 - \frac{R_{natural}}{R_{program}}$$

DNV used the verified site data to estimate the degradation due to unique external and human-behavioral factors. The thermal images taken on-site in conjunction with the measured thickness of insulation were used to estimate the present (evaluated) R-value of the program-installed insulation. The measured insulated area was then used to capture the effect of the reduction/removal of the program-installed insulation. Finally, the degradation due to unique external and human-behavioral factors was estimated as:

$$Degradation_{uniqe\&behavioral} = 1 - \frac{R_{Evaluated} \times Insulated\ Area_{Evaluated}}{R_{Program\ Claimed} \times Insulated\ Area_{Program\ Claimed}}$$

The insulation R-value after degradation due to unique external and human behavioral factors was then calculated as:

$$R_{Unique\&behavioral} = R_{program} \times Degradation_{uniqe\&behavioral}$$

Finally, the overall evaluated insulation degradation and the overall evaluated R-value were calculated as:

$$Degradation_{overall} = 1 - \{(1 - Degradation_{natural}) \times \left(1 - Degradation_{uniqe\&behavioral}\right)\}$$

$$R_{overall} = R_{program} \times (1 - Degradation_{overall})$$

The site-specific wall and ceiling degradation factors, estimated using the methodology described above, were weighted and averaged by the respective program-claimed savings to establish a single degradation factor for the wall and ceiling insulation measures.

[21] U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC). "Prediction of Long-Term Degradation of Insulating Materials." May 2015.

4 RESULTS

4.1.1 Wall insulation

4.1.1.1 EUL Results

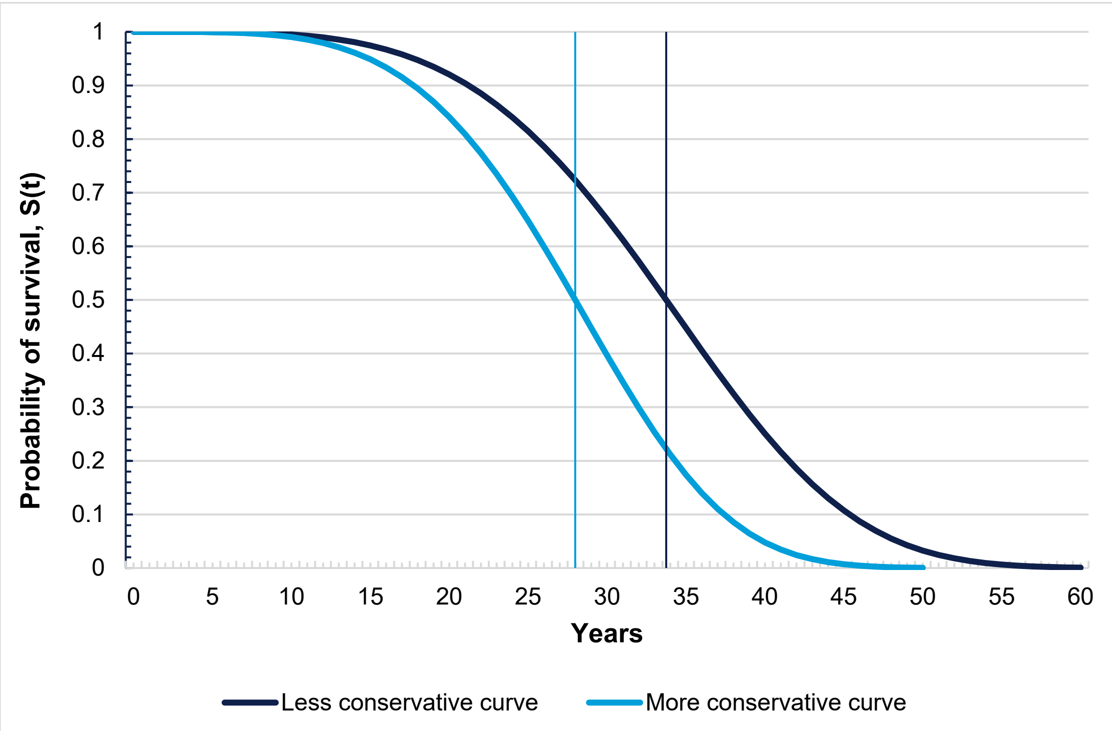
Our study developed site inspection sample size aiming for a basic rigor EUL study and assuming the current wall insulation EUL of 20 years to be accurate. We targeted the oldest available (16-17 years old) insulation participation data and were able to exceed our targeted sample size for the on-site inspection. However, site data (effectively unforeseeable), showed that most of the observed insulation was still in good working condition. As such, the Kaplan-Meier results do not reach the median level because more than 50% of the sampled measures were observed still surviving, so the parametric Weibull results provide the range of possible EULs. The predicted lower bound EUL for wall insulation is 28 years, with a 90% confidence interval of 9 – 47 years. This range represents an achieved precision of 68% at 90% confidence interval. Because of the nature of site data (i.e., inability to achieve median failure estimate due to very low failure of insulation), we did not quite achieve the basic rigor precision we aimed for. Despite this, we feel the EUL results presented here are sufficiently conclusive, especially in combination with the degradation results discussed in Section 4.1.1.2.

The predicted upper bound EUL for wall insulation is 34 years, with 90% confidence interval of <0 to 76 years. The wide confidence intervals of both estimates are the result of the relatively small population and the limited time range available in the data. While the confidence intervals of both lower bounds include the current 20-year EUL, it is important to remember that the lower bound estimate treats 10% and 20% degradation as 100% measure failure and still comes up with the EUL estimate of 28 years. The upper bound, which is somewhat generous in ignoring all partial degradation produces an EUL estimate of 34. The wider confidence interval reflects the fact that by ignoring partial degradation there is even less information informing the model fit. While the lower bound of EUL is below the 30-year cap allowed by D.23-04-035 [22], the upper-bound EUL estimate is still well above the 30-year cap, and these upper and lower bound results bracket the proposed 30-year EUL cap. Given we think the true EUL lies somewhere between these upper and lower bounds, we consider the midpoint to be a reasonable estimate. In light of the midpoint value (31 years) falling above the proposed 30-year EUL cap, our recommendation is to adopt the capped 30 year value for the wall insulation measure.

Figure 4-1 provides a plot of the two Weibull survival curves for the wall insulation data that represent the most conservative possible assumptions for partial degradation (Lower Bound) and less conservative assumptions (Upper Bound). Despite the wide confidence intervals, these represent typical survival curves for a measure like this and the two medial results bracket the proposed 30-year EUL.

[22] Decision 23-04-035. April 6, 2023. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF

Figure 4-1. Lower and upper bound Weibull distribution survival curves for wall insulation

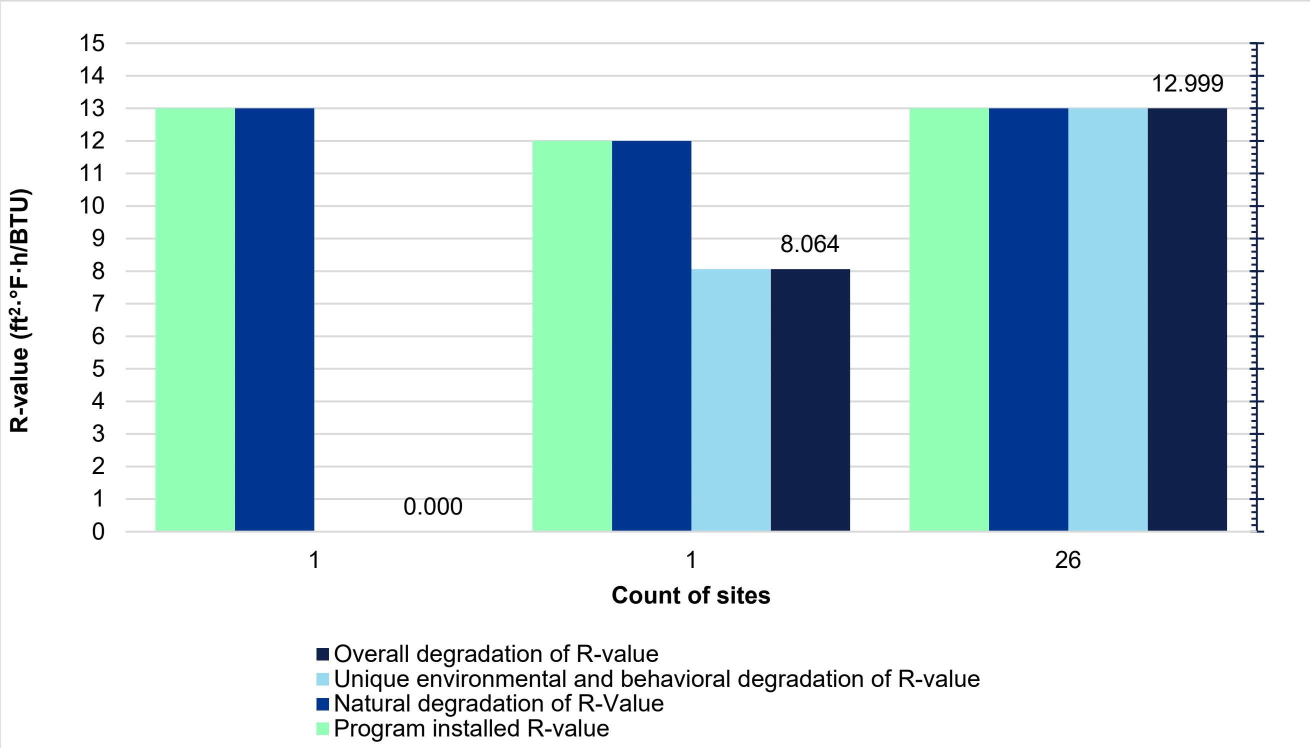


4.1.1.2 Degradation Results

For the 28 wall insulation PY2006-PY2007 program participants visited by DNV, as concluded by the ERDC study, the wall insulation is expected to retain 99.99% of its original R-value (<0.01% degradation) if subjected to natural degradation only. However, as shown in Figure 4-2 below, for 2 out of the 28 sites, DNV observed degradation due to unique external and human-behavioral factors. For one site, 37% of the program claimed wall insulation was removed due to remodeling and for the other site, all the program claimed wall insulation was removed due to major renovation.

Overall, the wall insulation degradation factor is estimated to be 2.15% (site-specific overall degradation factor weighted by program-claimed savings). Details on site-specific wall insulation degradation analysis results can be found in Appendix C, Table 8-2.

Figure 4-2. Wall insulation degradation results



4.1.2 Ceiling/Attic insulation

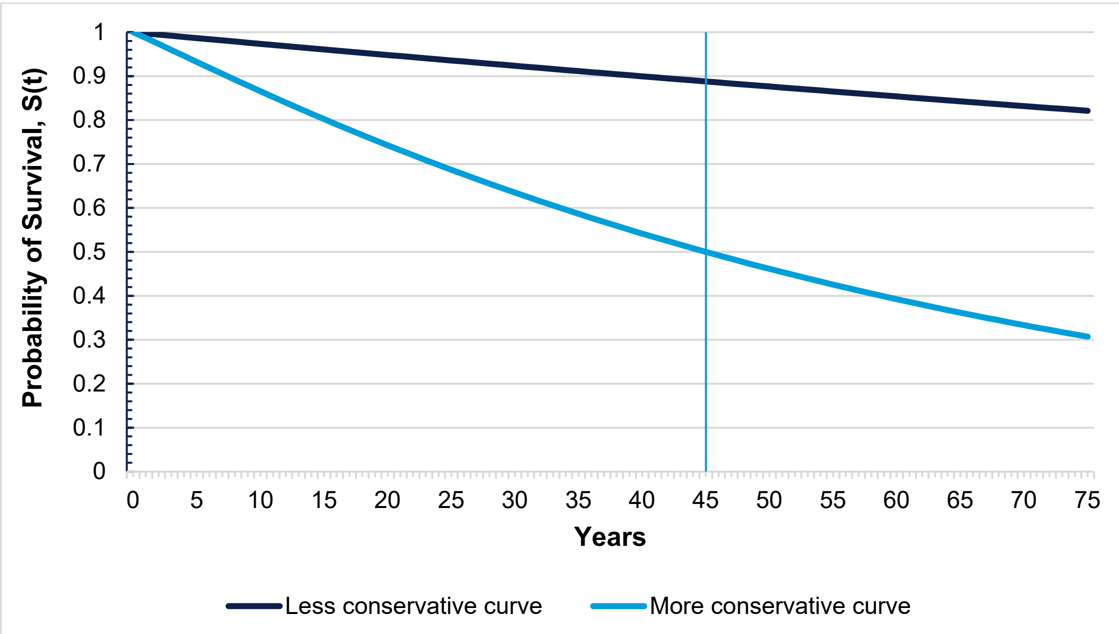
4.1.2.1 EUL Results

Our study developed site inspection sample size aiming for a basic rigor EUL study and assuming the current insulation EUL of 20 years to be accurate. We targeted oldest available (16-17 years old) insulation participation data and were able to exceed our targeted sample size for the on-site inspection retention (i.e., survival) analysis. However, site data (effectively unforeseeable), showed that most of the observed insulation was still in good working condition. As such, the Kaplan-Meier results do not reach the median level because more than 50% of the sampled measures were observed still surviving, so the parametric Weibull results provide the range of possible EULs. The predicted lower bound EUL for wall insulation is 45 years, with a 90% confidence interval of 1 to 89 years. This range represents an achieved precision of 98% at 90% confidence interval. Because of the nature of site data (i.e., inability to achieve median failure estimate due to very low failure of insulation), we did not quite achieve the basic rigor precision we aimed for. Despite this, we feel the EUL results presented here are sufficiently conclusive, especially in combination with the degradation results presented in Section 4.1.2.2.

The predicted upper bound EUL for ceiling/attic insulation is 267 years, with an extremely wide 90% confidence interval. Again, the wide confidence intervals of both estimates are the result of the relatively small population and the limited time range available in the data. While the confidence interval of the lower bound includes the current 20-year EUL, it is important to remember that this estimate treats 10% and 20% degradation as 100% measure failure and still comes up with the EUL estimate of 45 years. The upper bound, which is somewhat generous in ignoring all partial survival produces an EUL estimate of 267 years. Clearly, both lower and upper-bound of the EUL estimates are well above the 30-year EUL cap directed by Decision 23-04-035.[23] The average of the two EUL bounds is 156 years for ceiling/attic insulation, which is well-above the 30-year cap. Therefore, a 30-year EUL is recommended for the ceiling insulation measure.

Figure 4-3 provides a plot of the two Weibull survival curves that represent the most conservative possible assumptions for partial degradation (Lower Bound) and less conservative assumptions (Upper Bound). In this case, the Weibull distribution is effectively reducing to an exponential distribution indicating a constant probability of failure rather than one that increases with time.

Figure 4-3. Lower and upper bound Weibull distribution survival curves for ceiling insulation



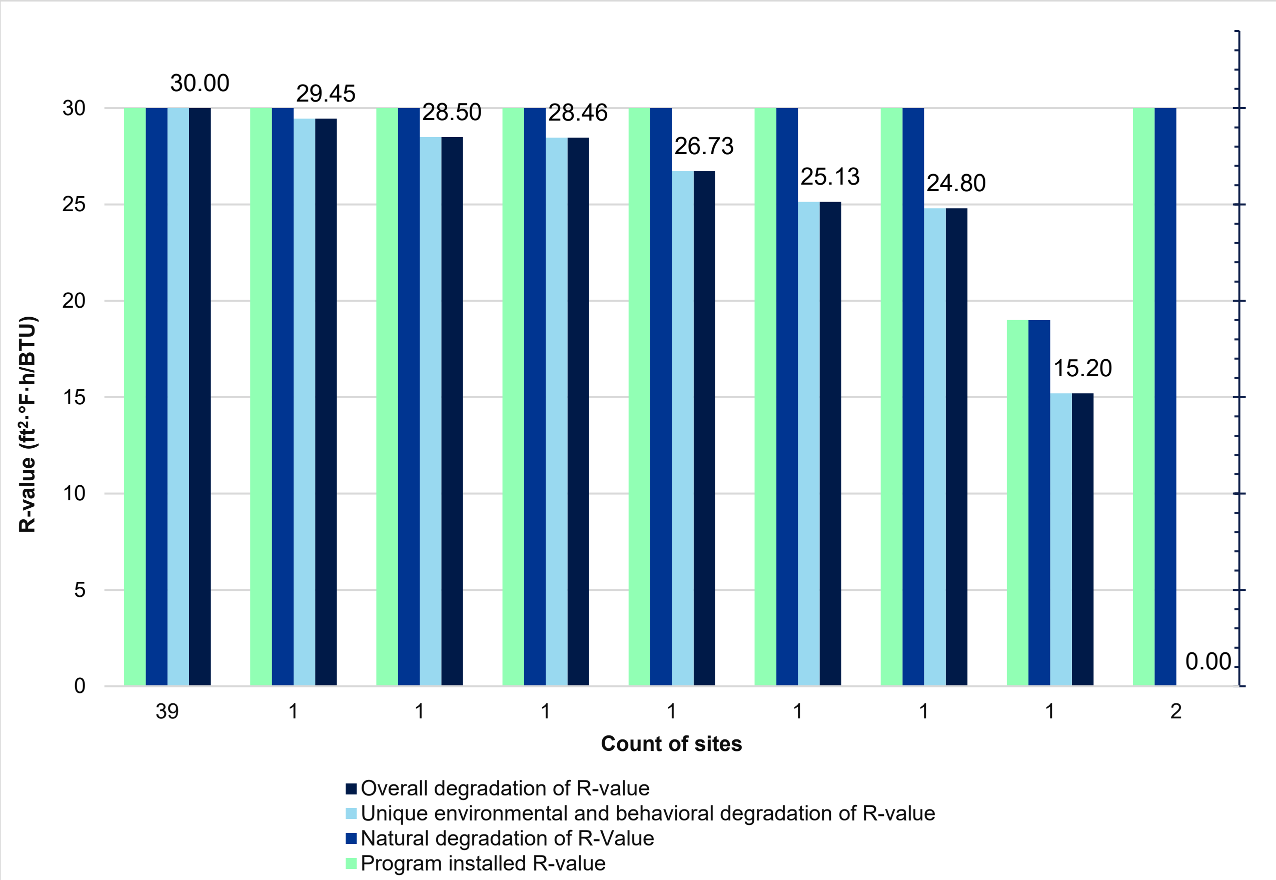
4.1.2.2 Degradation Results

For all 48 ceiling insulation PY2006-PY2007 program participants visited by DNV, the ceiling insulation is expected to degrade less than 0.01% of its original R-value if subjected to natural degradation only. For 39 out of 46 sites, DNV observed that there was no degradation due to unique external and human behavioral factors, resulting in an overall degradation of less than 0.01%. DNV observed partial degradations ranging from 1.8% to 20% for seven out of 48 ceiling insulation sites. For two out of 48 sites, all the program-installed ceiling insulation was completely removed, resulting in an overall degradation of 100%.

Overall, the ceiling insulation degradation factor is estimated to be 5.90% (site-specific overall degradation factor weighted by program-claimed savings). Details on site-specific ceiling insulation degradation analysis results can be found in Appendix C, Table 8-2.

[23] Decision 23-04-035. April 6, 2023. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF

Figure 4-4. Ceiling insulation degradation results



5 CONCLUSIONS AND RECOMMENDATIONS

Based on the persistence (i.e., retention and degradation) evidence shown by evaluated site-specific data, DNV concludes that the existing wall and ceiling insulation measure EUL values of 20 years is low for ceiling and wall insulation. The persistence of insulation is impacted either due to natural degradation of insulating materials or due to degradation caused by unique external and human-behavioral factors. Based on the review of the ERDC's study that discusses long-term natural degradation of insulation [24], DNV concludes that the performance and therefore, savings associated with wall and ceiling insulation is minimally (<0.01%) reduced if exposed to natural conditions (temperature and humidity) only. Based on site inspection data, DNV concludes that the insulation persistence and the associated savings are most commonly reduced due to unique external and human-behavioral factors.

Overall, the savings associated with wall insulation installed in 2006-2007 is expected to lower only by 2.15% in 2023 (after 16-17 years), mostly due to renovation. Similarly, the savings associated with ceiling insulation installed in 2006-2007 is expected to lower only by 5.90% in 2023, mostly due to pest/fungus damage, long-term storage compression, renovation, and fire damage. DNV extrapolated these low reductions in insulation performance even after 16-17 years of installation to

[24] U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC). "Prediction of Long-Term Degradation of Insulating Materials." May 2015

conclude that the EUL values of wall and ceiling insulation measures are expected to be well above the current cap of 20 years.

DNV applied a parametric model with a Weibull distribution to estimate lower and upper bound estimates of retention (i.e., survival) to inform insulation EUL values. DNV estimated wall insulation EUL of 28 years using a conservative approach that treats any degradation of more than 10% as a failure. A more generous approach that ignores the partial degradations would result in a wall insulation EUL value of 34 years. While the lower bound of EUL is below the 30-year cap allowed by D.23-04-035 [25], the upper-bound EUL estimate is still well above the 30-year cap, and these upper and lower bound results bracket the proposed 30-year EUL cap. An average of the two bounds is 31 years, which is greater than the 30-year cap allowed by decision, so an EUL of 30 year is recommended for the wall insulation measure.

For the ceiling insulation measure, DNV estimated a lower-bound EUL of 45 years using a conservative approach. DNV estimated an upper-bound EUL of 267 years using a more generous approach that ignores the partial survival. While these results provide a wide range of possible outcomes, the 30-year cap allowed by D.23-04-035 [25] is clearly well above the estimated lowest possible EUL value. Therefore, an EUL of 30 year is recommended for the ceiling insulation measure.

Based on site evidence, DNV concludes that the EUL values of residential wall and ceiling insulation measures can be updated from the current 20-year cap to the new 30-year cap.

Table 5-1. EUL analysis results

Measure description and EUL ID	# of site inspections	Degradation factor (%)	Lower bound of EUL (years)	90% confidence interval of lower bound	Relative Precision Achieved at 90% CI	Upper bound of EUL (years)	Proposed EUL cap (years)
Wall insulation, BS-BlowInIns	28	2.15	28	9 to 47	68%	34	30
Ceiling insulation, BS-CeilIns	48	5.90	45	1 to 89	98%	267	30

[25] Decision 23-04-035. April 6, 2023. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF

6 APPENDIX A. SAMPLING METHODOLOGY FOR INSULATION ON-SITE DATA COLLECTION

The insulation site visits will determine a non-degradation factor for each project, rather than determining a yes/no persistence status. For planning, we assume that the coefficient of variation of the non-degradation factor is 1.0. This is a conservative assumption, meaning that the variation is likely not this wide so that the achieved precision will likely be better than the projection.

The sample size and precision calculations for 30% relative precision at 90% confidence are as follows:

$n_{desired} = (Z_5 \times CV / p_{desired})^2$

$= (1.645 \times 1/0.3)^2$

$= 30$

Where Z_5= 1.645 is the standard normal deviate that gives 90 percent confidence

Projected precision with a sample size of 45 is

$P = Z_5 \times CV/(n^{1/2})$

$= 1.645 \times 1/(45^{1/2})$

$= 25\%$.

To the extent the assumptions are in fact conservative, better overall precision may be obtained, and separate estimates for wall versus ceiling may be supported by the data. For the insulation assessments, we will sample from the oldest available projects, which is the list of projects from the PY2006-2007 program tracking data, distributed proportionately over climate regions. The breakdown of wall and ceiling insulation measure type by climate region and installation year is shown in Table 6-1.

Table 6-1. Residential Insulation EUL study population by climate region and installation year

Program year	Measure description	Central Coastal	Central Valley	High and Low Desert	Mountain	North Coastal
2006	Ceiling (attic) insulation vintage to r-30	644	2135	5	23	1266
	Wall insulation	378	570		6	829
2007	Ceiling (attic) insulation vintage to r-30	507	2006		12	949
	Wall insulation	260	388		2	612

The climate regions are groupings of California climate zones, as indicated in Table 6-2.

Table 6-2. Climate region classification

Climate zone	Climate region
CZ01	North Coastal
CZ02	North Coastal
CZ03	North Coastal
CZ04	Central Coastal
CZ05	Central Coastal
CZ06	South Coastal
CZ07	South Coastal
CZ08	Inland
CZ09	Inland
CZ10	Inland
CZ11	Central Valley
CZ12	Central Valley
CZ13	Central Valley
CZ14	High and Low Desert
CZ15	High and Low Desert
CZ16	Mountain

7 APPENDIX B. INSULATION ON-SITE DATA COLLECTION FORM

CPUC EUL Study - Wall and Ceiling Insulation Data Collection Instrument	
Site ID	
Site Address	
Site Contact Name	
Site Contact Email	
Site Contact Phone Number	
Data Collection Date	
Site Engineer	

Wall Assembly Data Collection

Inspection - Insulation Condition?

damaged		**removed**		**reduced**		**shifted**		**other**	

Wall R-value from Claim:			
Wall Dimensions			
	Thickness	**Width**	**Height**
N			
S			
W			
E			

Data collected from Inspection	
Wall Material:	
Insulation Material:	
Wall Framing Type:	

Data collected from Measurement

Parameter	basic definition	method/source	value/description	notes
Wall Spacing/Cavity	Spacing between outer wall frame and insulation	tape measure		
Wall Thickness	measured from outer layer to inner layer	tape measure		

CPUC EUL Study - Wall and Ceiling Insulation Data Collection Instrument				
labelled R-value	from labels, if any	observation		
Thermal Snapshot of wall section	profile of surface perpendicular to wall surface	FLIR infrared camera		(get Temp delta, and heat transfer, back out R- value)
Sketch of wall assembly/elevation plan, if able:				

Ceiling/Attic Assembly Data Collection

Ceiling/Attic R-value from Claim:			
Ceiling Dimensions			
	Length	**Width**	**Notes**
Ceiling 1			
Ceiling 2			
Ceiling 3			
Ceiling 4			

Data collected from Inspection	
Ceiling Material:	
Insulation Material:	
Ceiling Framing Type:	

Data collected from Measurement

Parameter	**basic definition**	**method/source**	**value/description**	**notes**
Ceiling cavity	space between ceiling and external roof			
Ceiling Insulation Loft / Depth	the height/depth of the insulation			
labelled R-value	from labels, if any	observation		
Thermal Snapshot of ceiling	profile of surface perpendicular to wall surface	FLIR infrared camera		

Sketch of wall Ceiling assembly/elevation plan, if able:

Ceiling/Attic Assembly Data Collection									
Inspection - Insulation Condition?									
damaged		**removed**		**reduced**		**shifted**		**other**	
Additional Notes									

Additional questions for each assembly		
	(duplicate this page as necessary)	
Question	**Answer**	
How old was the original insulation?		
Does the existing insulation still insulate as well as it did when it was new?		
What made you replace the insulation?	environmental factors (i.e., rodents, pests, plumbing leakage, rainwater)	
	Home renovation	
	To improve thermal comfort	

Additional questions for each assembly		
	Other reasons	
Did any alteration occur for the current insulation?		
Did it get removed, or replaced?		
Why? How much was removed / replaced?		

8 APPENDIX C. INSULATION SITE DATA AND ANALYSIS

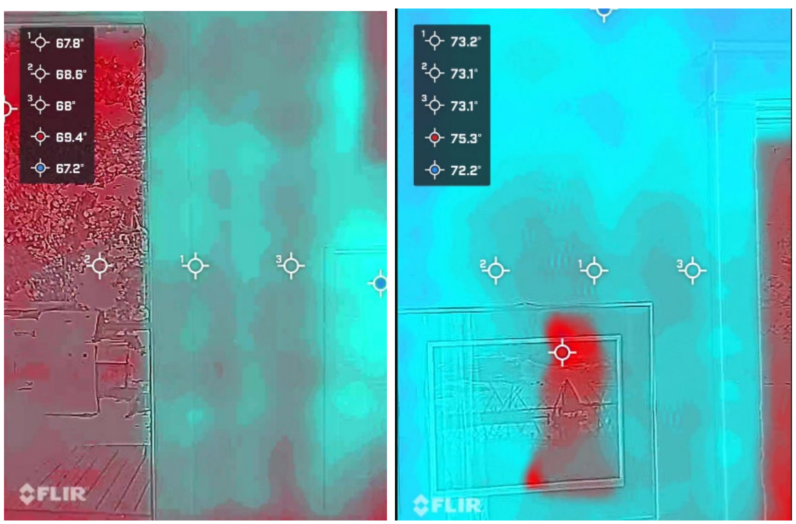
Table 8-1. Wall insulation site data

Site ID	Climate region	Installed year	Program claimed R-value (ft^2·°F·h/ BTU)	Program claimed wall area (ft^2)	Wall framing	Wall thickness (inches)	Wall cavity (inches)	Total measured exterior wall area (ft^2)	Total doors and glazing area (ft2)	Verified insulated wall area (ft^2)	Insulation type	Observed wall insulation R-value (ft^2·°F·h/BTU)
WI_01	North Coastal	2006	13	1635	2 * 4	5.25	3.5	1,860.0	225.0	1,635	Blown-in cellulose	13
WI_02	North Coastal	2006	13	500	2 * 4	7	3.5	799.0	299.0	500	Batt	13
WI_03	Central Valley	2006	13	704	2 * 4	5.25	3.5	852.0	148.0	704	Blown-in	13
WI_04	North Coastal	2006	13	993	2 * 4	7	3.5	1,033.0	40.0	993	Blown-in loose fill	13
WI_05	North Coastal	2006	13	2153	2 * 4	5.25	3.5	2,153.0	-	2,153	Blown-in	13
WI_06	North Coastal	2006	13	319	2 * 4	6	3.5	573.5	254.5	319	Blown-in	13
WI_07	Central Coastal	2006	13	900	2 * 4	5.25	3.5	1,255.0	355.0	900	Blown-in	13
WI_08	North Coastal	2006	13	576	2 * 4	6.25	3.5	823.5	247.5	576	Blown-in cellulose	13
WI_09	Central Coastal	2006	13	714	2 * 4	5.5	3.5	818.0	104.0	714	Fiberglass batt	13
WI_10	Central Valley	2006	13	582	2 * 4	6.5	3.5	826.0	244.0	582	Blown-in cellulose	13
WI_11	North Coastal	2006	12	2165	2 * 4. West wall is 2 * 6	7	3.5, west wall is 5.5	1,691.0	236.0	1,455	Fiberglass batt	12
WI_12	North Coastal	2006	13	390	2 * 4	6.25	3.5	697.0	307.0	390	Fiberglass batt	13
WI_13	Central Coastal	2006	13	1500	2 * 4	8.25	3.5	1,643.0	143.0	1,500	Fiberglass batt	13
WI_14	Central Coastal	2006	13	1252	2 * 4	4.25	3.5	1,475.0	223.0	1,252	Blown-in cellulose	13
WI_15	North Coastal	2006	13	277	2 * 4	6	3.5	461.5	184.5	277	Blown-in cellulose	13
WI_16	North Coastal	2006	13	2005	2 * 4	6.5	3.5	2,113.0	108.0	2,005	Fiberglass batt	13

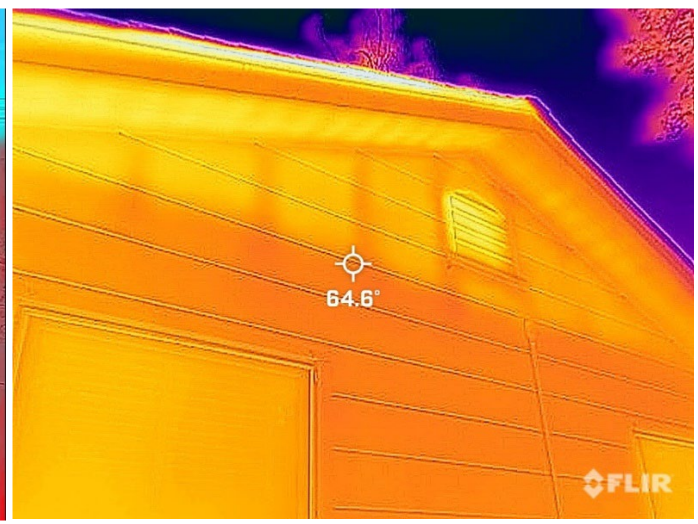
Site ID	Climate region	Installed year	Program claimed R-value (ft^2·°F·h/ BTU)	Program claimed wall area (ft^2)	Wall framing	Wall thickness (inches)	Wall cavity (inches)	Total measured exterior wall area (ft^2)	Total doors and glazing area (ft2)	Verified insulated wall area (ft^2)	Insulation type	Observed wall insulation R-value (ft^2·°F·h/BTU)
WI_17	Central Coastal	2007	13	1250	2 * 4	7	3.5	1,529.9	279.9	1,250	Fiberglass batt	13
WI_18	North Coastal	2007	13	960	2 * 6	7	2	960.0	-	960	Blown-in	13
WI_19	North Coastal	2007	13	760	2 * 4	6.5	3.5	1,035.1	275.1	760	Blown-in and batt	13
WI_20	North Coastal	2007	13	213	2 * 4	5.5	3.5	572.0	359.0	213	Blown-in cellulose	13
WI_21	North Coastal	2007	13	854	2 * 4	6	3.5	989.0	135.0	854	Batt	13
WI_22	Central Coastal	2007	13	938	2 * 4	5.25	3.5	1,197.0	259.0	938	Blown-in cellulose	13
WI_23	North Coastal	2007	13	1022	2 * 4	6.5	3.5	1,216.6	194.6	1,022	Blown-in	13
WI_24	North Coastal	2007	13	1312	2 * 4	6.5	3.5	1,869.1	557.1	1,312	Blown-in	13
WI_25	Central Coastal	2007	13	1232	2 * 4	5.25	3.5	1,454.0	222.0	1,232	Blown-in cellulose	13
WI_26	Central Coastal	2007	13	40	2 * 4	5.25	3.5	0	0	0	Fiberglass batt	0
WI_27	North Coastal	2007	13	1400	2 * 4	6.5	4	1,779.5	379.5	1,400	Blown-in cellulose	13
WI_28	North Coastal	2007	13	3144	2 * 4	6.5				3144	Could not identify	13

The wall insulation site pictures and thermal images are shown below:

Image showing removal of program insulation during remodel event for site WI_11.



FLIR™ infrared image of insulated walls



FLIR™ infrared image showing a section of insulated wall

Table 8-2. Wall insulation degradation analysis

Site ID	Program claimed data		Natural degradation evaluation results		Unique external and behavioral degradation evaluation results					Overall degradation evaluation results	
	Program claimed R-value	Program claimed R-value and area product	Natural degradation (%)	Natural degradation of R-Value	Evaluated R-value and area product	Unique and behavioral degradation (%)	Unique environmental and behavioral degradation of R-value	Date of occurrence	Reason for degradation	Overall degradation (%)	Overall degradation R-value
WI_01	13	21255	0.0008%	12.999	21255	0.00%	13.000	ND	ND	0.0008%	12.999
WI_02	13	6500	0.0008%	12.999	6500	0.00%	13.000	ND	ND	0.0008%	12.999
WI_03	13	9152	0.0008%	12.999	9152	0.00%	13.000	ND	ND	0.0008%	12.999
WI_04	13	12909	0.0008%	12.999	12909	0.00%	13.000	ND	ND	0.0008%	12.999
WI_05	13	27989	0.0008%	12.999	27989	0.00%	13.000	ND	ND	0.0008%	12.999
WI_06	13	4147	0.0008%	12.999	4147	0.00%	13.000	ND	ND	0.0008%	12.999
WI_07	13	11700	0.0008%	12.999	11700	0.00%	13.000	ND	ND	0.0008%	12.999
WI_08	13	7488	0.0008%	12.999	7488	0.00%	13.000	ND	ND	0.0008%	12.999
WI_09	13	9282	0.0008%	12.999	9282	0.00%	13.000	ND	ND	0.0008%	12.999
WI_10	13	7566	0.0008%	12.999	7566	0.00%	13.000	ND	ND	0.0008%	12.999
WI_11	12	25980	0.0008%	11.999	17460	32.79%	8.065	2019	A	32.8001%	8.064
WI_12	13	5070	0.0008%	12.999	5070	0.00%	13.000	ND	ND	0.0008%	12.999
WI_13	13	19500	0.0008%	12.999	19500	0.00%	13.000	ND	ND	0.0008%	12.999
WI_14	13	16276	0.0008%	12.999	16276	0.00%	13.000	ND	ND	0.0008%	12.999
WI_15	13	3601	0.0008%	12.999	3601	0.00%	13.000	ND	ND	0.0008%	12.999
WI_16	13	26065	0.0008%	12.999	26065	0.00%	13.000	ND	ND	0.0008%	12.999
WI_17	13	16250	0.0008%	12.999	16250	0.00%	13.000	ND	ND	0.0008%	12.999
WI_18	13	12480	0.0008%	12.999	12480	0.00%	13.000	ND	ND	0.0008%	12.999
WI_19	13	9880	0.0008%	12.999	9880	0.00%	13.000	ND	ND	0.0008%	12.999
WI_20	13	2769	0.0008%	12.999	2769	0.00%	13.000	ND	ND	0.0008%	12.999
WI_21	13	11102	0.0008%	12.999	11102	0.00%	13.000	ND	ND	0.0008%	12.999
WI_22	13	12194	0.0008%	12.999	12194	0.00%	13.000	ND	ND	0.0008%	12.999
WI_23	13	13286	0.0008%	12.999	13286	0.00%	13.000	ND	ND	0.0008%	12.999
WI_24	13	17056	0.0008%	12.999	17056	0.00%	13.000	ND	ND	0.0008%	12.999
WI_25	13	16016	0.0008%	12.999	16016	0.00%	13.000	ND	ND	0.0008%	12.999

Site ID	Program claimed data		Natural degradation evaluation results		Unique external and behavioral degradation evaluation results					Overall degradation evaluation results	
	Program claimed R-value	Program claimed R-value and area product	Natural degradation (%)	Natural degradation of R-Value	Evaluated R-value and area product	Unique and behavioral degradation (%)	Unique environmental and behavioral degradation of R-value	Date of occurrence	Reason for degradation	Overall degradation (%)	Overall degradation R-value
WI_26	13	520	0.0008%	12.999	0	100.00%	0.000	2020	B	100.0000%	0
WI_27	13	18200	0.0008%	12.999	18200	0.00%	13.000	ND	ND	0.0008%	12.999
WI_28	13	40872	0.0008%	12.999	40872	0.00%	13.000	ND	ND	0.0008%	12.999

ND = no degradation observed
A = partially removed for remodelling
B = Fully removed for renovation

Table 8-3. Ceiling insulation site data

Site ID	Climate region	Installed year	Program claimed R-value	Program claimed attic area (ft2)	Insulation thickness (inches)	Insulation type	Verified area (ft2)	Verified R-value
CI_01	Central Coastal	2006	30	1464	18"	Yellow fiberglass batt	1464	30.00
CI_02	North Coastal	2006	30	1161	6"	Blown-in	1161	30.00
CI_03	North Coastal	2006	30	1400	10"	Blown-in rockwool	1173	30.00
CI_04	North Coastal	2006	30	872	3" minimum	Fiberglass batting	872	30.00
CI_05	North Coastal	2006	30	1760	Inaccessible	Inaccessible	1760	30.00
CI_06	North Coastal	2006	30	450	4"	Blown-in loose fill	450	30.00
CI_07	Central Coastal	2006	30	935	12"	Blown-in in loose fill	935	30.00
CI_08	North Coastal	2006	30	1300	10"	blow-in cellulose	1300	30.00
CI_09	North Coastal	2006	30	1000	6"	Cellulose	1000	30.00
CI_10	Central Valley	2006	30	880	10"	Blown-in	864	30.00
CI_11	North Coastal	2006	30	448	11"	Blow-in in fiberglass	448	30.00

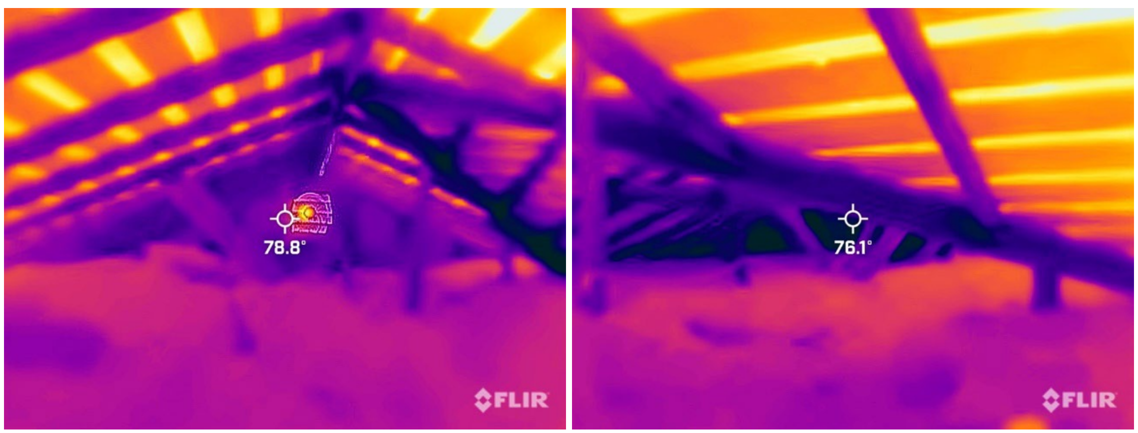
Site ID	Climate region	Installed year	Program claimed R-value	Program claimed attic area (ft2)	Insulation thickness (inches)	Insulation type	Verified area (ft2)	Verified R-value
CI_12	North Coastal	2006	30	800	9"	Blown-in loose fill	800	30.00
CI_13	Central Valley	2006	30	1625	10"	Fiberglass batt	1625	30.00
CI_14	North Coastal	2006	30	1614	9"	Blown-in, loose fill	1614	28.50
CI_15	Central Coastal	2006	30	586	5.5"	Blown-in loose fill	586	30.00
CI_16	North Coastal	2006	30	1600	10"	Blown-in cellulose	1600	30.00
CI_17	Central Coastal	2006	30	880	12"	Double layer of R-19 batt	880	30.00
CI_18	North Coastal	2006	30	1200	Inaccessible	Inaccessible	1200	30.00
CI_19	North Coastal	2006	30	650	Inaccessible	Inaccessible	650	30.00
CI_20	North Coastal	2006	30	2153	Inaccessible	Inaccessible	2153	30.00
CI_21	Central Coastal	2006	30	1056	9"	Fiberglass batting	1056	30.00
CI_22	North Coastal	2006	30	176	6-10"	Blown-in rockwool	167	30.00
CI_23	Central Coastal	2006	30	1600	10"	Blown-in cellulose	1600	30.00
CI_24	North Coastal	2006	30	740	6-12"	Batt	740	30.00
CI_25	Central Coastal	2006	30	898	5" over front half of house; 3-5' over rear (north) side	Fiberglass batt	898	30.00
CI_26	Central Valley	2006	30	1615	10"	blow-in cellulose	1439	30.00
CI_27	North Coastal	2006	32	1584	6"	R-32 fiberglass batting	1584	32.00
CI_28	North Coastal	2006	30	900	10"	Blown-in cellulose	900	30.00
CI_29	Central Coastal	2006	30	1450	10"	Batt R-30	1450	30.00
CI_30	Central Coastal	2006	30	1690	N/A	N/A	1690	0.00
CI_31	North Coastal	2006	30	1280	10"	Blown-in cellulose	1280	30.00
CI_32	North Coastal	2006	30	703	N/A	N/A	0	0.00

Site ID	Climate region	Installed year	Program claimed R-value	Program claimed attic area (ft2)	Insulation thickness (inches)	Insulation type	Verified area (ft2)	Verified R-value
CI_33	North Coastal	2006	30	1060	10"	Blown-in	1060	30.00
CI_34	Central Coastal	2007	30	1500	10"	Fiberglass batt	1500	24.80
CI_35	North Coastal	2007	30	1389	4.5 - 8 "	Blown-in, loose fill, some existing batting	1389	30.00
CI_36	Central Valley	2007	30	1400	10"	Blown-in cellulose	1400	30.00
CI_37	North Coastal	2007	30	1500	Inaccessible	Inaccessible	1500	30.00
CI_38	North Coastal	2007	30	1350	10"	fiberglass batt	1350	30.00
CI_39	North Coastal	2007	19	613	6.25-inch batting; 37" blown in	R-19 (Existing)	613	19.00
CI_40	North Coastal	2007	30	87	8-24"	Blown-in	87	30.00
CI_41	North Coastal	2007	19	1584	4"	R-10 blown in cellulose	1584	15.20
CI_42	Central Coastal	2007	30	1062	11"	Blown-in cellulose	1062	30.00
CI_43	North Coastal	2007	30	1611	12"	Blown-in rockwool	1611	30.00
CI_44	North Coastal	2007	30	1260	Inaccessible	Inaccessible	1260	30.00
CI_45	Central Coastal	2007	30	1435	5" min, piled to 10" in areas	Blown-in cellulose	1435	30.00
CI_46	Central Coastal	2007	30	176	20"	Fiberglass batt	176	30.00
CI_47	North Coastal	2007	30	1872	10" (or more in spots)	Blown-in rock wool	1872	30.00
CI_48	North Coastal	2007	30	1431	5"	Blown-in	1431	30.00

Inaccessible – attic/ceiling could not be accessed. Verified data based on site interviews and/or past work orders/invoices.
N/A – not applicable as the program-installed insulation was completely removed.

The ceiling insulation site pictures and thermal images are shown below:

Images showing insulated ceiling/attic.



FLIR™ infrared image of ceiling/attic insulation

Table 8-4. Ceiling insulation degradation analysis

Site ID	Program claimed R-value	Program claimed R-value and area product	Natural degradation evaluation results		Unique external and behavioral degradation evaluation results					Overall degradation evaluation results	
			Natural degradation (%)	Natural degradation of R-Value	Evaluated R-value and area product	Unique and behavioral degradation (%)	Unique environmental and behavioral degradation of R-value	Date of occurrence	Reason for degradation	Overall degradation (%)	Overall degradation of R-value
CI_01	30	43920	0.0008%	29.999	43920	0.00%	30.000	ND	ND	0.0008%	29.999
CI_02	30	34830	0.0008%	29.999	34830	0.00%	30.000	ND	ND	0.0008%	29.999
CI_03	30	42000	0.0008%	29.999	35190	16.21%	25.136	2009	A	16.2149%	25.135
CI_04	30	26160	0.0008%	29.999	26160	0.00%	30.000	ND	ND	0.0008%	29.999
CI_05	30	52800	0.0008%	29.999	52800	0.00%	30.000	ND	ND	0.0008%	29.999
CI_06	30	13500	0.0008%	29.999	13500	0.00%	30.000	ND	ND	0.0008%	29.999
CI_07	30	28050	0.0008%	29.999	28050	0.00%	30.000	ND	ND	0.0008%	29.999
CI_08	30	39000	0.0008%	29.999	39000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_09	30	30000	0.0008%	29.999	30000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_10	30	26400	0.0008%	29.999	25920	1.82%	29.455	LT	B	1.8189%	29.454
CI_11	30	13440	0.0008%	29.999	13440	0.00%	30.000	ND	ND	0.0008%	29.999
CI_12	30	24000	0.0008%	29.999	24000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_13	30	48750	0.0008%	29.999	48750	0.00%	30.000	ND	ND	0.0008%	29.999
CI_14	30	48420	0.0008%	29.999	45999	5.00%	28.500	LT	C	5.0007%	28.499
CI_15	30	17580	0.0008%	29.999	17580	0.00%	30.000	ND	ND	0.0008%	29.999
CI_16	30	48000	0.0008%	29.999	48000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_17	30	26400	0.0008%	29.999	26400	0.00%	30.000	ND	ND	0.0008%	29.999
CI_18	30	36000	0.0008%	29.999	36000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_19	30	19500	0.0008%	29.999	19500	0.00%	30.000	ND	ND	0.0008%	29.999
CI_20	30	64590	0.0008%	29.999	64590	0.00%	30.000	ND	ND	0.0008%	29.999
CI_21	30	31680	0.0008%	29.999	31680	0.00%	30.000	ND	ND	0.0008%	29.999
CI_22	30	5280	0.0008%	29.999	5010	5.11%	28.466	LT	B	5.1144%	28.465
CI_23	30	48000	0.0008%	29.999	48000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_24	30	22200	0.0008%	29.999	22200	0.00%	30.000	ND	ND	0.0008%	29.999
CI_25	30	26940	0.0008%	29.999	26940	0.00%	30.000	ND	ND	0.0008%	29.999
CI_26	30	48450	0.0008%	29.999	43170	10.90%	26.731	2018	D	10.8985%	26.730
CI_27	32	50688	0.0008%	31.999	50688	0.00%	32.000	ND	ND	0.0008%	31.999

Site ID	Program claimed R-value	Program claimed R-value and area product	Natural degradation evaluation results		Unique external and behavioral degradation evaluation results					Overall degradation evaluation results	
			Natural degradation (%)	Natural degradation of R-Value	Evaluated R-value and area product	Unique and behavioral degradation (%)	Unique environmental and behavioral degradation of R-value	Date of occurrence	Reason for degradation	Overall degradation (%)	Overall degradation of R-value
CI_28	30	27000	0.0008%	29.999	27000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_29	30	43500	0.0008%	29.999	43500	0.00%	30.000	ND	ND	0.0008%	29.999
CI_30	30	50700	0.0008%	29.999	0	100.00%	0.000	2009	C	100.0000%	0.000
CI_31	30	38400	0.0008%	29.999	38400	0.00%	30.000	ND	ND	0.0008%	29.999
CI_32	30	21090	0.0008%	29.999	0	100.00%	0.000	2018	C	100.0000%	0
CI_33	30	31800	0.0008%	29.999	31800	0.00%	30.000	ND	ND	0.0008%	29.999
CI_34	30	45000	0.0008%	29.999	37200	17.33%	24.800	LT	B	17.3340%	24.799
CI_35	30	41670	0.0008%	29.999	41670	0.00%	30.000	ND	ND	0.0008%	29.999
CI_36	30	42000	0.0008%	29.999	42000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_37	30	45000	0.0008%	29.999	45000	0.00%	30.000	ND	ND	0.0008%	29.999
CI_38	30	40500	0.0008%	29.999	40500	0.00%	30.000	ND	ND	0.0008%	29.999
CI_39	19	11647	0.0008%	29.999	11647	0.00%	19.000	ND	ND	0.0008%	18.999
CI_40	30	2610	0.0008%	29.999	2610	0.00%	30.000	ND	ND	0.0008%	29.999
CI_41	19	30096	0.0008%	18.999	24077	20.00%	15.200	LT	C	20.0006%	15.199
CI_42	30	31860	0.0008%	29.999	31860	0.00%	30.000	ND	ND	0.0008%	29.999
CI_43	30	48330	0.0008%	29.999	48330	0.00%	30.000	ND	ND	0.0008%	29.999
CI_44	30	37800	0.0008%	29.999	37800	0.00%	30.000	ND	ND	0.0008%	29.999
CI_45	30	43050	0.0008%	29.999	43050	0.00%	30.000	ND	ND	0.0008%	29.999
CI_46	30	5280	0.0008%	29.999	5280	0.00%	30.000	ND	ND	0.0008%	29.999
CI_47	30	56160	0.0008%	29.999	56160	0.00%	30.000	ND	ND	0.0008%	29.999
CI_48	30	42930	0.0008%	29.999	42930	0.00%	30.000	ND	ND	0.0008%	29.999

ND – no degradation observed on site.
LT – long-term degradation.
A – renovation
B – long-term storage
C – pest/fungus damage
D – fire damage

9 APPENDIX D. STAKEHOLDER COMMENTS AND EVALUATOR RESPONSES

Study ID	Study Type	Study Title	CPUC Study Manager
Group A: CALMAC ID CPU0368.01	Energy Efficiency	Residential Insulation Measure Effective Useful Life Study	Melissa Matis

Entity	Section	Page	Question or Comment	Evaluator Response
SDG&E	Overall	N/A	In Decision (D.) 23-04-035 (at 11) the Commission permitted, and directed, program administrators to update the effective useful lives (EUL) of exempt measures, if supported by evidence, up to 30 years. The findings of this study suggest an EUL of greater than 30 years for both wall and ceiling insulation is feasible and should be considered for future updates. As such, SDG&E recommends the Commission utilize the findings of this study to re-evaluate the cap of 30 years given to insulation measures.	Thank you for the comment. While the data suggests the medians could be higher than the current values, 30 for walls and 45+ for ceiling, the uncertainty of future avoided costs and discount rates make it difficult to accurately assess accurate value beyond the current 30-year limitations with only the data gathered and analyzed under the scope of this project.
SoCalREN	4.1.2.1	13	Ceiling Insulation: The draft study finds an upper bound EUL to be 267 years. From a practical perspective this figure does not appear to be credible. The building containing the insulation would need to be expected to last at least as long.	Thank you for your comment. We were limited to 16-17 years old site data, so we could only project how long the installed insulation could last for beyond 16-17 years. Site data suggests the true EUL value for this 16-17 years old sample is likely between 45 and 267 and the higher value is meant to bracket an upper range. In reality, there are several unique external and human behavioral factors (building age that you pointed out) that would come into play to impact the upper range survival of insulation.

SoCalREN	Overall	N/A	Projected savings reductions: The study would benefit from more detail on if any projected savings reductions are forecasted by year. Or alternatively if any reductions are assumed to be negligible, this should be made explicit	Thank you for your comment. The scope of this study was to determine an overall degradation rate and an EUL estimate. As stated in our findings and recommendations, natural degradation of insulation was found to be negligible (<0.01%), while the unique external and human behavioral factors significantly impacted retention and savings associated with wall and ceiling insulation and thus, the EUL. We estimate that the savings associated with the residential wall insulation and residential ceiling insulation measures installed in 2006-2007 to reduce by 2.15% and 5.90%, respectively, in 2023. It was not within the scope of this study to develop savings reduction factors by year. In order to forecast savings reductions by year, a study would have to be conducted using insulation data that are 1 to 30 years old. This type of study would be costly and would require extensive on-site data collection from different insulation age groups.
SoCalREN	Overall	N/A	Multifamily and single-family comparisons: The study could benefit from providing any differences or comparisons between multifamily and single-family residences. Was any such comparison reviewed as part of the study?	The oldest available population that we could find for wall and ceiling insulation measure had single family homes only, so our study data comes from single family homes only. It was not within the scope of our study to develop and compare building type specific EUL values, but the EUL values that we have recommended would apply to all residential building types (single family, multifamily and double-wide mobile homes).

SoCalREN	3.2.2	8	Degradation curves: The draft study states that it used the estimated natural degradation in R-Value presented by the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) study. SoCalREN recommends that the draft study clarify if the degradation curve accounts for settling/compaction	We have mentioned in section 3.2.2 Secondary research (Page 7) of the report that ERDC's study on natural degradation investigated natural aging of insulation without any external influence. Natural aging includes any settling/compaction that would occur naturally. To clarify this in the report, we have added an explanation of natural aging in the first sentence of page 8 in the report.
SoCalREN	3.3.1	9	External impacts: The draft study discusses unique external and human behavioral factors that impact insulation persistence. The draft study documents that nine out of 48 on-site inspections were subject to these factors. SoCalREN recommends that the draft study elaborate on how these external impacts factored into the EUL projections.	Thank you for your comment. In section 3.3.1, page 9 of the report, we have explained how we incorporated the external impacts for the EUL projections. We have discussed a conservative and a generous scenario explaining how we factored the external impacts for establishing upper and lower bounds of EUL.
SoCal REN	Overall	N/A	EUL of wall insulation and ceiling insulation: The draft study proposes an EUL cap of 30 years for Wall insulation (EUL ID BS-BlowInIns) and Ceiling insulation (EUL ID BS-CeilIns). It is unclear whether the 30-year EUL applies to all types of ceiling/wall insulation. Wall/ceiling insulation can come in different forms, such as fiberglass, cellulose, mineral (rock/slag), wool, and polyurethane expanding foam. The EUL for wall insulation specifies only for "BlowIn Insulation" (in the DEER ID). It would be helpful if the draft study clarified if the DEER EUL IDs (BS-CeilIns and BS-BlowInIns) encompass all forms of insulation, and specifically for wall insulation, to ensure non-blown-in forms of insulation (such as fiberglass batts) would qualify for a 30-year EUL cap, as the wall insulation EUL ID specifically calls out "BlowInIns."	The degradation curves employed in our study, derived from the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) research, encompassed various insulation materials such as fiberglass and extended polystyrene. The ERDC study indicated a relatively consistent natural degradation across diverse material types. Additionally, our on-site data incorporates various forms of insulation materials, including fiberglass, batt, blown-in, rockwool, etc., for both walls and ceilings. Therefore, the EUL values for wall and ceiling insulation presented in our study encompass all commonly used insulation materials. We have expanded our study's recommendation to include batt wall insulation (BS-WallIns) EUL ID.

About DNV