DNV

**GROUP A**

# Residential Insulation Measure Effective Useful Life Study Final Report

## California Public Utilities Commission

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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.

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[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.

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[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<br>➢ 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<br>➢ Telephone surveys/interviews with a research design that meets accepted social science behavioral research expectations for behavioral degradation<br>➢ 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<br>➢ For behavioral degradation: field observations and measurement |

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[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

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[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]**



LN ($R_T$-$R_F$) VS. TIME

Long term degradation in Ambient (75°F/50%RH)

$y = -0.0019x + 0.6825$
$R^2 = 0.8722$

Short term accelerated testing degradation in environmental chamber (150°F/90%RH)

$y = -0.0602x + 0.76$
$R^2 = 0.935$

Time (Days)

LN ($R_t$ - $R_f$)
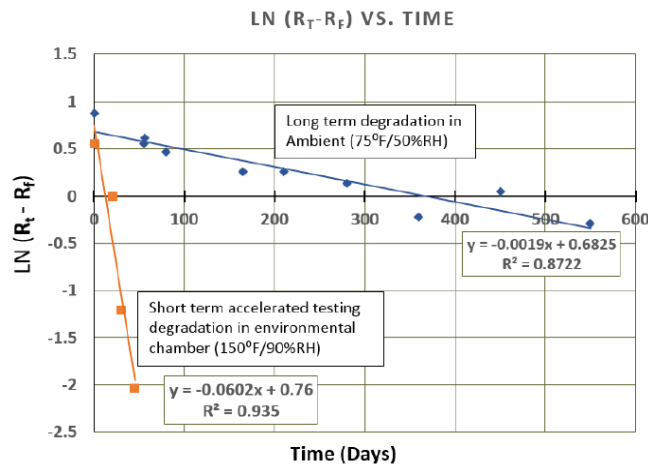
\*RT is the initial R-value of the insulation, whereas RF is the R-value of insulation at time T.[20]

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

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[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:

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

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

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.

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[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.

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[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**
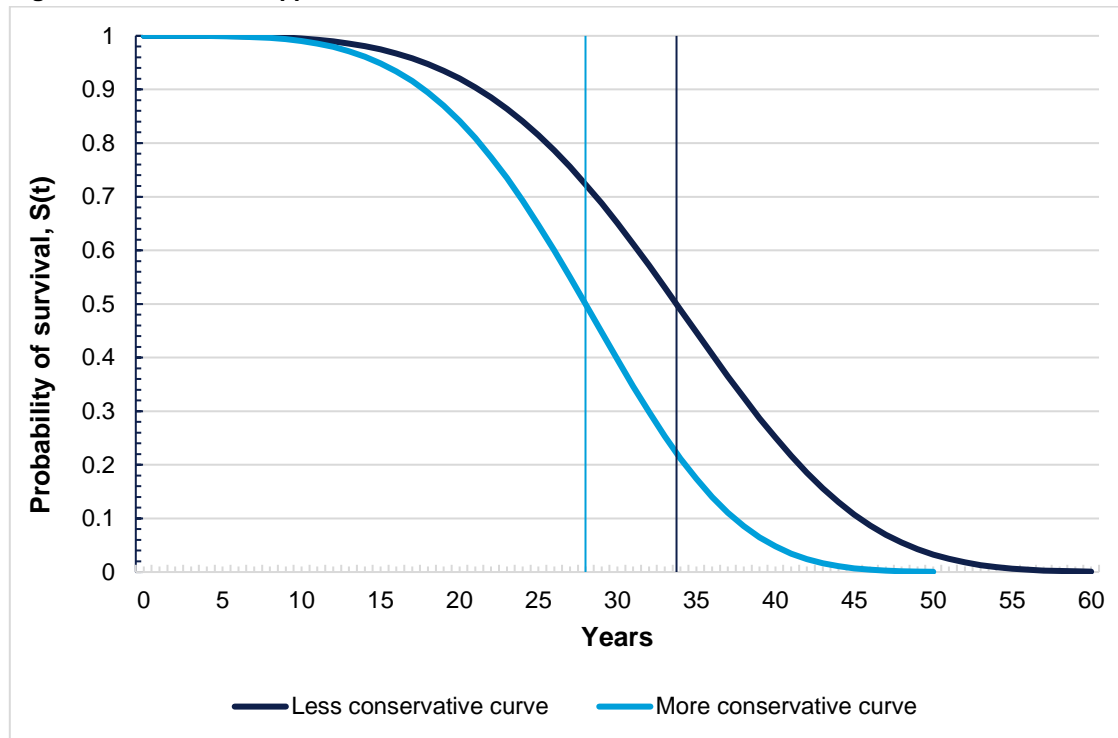


## 4.1.1.2 Degradation Results

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**
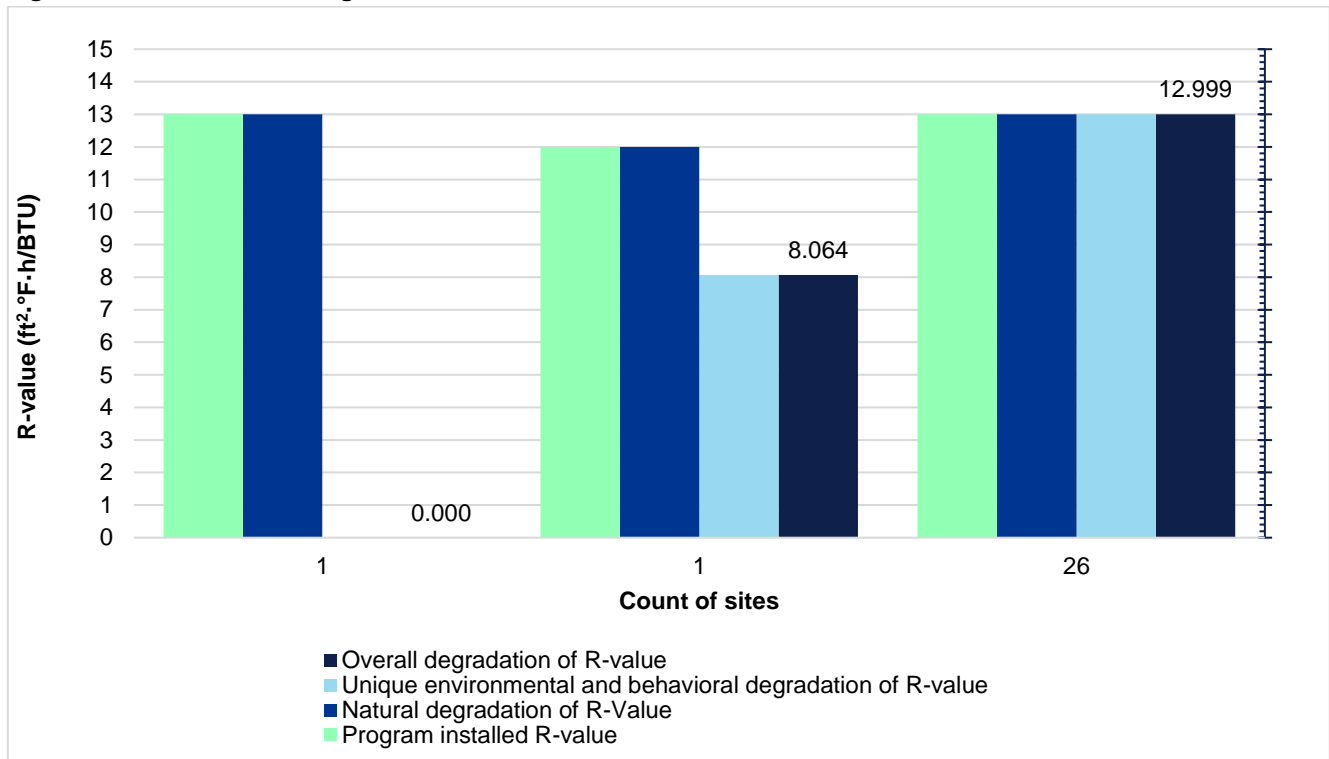


## 4.1.2 Ceiling/Attic insulation

### 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**
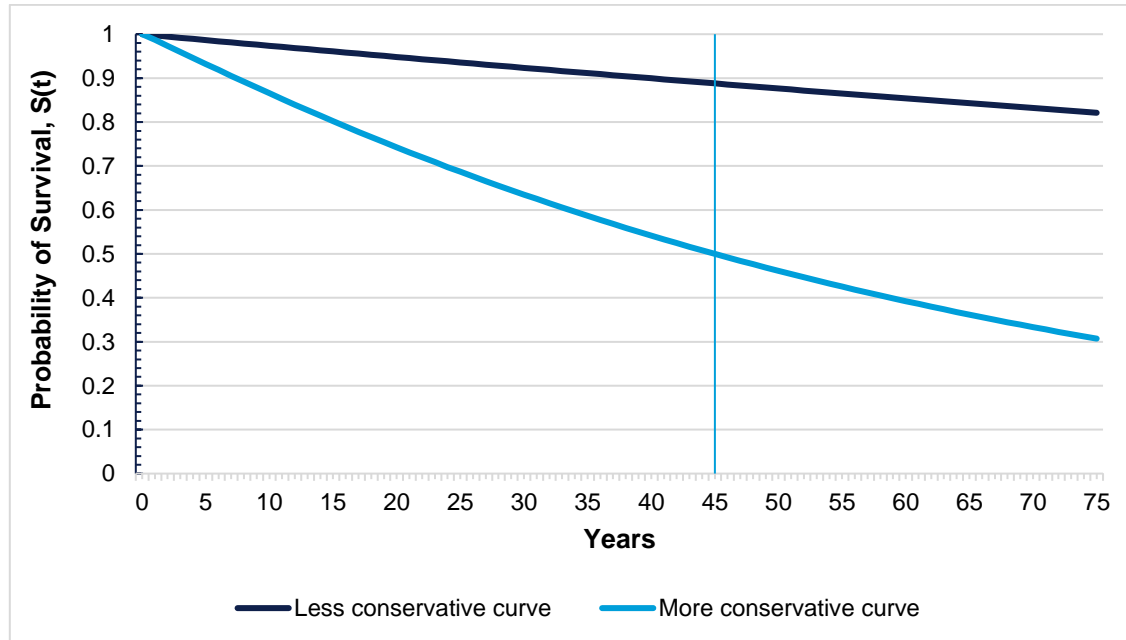


### 4.1.2.2 Degradation Results

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.

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[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**
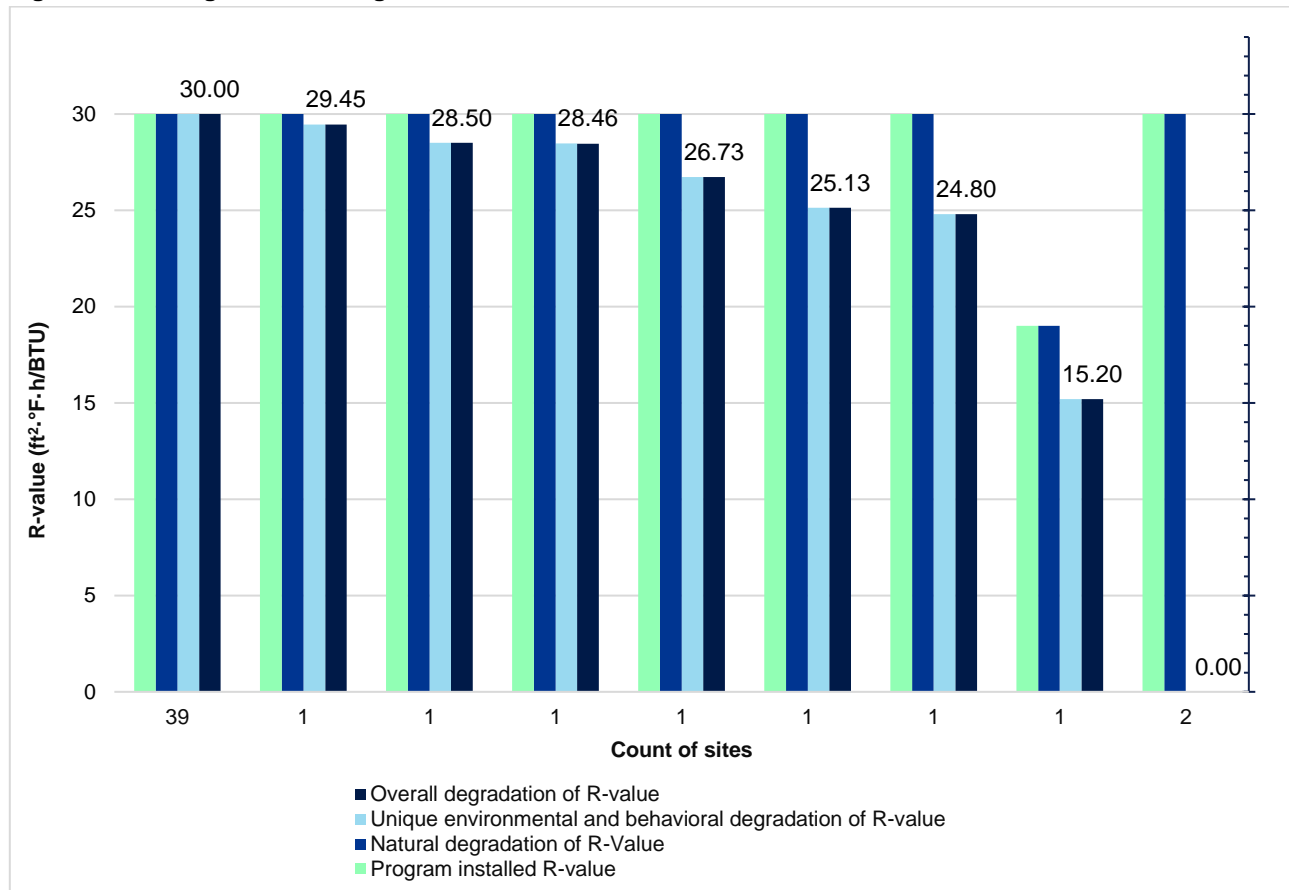


## 5 CONCLUSIONS AND RECOMMENDATIONS

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

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[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 |

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[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: | | | | Data collected from Inspection | | |
|---|---|---|---|---|---|---|
| **Wall Dimensions** | | | | **Wall Material:** | | |
| | **Thickness** | **Width** | **Height** | | | |
| N | | | | **Insulation Material:** | | |
| S | | | | | | |
| W | | | | **Wall Framing Type:** | | |
| E | | | | | | |

| 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: | | | | | Data collected from Inspection | | |
|---|---|---|---|---|---|---|---|
| **Ceiling Dimensions** | | | | | **Ceiling Material:** | | |
| | **Length** | **Width** | **Notes** | | | | |
| Ceiling 1 | | | | | **Insulation Material:** | | |
| Ceiling 2 | | | | | | | |
| Ceiling 3 | | | | | **Ceiling Framing Type:** | | |
| Ceiling 4 | | | | | | | |

| 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 (ft²·°F·h/BTU) | Program claimed wall area (ft²) | Wall framing | Wall thickness (inches) | Wall cavity (inches) | Total measured exterior wall area (ft²) | Total doors and glazing area (ft2) | Verified insulated wall area (ft²) | Insulation type | Observed wall insulation R-value (ft²·°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 (ft²·°F·h/ BTU) | Program claimed wall area (ft²) | Wall framing | Wall thickness (inches) | Wall cavity (inches) | Total measured exterior wall area (ft²) | Total doors and glazing area (ft2) | Verified insulated wall area (ft²) | Insulation type | Observed wall insulation R-value (ft²·°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.
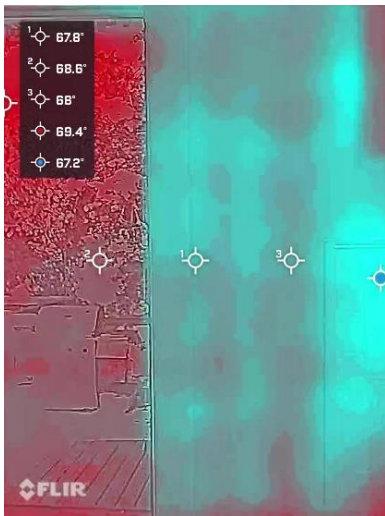

FLIR™ infrared image of insulated walls
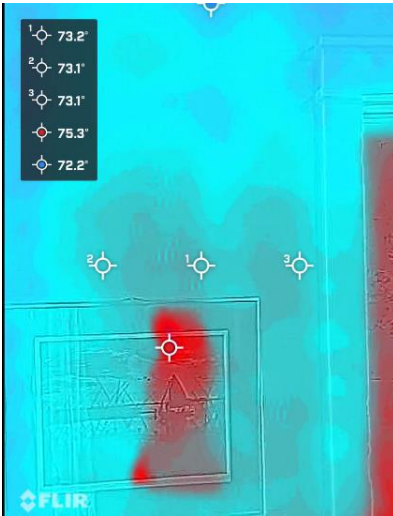

FLIR™ infrared image showing a section of insulated wall

**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.
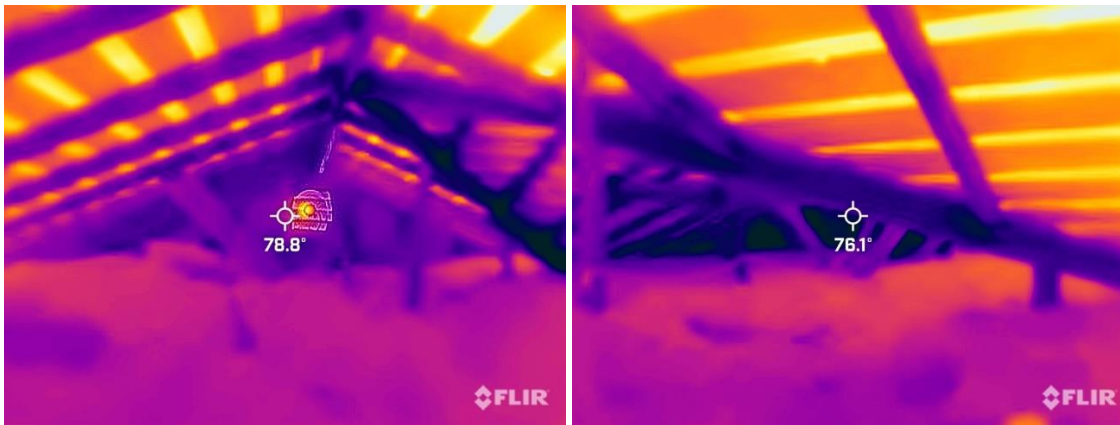


FLIR™ infrared image of ceiling/attic insulation

**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

| 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
DNV is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.