



MichaelsEnergy

[Subject]

C2117: Connecticut RCx Persistence Study

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Final Report

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Abstract

The C2117 Connecticut RCx Persistence Study Measure Life/EUL Update Study involves the update of the effective useful life (EUL) values for key retro-commissioning (RCx) measures offered through Connecticut's energy efficiency programs. The objectives of this study were to characterize the types of RCx measures and their savings installed in Connecticut in the past 5 years, develop effective useful life estimates for 4-6 RCx measures expected to be installed in Connecticut over the next 5 years, and recommend 3-5 RCx measure for field study to better estimate persistence.

This report focuses on five selected RCx measure categories, selected based on discussions with utilities and other stakeholders and review of utility program data and project data. Research activities included: interviews with utility staff; review of utility data; interviews with market actors, including RCx service providers (RSPs) and controls vendors; and a literature review. The goal of this study was to develop cost-effective EUL estimates of RCx measures based on other research; this study did not include statistical analysis of primary data from facilities.

Based on the research conducted in this study, the Evaluation Team recommends updating the EUL values in the 2022 Program Savings Document (PSD) to the following values:

	2022 PSD EUL Value	Recommended EUL Value
Air Handling Unit (AHU) Scheduling and Optimization	6/8	5
Constant Air Volume (CAV) to Variable Air Volume (VAV) AHU Conversion	8	7
HVAC Occupancy Sensors	8	7
Chilled Water (ChW) Controls	8	7
Exhaust Fan Controls	8	7
Non-Specific HVAC RCx Measures	8	7

*The PSD EUL values for adjust scheduling and reset set-points are 6 years while the EUL value for controls to eliminate simultaneous heating and cooling is 8 years.

The Evaluation Team also recommends the following:

Recommendation Category	Recommendation
Effective Useful Life (EUL)	<ol style="list-style-type: none"> 1. Update the effective useful life (EUL) values in the Program Savings Document (PSD) based on the findings in this study. Based on the information gathered through the literature review and market actor interviews, we recommend updating the EUL for AHU scheduling and optimization to 5 years and updating all other non-lighting, non-refrigeration, and non-process retro-commissioning measures to a single value of 7 years. 2. Continue to use the existing EUL values in the 2022 PSD for refrigeration and process equipment retro-commissioning measures, as these measures were not a focus of this study.
Guidance for Future Persistence Studies	<ol style="list-style-type: none"> 3. To improve the measure life estimates used in Connecticut, the Evaluation Team recommends conducting a field study to measure the persistence of common RCx measures. The Evaluation Team recommends developing RCx EUL values for broad measure categories where there may be a distinction in persistence, such as measure related to scheduling and measures not related to scheduling, to maximize the precision of results. The Evaluation Team provides the following guidance for future persistence studies: <ol style="list-style-type: none"> a. Field studies for retro-commissioning persistence typically determine persistence through reviewing measure trends or control logic in facilities' building automation system (BAS). This would be supplemented by functional testing of measures if the BAS data is not available. While this approach is the industry standard, other methods are available that can decrease fielding costs and potentially improve the rigor of the results. Unlike past studies, a persistence field study in Connecticut could utilize multiple modes, such as in-person site visits, virtual site visits with remote BAS access, and surveys to gather detailed persistence information. b. Understanding that limitations in available budget and the small population of RCx projects in Connecticut, may restrict the ability to conduct such a study, the Evaluation Team suggests considering coordinating with other utilities or organizations in the Northeast to develop more robust regional estimates. c. When collecting persistence estimates from surveys or interviews in future studies, clearly define persistence and measure failure to match the study's definition to maintain consistency across responses. Additionally, provide examples of reasons why savings may not persist, such as changes in control settings and changes in building use.
Increasing RCx Persistence	<ol style="list-style-type: none"> 4. To remedy persistence issues, programs may consider implementing or continuing a variety of best practices for participants and participating RSPs described in this study. This includes requiring RSPs to conduct follow-up visits to check for persistence issues, conduct post-RCx training with building operations staff, and encourage measures that are more difficult to change or overwrite when there are multiple options with similar savings for a given opportunity.

1 Executive Summary

This report presents the results of research to update the effective useful life (EUL) values for key retro-commissioning (RCx) measures offered through Connecticut's energy efficiency programs. The Connecticut Energy Efficiency Board (EEB) Evaluation Administrators (EA) commissioned the Michaels Energy (the Evaluation Team) to conduct this research. The objectives of this study were to characterize the types of RCx measures and their savings installed in Connecticut in the past 5 years, develop effective useful life estimates for 4-6 RCx measures expected to be installed in Connecticut over the next 5 years, and recommend 3-5 RCx measure for field study to better estimate persistence.

This report focuses on five selected RCx measure categories, selected based on discussions with utilities and other stakeholders and review of utility program data and project data.¹ The five selected measure categories accounted for 85% of electric (kWh) and 75% of natural gas (CCF) savings of a sample of reviewed projects. The measure categories were:

- Air Handling Unit (AHU) Scheduling and Optimization
- Constant Air Volume (CAV) to Variable Air Volume (VAV) Air Handling Unit (AHU) Conversion
- HVAC Occupancy Sensors
- Chilled Water (ChW) Controls
- Exhaust Fan Controls

Research activities included: interviews with utility staff; review of utility data; interviews with market actors, including RCx service providers (RSPs) and controls vendors; and a literature review.

1.1 Key Findings

In line with industry standards, the Evaluation Team defines the persistence of retro-commissioning measures as the median length of time that equipment or control strategies are in place and operational, with operational meaning functioning as originally intended and with energy savings equal to or greater than 50% of the original savings.

The Evaluation Team compared our findings to the values currently used in the 2022 Program Savings Document (PSD) to determine if the values should be updated. Based on the information gathered through the literature review and market actor interviews, we recommend updating the EUL for AHU scheduling and optimization to 5 years and updating all other non-lighting, non-refrigeration, and non-process retro-commissioning measures to a single value 7 years. Although our research resulted in different EUL estimates for the five measure categories under study, the Evaluation Team recommends using a single value because the differences

¹ Review of the utility data revealed that the project files did not contain consistent measure names and needed to be categorized. We grouped measures of similar intent into common categories for better comparison across time and with other sources. For example, we grouped the measures described as "Implement an optimal start program for RTUs 1 & 2" and "Implement a reduced occupancy schedule for air handling systems serving classrooms in the D wing based on actual occupancy usage" into the "Air Handling Unit Scheduling and Optimization" category.

between the values for each measure category are not large and are based on low numbers of observations.

Table 1 shows the EUL estimates from the literature review and market actor interviews, the EUL value from the Program Savings Document (PSD), and the updated EUL value recommended by the Evaluation Team. Because the literature review also included RCx measures outside the five categories targeted in this study, the Evaluation Team recommends using the non-specific HVAC RCx measure EUL of 7 years for any HVAC RCx measure categories not listed in the table below.² Appendix C provides specific recommended updates to the PSD values as well as listing the RCx measure with no recommended change.³

Table 1: Comparison of Calculated EULs From This Study to EULs from PSD

	Mean EUL from Literature Review	Mean EUL from Market Actor Interviews	2022 PSD EUL	Recommended Value	PSD HVAC Controls Measures Covered
AHU Scheduling and Optimization	5.5	3.4	6/8*	5	Adjust scheduling, controls to eliminate simultaneous heating and cooling, and reset set-points
CAV to VAV AHU Conversion	5.8	7.7	8	7	Not included in PSD
HVAC Occupancy Sensors	6.3	9.0	8	7	Demand control ventilation, Modify HVAC controls
ChW Controls	5.3	9.8	8	7	Modify HVAC controls
Exhaust Fan Controls	7.3	9.8	8	7	Modify HVAC controls
Non-Specific HVAC RCx Measures	6.6	8.1	8	7	

*The PSD EUL values for adjust scheduling and reset set-points are 6 years while the EUL value for controls to eliminate simultaneous heating and cooling is 8 years.

Notably, the measure life estimates from the market actor interviews differed from the reviewed research, with the average values from market actors higher than the average values from the literature review in most cases. This raised questions about the market actors' assumptions when providing their estimates. The measure life estimates from market actors varied considerably, in

² Note that the PSD also lists lifetime values for refrigeration and process equipment retro-commissioning measures. The Evaluation Team's review of these measures was very limited and therefore we recommend continuing to use the EUL values in the PSD for refrigeration and process equipment retro-commissioning measures.

³ Note that impact evaluations, such as the C2211 BES Impact Evaluation, develop realization rates for first-year savings of a measure (based on equipment failure, incorrect installation, or other errors) while persistence studies address the length of time the measure and its savings last. By definition, some measures and savings will last beyond the median lifetime (the EUL), but mathematically these savings are accounted for by giving full first-year savings to all measures until the EUL, even though a portion of them will have failed before that time.

one case ranging from 1 to 10 years. It is unclear if the market actors' higher average measure life estimates are due to a difference in definition (i.e., technical life or effective useful life) or if they are because the interviewed market actors are more engaged with customers, resulting in higher persistence over time. Regardless of the reason for the discrepancy, the Evaluation Team suggests generally considering the market actor estimates as the high end of the range of estimates.

When developing our recommended values, the Evaluation Team placed more importance on the literature review findings because they were based on multiple studies conducted by independent parties using industry-accepted methodologies. The measure life estimates from the market actor interviews were generally higher than the reviewed research, raising questions about the market actors' assumptions when providing their estimates. Therefore, when developing the recommended EUL values, the Evaluation Team weighted the results of the literature review twice as much as the market actor interviews (i.e., we used weights of 0.67 and 0.33 respectively).⁴

1.2 Additional Findings

- Human factors, such as lack of training, staff turnover and not adjusting schedules when a facility's hours of operation change, drive the failure of most retro-commissioning measures. Hardware fixes and control changes that cannot be easily overwritten tend to persist longer. Persistence is typically higher in facilities that outsource some of their building operations to controls vendors due to their higher level of knowledge and documentation of the RCx measures.
- Non-human factors resulting in failures of RCx measures include undetected mechanical/control component failures, such as a stuck economizer damper, and changes to the building, such as major retrofits and renovations and space changes.
- There are very few RCx persistence studies that incorporate primary data (e.g., field studies and surveys) and none in the Northeast. Field studies for retro-commissioning persistence typically determine persistence through reviewing measure trends or control logic in facilities' building automation system (BAS), supplemented by functional testing of measures if the BAS data is not available. While this approach is the industry standard, other methods are available that can decrease fielding costs and potentially improve the rigor of the results. Unlike past studies, a persistence field study in Connecticut could utilize multiple modes, such as in-person site visits, virtual site visits with remote BAS access, and surveys to gather detailed persistence information. Future field studies should consider including a mix of behavior and capital RCx measures that represent large shares of RCx savings, such as the five measure categories identified in this study.

⁴ The weighted average EUL for exhaust fan controls was 8 years, but the Evaluation Team recommends using a value of 7 years because of the small difference between values and low number of observations.

2 Introduction

2.1 Study Objectives

The primary objectives of this study were to:

- Characterize selected types of RCx measures and their savings installed in Connecticut in the past 5-10 years
- Develop effective life estimates for 4-6 RCx measures expected to be installed in Connecticut over the next 5 years
- Recommend 3-5 RCx measure for field study to better estimate persistence

2.2 Program Background

Retro-commissioning (RCx) is a systematic process that identifies and implements operational and maintenance and control strategy improvements to increase the energy performance of existing building. It targets malfunctioning and outdated control logic that causes a building's energy management system (EMS) to use more energy and prevent it from operating at peak performance.

The Connecticut utilities offer a retro-commissioning program to commercial and industrial customers to help defray the cost of an RCx investigation effort and adoption of recommended energy efficiency measures. To participate in the program, buildings must be over 100,000 square feet, have a direct digital controls-based energy management system with trending capability, and have a current ENERGY STAR benchmark. The program targets a variety of markets with large buildings, including universities, schools, hospitals, and office or retail space.

2.3 Methodology

2.3.1 Definition of Persistence

Retro-commissioning involves both the installation of energy-saving equipment (e.g., occupancy sensors) and the adoption of energy-saving operational and control strategies. Because of this, determining the persistence of RCx measures requires a more nuanced approach than simple energy efficient equipment. The Evaluation Team defines the persistence of retro-commissioning measures as the median length of time that equipment or control strategies are in place and operational, with operational meaning functioning as originally intended and with energy savings equal to or greater than 50% of the original savings.⁵

⁵ This definition is in line with other persistence studies such as Seventhwave (2018). In some studies, such as Friedman (2011), the definition of persistence was less clear for measures that were modified from their commissioned condition. That study states that "even if the original [commissioned control strategy] was more energy efficient, if the modified [control strategy] still significantly improved energy efficiency compared to the pre-commissioning operation, then we defined the measure to persist. If the [control strategy] had been disabled or modified to decrease energy efficiency compared to the pre-commissioning operation, then the measure did not persist." In this case, the choice of the term "still

2.3.2 Research Activities

To meet the study objectives, the Evaluation Team engaged in the following research activities:

- **Interviews with utility staff** – The Evaluation Team conducted interviews with program staff from Eversource and Avangrid. The topics covered in these interviews included past program offerings and measures, expected changes to the program and measure mix, and other elements that factor into persistence, such as the program's customer mix, the level of customer training, participation in other programs, and business turnover. Finally, we discussed the availability of program tracking data.
- **Utility data review** – The Evaluation Team analyzed the utility program tracking data from 2015 to 2020 to identify the most implemented RCx measures in recent years. After an initial data review and discussions with the utilities, the Evaluation Team found that the utilities' tracking databases could only provide high level measure data for most projects. The granular measure-level information required for our analysis was not stored in a central location and needed to be requested from the participating RSPs. To reduce the burden on the utilities and RSPs, the Evaluation Team drew a random sample of projects and requested the full documentation for each of the selected projects.
- **Interviews with market actors** – We conducted targeted in-depth interviews with market actors with knowledge of RCx measure persistence, this included the two participating retro-commissioning service providers (RSPs) operating in Connecticut at the time of the study and seven HVAC equipment and controls vendors. These interviews explored market actors' in-field observations about the persistence of savings of the RCx measures, focusing on the measures targeted in this study. The interviews also investigated the reasons for failure and how best to increase measure and savings persistence, customer training, and the effect on COVID on their practices and their customers' uptake and continuation of RCx measures.
- **Literature review** – The Evaluation Team conducted a thorough review of past RCx persistence research to answer the following research questions:
 - What is the best estimate of life for the RCx measures targeted in this study?
 - Will the mix of RCx measures change in the next 5 years and, if so, how?
 - What are the common reasons for the failure of RCx measures?
 - How can persistence issues be remedied?
 - What are the measurements and approaches needed for a field study?

significantly improved" can be read to indicate savings equal to at least 50% of the original savings, but the exact threshold is not defined.

3 RCx Measure Characterization

Retro-commissioning (RCx) is a systematic process that identifies and implements operational and maintenance and control strategy improvements to increase the energy performance of existing building. It targets malfunctioning and outdated control logic that causes a building's energy management system (EMS) to use more energy and prevent it from operating at peak performance.

The Connecticut utilities offer a retro-commissioning program to commercial and industrial customers to help defray the cost of an RCx investigation effort and implementing recommended energy efficiency measures. To participate in the program, buildings must be over 100,000 square feet, have an energy management system with trending capability, and have a current ENERGY STAR benchmark. The program targets a variety of markets with large buildings, including universities, schools, hospitals, and office or retail space.

3.1 Program Summary

As an initial task, the Evaluation Team analyzed the utility program tracking data from 2015 to 2020 to understand the level of program participation and to identify the most implemented RCx measures and the facilities in which they were implemented. In that period, the Connecticut utilities combined to provide incentives for 76 RCx projects, with Eversource accounting for the large majority (71). As shown in Table 2, the Connecticut utilities claimed over 10 GWh of electric savings and over 27 million cubic feet of natural gas savings from 2015 to 2020.

Table 2: Summary of Connecticut RCx Projects by Year (2015-2020)

Year	Number of Projects	Annual Electric Savings (MWh)	Annual Natural Gas Savings (CCF)
2015	22	5,194	139,659
2016	12	1,444	10,733
2017	10	526	6,606
2018	12	286	12,419
2019	14	1,338	28,323
2020	6	1,396	75,582
Total	76	10,184	273,332

Table 3 breaks out the savings from Connecticut utility RCx projects in 2015 to 2020 by business segment. The education segment, including both schools and universities, accounted for the most projects during this time period as well as the largest share of savings. Notably, the education segment accounted for very similar shares of projects during this study period (60% in

2015-2020) and during the period covered by the last impact evaluation (59% in 2008-2010).⁶ Similarly, this segment accounted for 45% of kWh savings in 2015-2020 and 49% in 2008-2010.

Table 3: Summary of Connecticut RCx Projects by Segment (2015-2020)

Year	Number of Projects	Electric Savings (MWh)	Natural Gas Savings (CCF)
Office/Retail	19	4,092	55,637
College/University	26	3,044	125,744
School (K-12)	20	1,526	27,242
Museum	4	961	56,462
Hospitals/Health Care	2	349	--
Municipal	2	134	--
Total	76	10,184	273,332

3.2 Measure Selection

The Evaluation Team sought to target four to six RCx measures to study, based on what was most implemented in recent years and what is expected to be implemented in the next five years. After discussions with utilities and other stakeholders and review of utility program data, the Evaluation Team focused on the following five measure categories for this study:

- **Air Handling Unit (AHU) Scheduling and Optimization** – Turning off equipment during unoccupied times or periods with low loads. Optimizations include allowing the equipment to operate more efficiently at part-load conditions
- **Constant Air Volume (CAV) to Variable Air Volume (VAV) Air Handling Unit (AHU) Conversion** – Adding variable speed controls to allow central units to slow down and match the load, which saves both fan energy and heating and cooling energy
- **Occupancy Sensors** – Only providing ventilation and space conditioning to occupied spaces
- **Chilled Water (ChW) Controls** – Changing how chillers are operated to allow them to most efficiently meet the load by slowing down pumps, properly staging equipment, or maximizing heat transfer in the system
- **Exhaust Fan Controls** – Eliminates fan energy and space conditioning energy by avoiding exhausting conditioned air during unoccupied periods

The Evaluation Team reviewed detailed project files from 25 sampled buildings that participated in the RCx program from 2015 to 2020. As shown in Table 4, the five selected measure categories

⁶ Michaels Energy. (2013) *Impact Evaluation of the Retrocommissioning, Operation & Maintenance, and Business Sustainability Challenge Programs*. Connecticut Energy Efficiency Board. https://energizect.com/sites/default/files/documents/RCx-OM-Draft%20Final%20Report_121712.pdf

accounted for 85% of electric (kWh) and 75% of natural gas (CCF) savings of the sampled projects.⁷

Table 4: Selected Measures' Share of Savings from Sampled Projects

Selected Measures	% kWh Savings	% Summer kW Savings	% Winter kW Savings	% Natural Gas Savings
AHU Scheduling and Optimization	35%	50%	23%	52%
CAV to VAV AHU Conversion	20%	13%	30%	3%
HVAC Occupancy Sensors	14%	12%	10%	12%
Chilled Water Controls	11%	4%	14%	1%
Exhaust Fan Controls	5%	4%	9%	8%
Other Measures	15%	16%	15%	25%
Total	100%	100%	100%	100%

3.3 Expected Changes to RCx Measures

When selecting the RCx measures on which to focus, the Evaluation Team also asked program staff and market actors about the expected changes in the mix of RCx measures in the next five years. Interviewees agree that the major measures selected above will continue to contribute significant savings to the program in coming years. However, other versions of RCx programs are likely to emerge, such as tune-up programs focusing on buildings with area of less than 100,000 square feet or continuous commissioning offerings that use cloud-based analytics software.

Additionally, interviewees identified fault detection and diagnostics (FDD) as an area of interest. FDD is a software tool that monitors data in control systems in real time to immediately identify problems with building systems before they become larger issues. Other new technologies mentioned included wireless sensors that include temperature, humidity, CO2, and occupancy sensing all in one device and particulate monitoring for indoor air quality.

⁷ To address the measure not explicitly covered in this study, the Evaluation Team developed a recommendation for "non-specific HVAC RCx measures." Additionally, as described later, RCx measures related to non-HVAC systems (e.g., lighting and refrigeration) were not covered in the study.

4 RCx Measure Persistence

To develop an estimate of life for RCx measures expected to be installed in Connecticut in the next five years, the Evaluation Team conducted a thorough review of relevant literature and supplement that with expert interviews.⁸ The following sections present the findings from those activities followed by our measure life recommendations for including in the Program Savings Document (PSD).

4.1 Literature Review Findings

The Evaluation Team conducted a thorough review of literature that researched the persistence of retro-commissioning. In the course of this review, we identified 11 studies with rigorous estimates of persistence to use in our analysis. Table 5 summarizes the findings from these studies.

Table 5: Summary of RCx Persistence Values from Literature Review

RCx Measure	Number of Studies	Minimum EUL (Years)	Maximum EUL (Years)	Mean EUL (Years)
AHU Scheduling and Optimization	5	1	9	5.5
CAV to VAV AHU Conversion	5	3	8.5	5.8
HVAC Occupancy Sensors	5	3	11	6.3
ChW Controls	5	2	8.5	5.3
Exhaust Fan Controls	5	3	12.5	7.3
Non-Specific RCx Measures	9	3	10	6.6

Table 6 provides a summary of the sources included in the literature review. Sources included a variety of study types from different jurisdictions. While the Evaluation Team sought to focus on studies in the Northeast to maximize applicability to Connecticut, the lack of RCx persistence studies compelled us to include studies from across the country. Whenever possible, the Evaluation Team picked studies that included primary data.^{9 10}

Table 7 shows the persistence results from those studies as well as the EUL estimates used in this study's analysis. In cases where studies did not provide an EUL estimate, the Evaluation Team extrapolated the results from the study to develop an estimate. For example, if a study found 70% persistence after three years, we assumed that 10% of units failed per year, resulting in an

⁸ Note that participation in RCx programs may have a positive effect on persistence, with the size of this effect dependent on the program's processes. The literature review and interviews focused on the targeted RCx measures overall and include both participants and non-participants.

⁹ In some cases, the reviewed studies used the same original sources. The Evaluation Team included these potentially "overlapping" studies because each reviewed study developed its own persistence estimates based on unique mixes of sources and weighting schemes.

¹⁰

EUL of 5, when 50% of units would have failed. The Evaluation Team recognizes that this is a simplifying assumption, and the actual survival curve would likely not be a straight line, but there is currently no research available with enough data points to estimate the distribution of the hazard function which would be used to estimate the EUL.¹¹

¹¹ In the Industrial O&M Persistence Study for Energy Trust of Oregon, DNV GL used a Kaplan-Meier (K-M) survival curve to estimate the EUL of O&M measures. The study also estimated the EUL using three parametric distributions (Weibull, log-normal, and log-logistic) to compare to the K-M estimate, but ultimately did not use a parametric approach for their final results.

Table 6: Summary of Literature Review Sources with RCx Persistence Estimates

Study Number	Study Author	Study Name	Study Sponsor	Study Jurisdiction	Study Year	Study Type	Uses BAS Data?
1	DNV GL	Persistence of O&M Energy-Efficiency Measures	Energy Trust of Oregon	OR	2017	Literature review	No
2	DNV GL	Industrial Systems Optimization Program Evaluation	Puget Sound Energy	WA	2017	Evaluation	No
3	Bourassa	An Evaluation of Savings and Measure Persistence from Retrocommissioning of Large Commercial Buildings	LBNL, SMUD (IEPEC paper)	CA	2003	Survey and field study	Yes
4	Toole	The Persistence of Retro-Commissioning Savings in Ten University Buildings	Texas A&M	TX	2011	Usage analysis and field study	No
5	KEMA	Business Programs: Measure Life Study	Focus on Energy	WI	2009	Literature review	No
6	Eardley	Persistence Tracking in a Retro-Commissioning Program	National Conference on Building Commissioning	Unknown	2007	Field study	Yes
7	Roberts	Do Savings from Retrocommissioning Last? Results from an Effective Useful Life Study.	CPUC (ACEEE paper)	CA	2010	Survey and study, survival analysis	Yes
8	Skumatz	Remaining Useful Lifetimes and	IEPEC paper	USA	2011	Secondary research	No

Study Number	Study Author	Study Name	Study Sponsor	Study Jurisdiction	Study Year	Study Type	Uses BAS Data?
		Persistence – Literature and Methods					
9	Friedman	Persistence of Benefits from New Building Commissioning	ACEEE paper	TX	2011	Field study, secondary research, survey	No
10	Seventh-wave	Persistence of Savings from Retro-Commissioning Measures	ComEd	IL	2018	Field study and secondary research	Yes
11	DNV GL	Industrial O&M Persistence Study	Energy Trust of Oregon	OR	2020	File review and interviews	No

Table 7: Summary of RCx Persistence Values from Literature Review

Study Number	Study Jurisdiction	Results	Effective Useful Life (EUL) Estimate Used in Analysis					
			RCx Overall	AHU Scheduling	ChW Controls	CAV to VAV AHU Conversion	HVAC Occ Sensors	Exhaust Fan Controls
1	OR	Persistence of O&M measures is 3 years. Persistence of HVAC scheduling is 1 year. Persistence of chiller and cooling tower measures is 2 years.	3	1	2	3	3	3
2	WA	97% of action items continued to persist after 6 to 30 months	5	5	5	5	5	5
3	CA	Overall persistence 2-8 years after commissioning is 69%	4	4	4	4	4	4

Study Number	Study Jurisdiction	Results	Effective Useful Life (EUL) Estimate Used in Analysis					
			RCx Overall	AHU Scheduling	ChW Controls	CAV to VAV AHU Conversion	HVAC Occ Sensors	Exhaust Fan Controls
4	TX	Savings for heating, cooling, and non-cooling electricity use declined by an average of 8%, 6%, and 4% per year, respectively. Overall persistence 3 years after commissioning is 83%. Estimated measure life of 6 to 12 years.	8.5	8.5	8.5	8.5	8.5	12
5	WI	Recommended 10 year EUL	10	--	--	--	--	--
6	Unknown	36% persistence	5	--	--	--	--	--
7	CA	Average EUL of 8 years based on simple linear extrapolation	8	--	--	--	--	--
8	USA	Across 100+ reviewed studies, occupancy sensors had EULs of 8-15 years	--	--	--	--	11	--
9	TX	Chilled water control strategies did not persist in three out of eight cases after 5 years.	--	--	7	--	--	--
10	IL	After 6 years, persistence for air distribution is 36%, for ventilation is 65%, for scheduling is 76%, and general persistence is 62%.	8.6*	9	--	8.5	--	12.5

Study Number	Study Jurisdiction	Results	Effective Useful Life (EUL) Estimate Used in Analysis					
			RCx Overall	AHU Scheduling	ChW Controls	CAV to VAV AHU Conversion	HVAC Occ Sensors	Exhaust Fan Controls
11	OR	Survival analysis provides an EUL of 7 years for O&M.	7	--	--	--	--	--
Mean			6.6	5.5	5.3	5.8	6.3	7.3

*EUL value developed by Guidehouse using Seventhwave's results

4.2 Market Actor Interviews

The Evaluation Team conducted in-depth interviews with market actors knowledgeable about the persistence of RCx measures. These interviews included two participating retro-commissioning service providers (RSPs) operating in Connecticut at the time of the study and seven HVAC equipment and controls vendors. In general, the lifetime estimates of the two groups were similar.

Table 8 provides a summary of the market actors' measure life estimates.

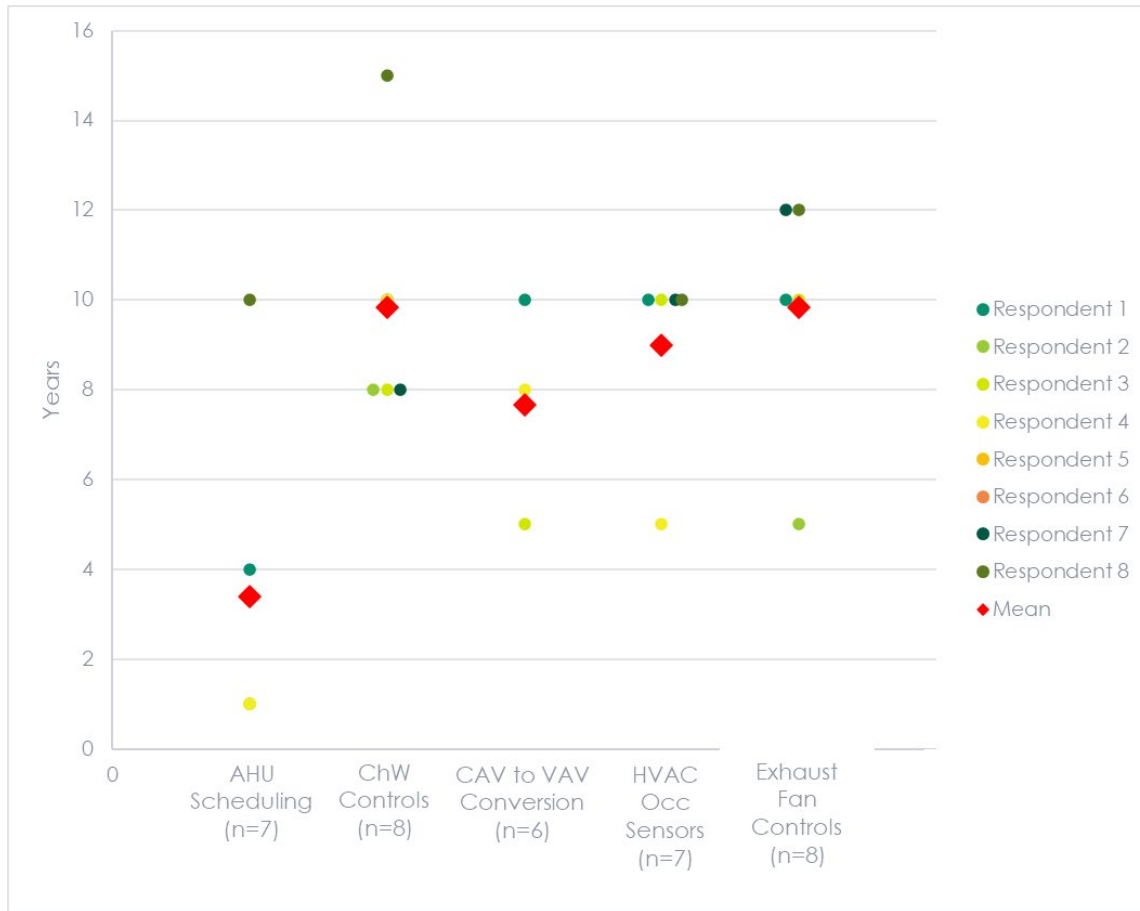
Table 8: Summary of RCx Persistence Values from Market Actor Interviews

RCx Measure	Number of Respondents	Minimum EUL (Years)	Maximum EUL (Years)	Mean EUL (Years)
AHU Scheduling and Optimization	5	1	10	3.4
CAV to VAV AHU Conversion	3	5	10	7.7
HVAC Occupancy Sensors	5	5	10	9.0
ChW Controls	6	8	15	9.8
Exhaust Fan Controls	6	5	12	9.8

Figure 1 presents the individual estimates for each respondent along with the mean EUL, shown as a red diamond. Two findings stand out from these results. First, the measure life estimates varied considerably by market actor, in some cases ranging from 1 to 10 years. Second, with the exception of AHU scheduling and optimization, the average measure life estimates from market actors are all higher than the average values from the literature review. It is unclear if the market actors' higher mean measure life estimates are due to a difference in definition (i.e., technical life or effective useful life) or if they are because the interviewed market actors are more engaged with customers, resulting in higher persistence over time.¹² Regardless of the reason for the discrepancy, the Evaluation Team suggests generally considering the market actor estimates as the high end of the range of estimates.

¹² The Evaluation Team did not include responses from two market actors in the analysis because their measure life estimates were much higher than other respondents and it appeared that they were referring to the technical life of the equipment rather than the median life of the RCx measure.

Figure 1: Market Actor Interview Measure Life Estimates



4.3 Recommended Changes to Program Savings Document

The Evaluation Team compared our findings to the values currently used in the 2022 Program Savings Document (PSD) to determine if the values should be updated. Based on the information gathered through the literature review and market actor interviews, we recommend updating the EUL for AHU scheduling and optimization to 5 years and updating all other non-lighting, non-refrigeration, and non-process retro-commissioning measures to a single value of 7 years.

Our recommendation of a shorter EUL for AHU scheduling and optimization is consistent with other studies we reviewed that found a shorter lifetime estimate for scheduling-related measures than other measures. Although our research resulted in different EUL estimates for the four non-scheduling measure categories under study, the Evaluation Team recommends using a single value for these measure categories because the differences between the values are not large and are based on low numbers of observations.

When developing our recommended values, the Evaluation Team placed more importance on the literature review findings because they were based on multiple studies conducted by independent parties using industry-accepted methodologies. The measure life estimates from

the market actor interviews were generally higher than the reviewed research, raising questions about the market actors' assumptions when providing their estimates. Therefore, when developing the recommended EUL values, the Evaluation Team weighted the results of the literature review twice as much as the market actor interviews (i.e., we used weights of 0.67 and 0.33 respectively).

Table 9 shows the EUL estimates from the literature review and market actor interviews, the EUL value from the 2022 PSD, and the updated EUL value recommended by the Evaluation Team.¹³

Table 9: Comparing Estimated EULs From This Study to EULs from 2022 PSD

	Mean EUL from Literature Review	Mean EUL from Market Actor Interviews	2022 PSD EUL	Recommended Value	PSD HVAC Controls Measures Covered
AHU Scheduling and Optimization	5.5	3.4	6/8*	5	Adjust scheduling, controls to eliminate simultaneous heating and cooling, and reset set-points
CAV to VAV AHU Conversion	5.8	7.7	8	7	Not included in PSD
HVAC Occupancy Sensors	6.3	9.0	8	7	Demand control ventilation, Modify HVAC controls
ChW Controls	5.3	9.8	8	7	Modify HVAC controls
Exhaust Fan Controls	7.3	9.8	8	7	Modify HVAC controls
Non-Specific HVAC RCx Measures	6.6	8.1	8	7	

*The PSD EUL values for adjust scheduling and reset set-points are 6 years while the EUL value for controls to eliminate simultaneous heating and cooling is 8 years.

The 2022 PSD uses EUL values of 6 and 8 years for the retro-commissioning of HVAC controls.¹⁵ The source for most of these values was the 2005 Measure Life Study prepared for the

¹³ The weighted average EUL for exhaust fan controls was 8 years, but the Evaluation Team recommends using a value of 7 years because of the small difference between values and low number of observations.

¹⁴ Note that impact evaluations, such as the C2211 BES Impact Evaluation, develop realization rates for first-year savings of a measure (based on equipment failure, incorrect installation, or other errors) while persistence studies address the length of time the measure and its savings last. By definition, some measures and savings will last beyond the median lifetime (the EUL), but mathematically these savings are accounted for by giving full first-year savings to all measures until the EUL, even though a portion of them will have failed before that time.

¹⁵ The 2022 PSD also lists lifetime values of 8 and 10 years for refrigeration and process equipment retro-commissioning measures. The Evaluation Team's review of these measures was very limited; therefore, we recommend continuing to use the EUL values in the 2022 PSD for refrigeration and process equipment retro-commissioning measures.

Massachusetts Joint Utilities by ERS, while some values were sourced from the California 2008 Database for Energy-Efficient Resources (DEER). Notably, the 8-year EUL value from the ERS (2005) study appears to be an agreement between parties for programmable thermostats and the source value of the 6-year EUL for the “adjust scheduling” and “reset set-points” measures is unclear. While the results from this study do not vary substantially to the values in the 2022 PSD, the sources used to develop our estimate are more recent and in better alignment with the program’s measure mix.

For additional specificity, Appendix C lists the RCx measures in the 2022 PSD, the current EUL value, and the recommended value from this study. Because the literature review also included HVAC RCx measures outside the five categories targeted in this study, the Evaluation Team recommends using the non-specific RCx measure EUL of 7 years for any HVAC RCx measure categories not listed in the table above.

5 Improving RCx Persistence

In the course of the literature review and market actor interviews, the Evaluation Team also sought to understand the common reasons for the failure of retro-commissioning measures and how to remedy persistence issues. This section summarizes the findings related to those two research topics.

5.1 Reasons for RCx Failure

The Evaluation Team found that human factors drive the failure of most retro-commissioning measures, including those categories targeted in this study. Hardware fixes and control changes that cannot be easily overwritten tend to persist longer. Persistence is typically higher in facilities that outsource some of their building operations to controls vendors due to their higher level of knowledge and documentation of the RCx measures.

Persistence issues may start as early as the retro-commissioning implementation phase if the appropriate building operation staff do not participate in the process and do not understand what changes are implemented and why. Next, RCx measures may not persist due to lack of post-commissioning building operation training, lack of appropriate documentation, or lack of internal staff support. This can be exacerbated when there is turnover in building operation staff. Other human factors reducing the persistence of RCx measures include changes to control settings due to comfort complaints, not adjusting schedules when a facility's hours of operation change, and general poor management of building automation systems.

Non-human factors resulting in failures of RCx measures include undetected mechanical/control component failures, such as a stuck economizer damper, and changes to the building, such as major retrofits and renovations, and space changes.

In addition to these general persistence issues, the Evaluation Team identified issues specific to the five RCx measures under study. These are listed in Table 10.

Table 10: Measure-Specific Reasons for Poor Persistence Among RCx Measures

AHU Scheduling and Optimization	Chilled Water Controls	CAV to VAV AHU Conversion	HVAC Occupancy Sensors	Exhaust Fans
<ul style="list-style-type: none"> • Actual occupancy is different than assumed occupancy • Lack of operating training around scheduling • Need to coordinate scheduling with other groups (e.g., Registrar's office in Higher Education) • Building renovations • Lack of proper maintenance 	<ul style="list-style-type: none"> • Failures due to programming changes • User does not understand or trust new control strategy • Equipment failure • Actual occupancy is different than assumed occupancy • Lack of proper maintenance 	<ul style="list-style-type: none"> • VFDs failing • Volume control issues • Poor sensor calibration • Aggregation of issues with individual spaces • Programming changes • Drives locked at 100% • Building renovations • Poor sequencing 	<ul style="list-style-type: none"> • Overriding by facility staff due to poor understanding • Bad application, location, or setup • Equipment failure 	<ul style="list-style-type: none"> • Airflow sensors out of calibration • Poor application/building pressure issues • Poor scheduling • Equipment failures • Changes to the space • Lack of proper maintenance

5.2 Best Practices to Increase RCx Persistence

Below the Evaluation Team presents best practices for increasing the persistence of retro-commissioning measures, gathered from the literature review and market actor interviews.

5.2.1 Programmatic Remedies

The following guidance includes remedies the Connecticut RCx programs can take to improve persistence. The utilities may already be incorporating many of these items, but the Evaluation Team suggests adding them to the program's standard operating procedures. Because some of these remedies would require additional work from RSPs, the utilities may consider altering the current incentive structure to reflect this. The Evaluation Team recognizes that some of the best practices may increase costs to the program to different degrees and therefore it may not be possible to implement all best practices as described.

1. Require adequate RCx follow-up services.
 - a. Consider withholding a portion of the incentive for several months to allow RSPs to work with facility to "dial in" measures.
 - b. Consider requiring additional follow-up visits (e.g., at 6 and/or 12 months) for the RSP to check measures and remedy any issues.
2. Consider holding back a portion of the incentive for a period of time after implementation and perform a persistence review.
 - a. If measures persist, pay the remainder of the incentive.
 - b. Alternatively, require verification or review of trend data three to six months after RCx for larger projects.
3. Require RCx providers to conduct post-RCx building operator training and create videos of training for later use
 - a. Continue delivering training prior to incentive payment.
4. Include performance tracking in the program.
 - a. Continue requiring tracking in ENERGY STAR Portfolio Manager.
 - b. Require RSPs set up trend analyses to help track the performance of measures that are not easily detected.
5. Consider conducting ongoing outreach to RCx participants to understand changes to facility that may affect RCx savings.
 - a. This is important for RCx projects with large savings and internal BAS management
 - b. This will help identify changes in staffing, major retrofits, or changes to the building use.

6. Continue to require RCx providers involve facility operations staff in the RCx process.
7. Continue to require RCx providers work with operations staff to thoroughly document RCx measures and new operating procedures, including:
 - a. Building and measure documentation
 - b. System manuals
 - c. Sequences of operation
 - d. System diagrams
8. Consider encouraging cost-effective measures that are difficult to change, including:
 - a. Controls with locks
 - b. Permission requirements
 - c. Hard-wired solutions
 - d. Hardware fixes/installations

5.2.2 Other Remedies

The following suggested recommendations fall outside of the program requirements but are things the utilities may be able to promote through RSP and customer education.

1. Encourage RCx participants to create a work environment for building operations staff that supports savings persistence, including:
 - a. Sufficient training for operations staff.
 - b. Dedicated operations staff with time to optimize building energy performance
 - c. Corporate commitment to building energy performance and reducing energy costs
2. Promote RCx measures that are simple and robust instead of more complex systems that may be more efficient on paper but may lack persistence because it is hard to understand how it is working, how it should be maintained, and how to adjust it if conditions change.¹⁶
 - a. Measures need to be understood by operations staff or will be overwritten.
3. When there is operations staff turnover, encourage sharing of knowledge from outgoing operator to new staff, in the form of program controls sequence documentation or other materials.

¹⁶ An example of this is using an outdoor air temperature reset instead of a Proportional-Integral-Derivative (PID) loop reset based on box positions.

4. Encourage ongoing commissioning to identify non-functional parts of systems or setpoint changes.
5. Encourage service contracts with equipment or controls vendors for preventive maintenance and periodic inspections.
6. Promote quarterly or annual meetings between building operations staff and vendors to ensure everything is operating as expected.
7. Encourage building persistence into automation, such as setting up the BAS to give an error message when a setpoint is altered.
8. Encourage use of FDD which can notify operators of performance issues quickly and more accurately, increasing the likelihood that issues are fixed at the root cause rather than simply overridden.

5.3 Impact of COVID-19 on RCx Persistence

The Evaluation Team sought to understand how COVID-19 affected retro-commission strategies and persistence and how to account for changes in baselines as a result of changes in building operation during the pandemic. Interviewed market actors state that COVID-19 had the largest impact on ventilation measures, such as demand controlled ventilation, as increased ventilation requirements resulted in lower energy savings using baselines established before 2020. These changes were most pronounced for hospitals, which may have converted many rooms into COVID-specific rooms with negative pressure. In other cases, it is difficult to establish accurate baselines if facilities were unoccupied for very long periods of time or have changing occupancy patterns.

However, the market actors found that most facilities understand these changes and now model savings using an updated baseline. Instead, market actors report that they have more issues calculating savings for utility program administrators who may have less flexibility changing the baseline for a project. However, this has become less of an issue as the increased ventilation requirements become standard practice and are built into baseline models.

Market actors were unsure of the effect of COVID-19 on the persistence of RCx measures. They speculate that persistence may increase because there are fewer people in buildings to override controls.

6 Future Research

In the course of the literature review, the Evaluation Team found that there are very few rigorous studies on the persistence of RCx measures. This is due to the relatively small size of most RCx programs and the technical requirements of assessing whether a measure still persists. Additionally, the Evaluation Team did not find any studies that estimated persistence using primary data that were from the Northeast, which may affect the accuracy of the estimates when applied to Connecticut. To improve the measure life estimates used in Connecticut, the Evaluation Team recommends conducting a field study to measure the persistence of common RCx measures. Understanding that limitations in available budget and the population of RCx projects in Connecticut, may restrict the ability to conduct such a study, the Evaluation Team suggests considering working with other utilities or organizations in the Northeast to develop more robust regional estimates.

To maximize the precision of results of future studies, the Evaluation Team recommends developing RCx EUL values for broad measure categories where there may be a distinction in persistence, such as measure related to scheduling and measures not related to scheduling. The study can target specific measures groups of interest, but with a limited population of participants, it will likely be very difficult to gather enough data to develop meaningful estimates for specific measures. If results for more granular measures are desired, then the study should target the five measures identified in this study, which account for the bulk of program savings.

The Evaluation Team recommends using a methodology similar to a measure life study, in which the evaluator estimates an EUL using a survival analysis by determines the survival or failure of measures over a wide range of years. While the RCx program lacks the large number of observations typically needed for this type of analysis, the relatively short life of RCx measures (estimated to be 7 years in this study) means that there will be a large share of failures. Additionally, by investigating the persistence of measures from 2015 (or even earlier), the study can likely use the Kaplan-Meier estimator and not be limited by the EUL being greater than the maximum elapsed time between implementation and the study. This limitation is why EUL studies typically use parametric survival analyses.

Field studies for retro-commissioning persistence typically determine persistence through reviewing measure trends or control logic in facilities' building automation system (BAS). This would be supplemented by functional testing of measures if the BAS data is not available. While this approach is the industry standard, other methods are available that can decrease fielding costs and potentially improve the rigor of the results. Table 11 lists different approaches available for a retro-commissioning field study. Unlike past studies, a persistence field study in Connecticut could utilize multiple modes, such as in-person site visits, virtual site visits with remote BAS access, and surveys to gather detailed persistence information.

Table 11: Potential Approaches for RCx Persistence Field Study

Method	Description	Advantages	Disadvantages	Cost Drivers	Data Quality	Cost	Customer Involvement
Enable data logging immediately and RSP/vendor collects data	Program BAS to trend and store data upon measure implementation. RSP/vendor downloads data later on and sends to evaluator	Ensures data collection from day 1	<ul style="list-style-type: none"> - Trending for some systems is limited - Requires additional time and cost to implement - Requires upfront agreement and coordination between RSP/vendor and evaluator 	<ul style="list-style-type: none"> - Age of BAS - Number of points (trends) required 	High	Medium	Medium
Facility staff downloads trend data periodically	Program BAS to trend and store data upon measure implementation. Facility staff downloads data and sends to evaluator	Ensures data collection from day 1	<ul style="list-style-type: none"> - Trending for some systems is limited - Requires additional time to implement - Requires upfront agreement and coordination between facility and evaluator 	<ul style="list-style-type: none"> - Age of BAS - Number of points (trends) required 	High	Low	High
Supplemental metering- long term	Evaluator installs data loggers in parallel with programming changes	<ul style="list-style-type: none"> - Independent of BAS and any system limitations - Can be installed separately 	<ul style="list-style-type: none"> - Meter, install cost - Another system/component to check - Data points may be limited 	<ul style="list-style-type: none"> - Type of meter installed (CT vs motor on/off) 	High	High	Low
Spot check data points (onsite)	Evaluator checks individual control points or measurements to verify persistence. Performed onsite.	- Fast	<ul style="list-style-type: none"> - No way to determine how long measure has been implemented 	<ul style="list-style-type: none"> - Number of points (trends) required 	Medium	Low	Low

Method	Description	Advantages	Disadvantages	Cost Drivers	Data Quality	Cost	Customer Involvement
			without data over time (trended)				
Spot check data points (remotely)	- Check individual control points or measurements to verify persistence. - Performed remotely by customer and reported back.	- No travel required - Relatively fast	- Requires customer to find and read out data	- Number of points (trends) required	Medium	Low	High
Facility staff interview	- Interview operators to ensure persistence	- Can be done onsite or remotely	- Requires customer time - No actual trend data collected	- Number of interviews	Low	Medium	Medium
Fault detection and diagnostics (FDD)	Using built-in software functionality	- Useful tool for building operators beyond ensuring measure persistence	- Requires compatible BAS or investment	- Age of BAS and compatibility with existing FDD platforms	High	High	Medium
Remote access	Log into customer BAS remotely and download trend data or observe operation	- Little to no customer involvement after initial setup	- May not be feasible or even allowed with some facility types (e.g., healthcare)	- Number of sites - Time spent coordinating with site contact	High	Medium	Low
Online survey	Survey of past and current participants about the persistence of measures. Can be sent quarterly for more accurate estimate of failure.	- Low cost - Regular survey will allow for more accurate estimate of timing of failure - Can be set up as part of participation process	- Survey may not be able to identify reduction in savings if not failure - May take several years to gather enough data for analysis - Regular contact may bias persistence	- Number of surveys - Incentives	Medium	Low	Medium

7 Conclusions and Recommendations

This section summarizes the conclusion and recommendations of this study based on the results presented above.

Conclusion 1: The EUL values in the 2022 PSD for RCx measures are based on dated studies that lack primary data. While the results from this study do not vary substantially from the values in the PSD, the sources used to develop our estimate are more recent and in better alignment with the program's measure mix.

Recommendation 1: Based on the information gathered through the literature review and market actor interviews, we recommend updating the EUL for AHU scheduling and optimization to 5 years and updating all other HVAC retro-commissioning measures to a single value of 7 years.

Recommendation 2: The Evaluation Team recommends continuing to use the existing EUL values in the 2022 PSD for refrigeration and process equipment retro-commissioning measures as these measures were not a focus of this study.

Conclusion 2: There are very few RCx persistence studies that incorporate primary data and none in the Northeast. The Evaluation Team provides the following the following guidance for future research.

Recommendation 3: To improve the measure life estimates used in Connecticut, the Evaluation Team recommends that the Connecticut EEB EA Team consider conducting a field study to measure the persistence of common RCx measures. The Evaluation Team recommends developing RCx EUL values for broad measure categories where there may be a distinction in persistence, such as measure related to scheduling and measures not related to scheduling, to maximize the precision of results. The Evaluation Team provides the following guidance for future RCx persistence studies:

- Field studies for retro-commissioning persistence typically determine persistence through reviewing measure trends or control logic in facilities' building automation system (BAS). This would be supplemented by functional testing of measures if the BAS data is not available. While this approach is the industry standard, other methods are available that can decrease fielding costs and potentially improve the rigor of the results. Unlike past studies, a persistence field study in Connecticut could utilize multiple modes, such as in-person site visits, virtual site visits with remote BAS access, and surveys to gather detailed persistence information and to better understand how facilities are using systems.
- Understanding that limitations in available budget and the small population of RCx projects in Connecticut, may restrict the ability to conduct such a study, the Evaluation Team suggests considering coordinating with other utilities or organizations in the Northeast to develop more robust regional estimates.
- When collecting persistence estimates from surveys or interviews in future studies, we recommend clearly defining persistence to match the study's definition to maintain consistency in responses. We also suggest providing examples of reasons why savings may not persist, such as changes in control settings and changes in building use.

Conclusion 3: Human factors, such as lack of training and turnover in building staff, drive the failure of most retro-commissioning measures. Hardware fixes and control changes that cannot be easily overwritten tend to persist longer. Persistence is typically higher in facilities that outsource some of their building operations to controls vendors due to their higher level of knowledge and documentation of the RCx measures.

Recommendation 4: To remedy persistence issues, programs may consider implementing or continuing a variety of best practices for participants and participating RSPs. This includes requiring RSPs to conduct follow-up visits to check for persistence issues, conduct post-RCx training with building operations staff, and encourage measures that are difficult to change or overwrite when there are multiple options with similar savings for a given opportunity.

8 Comparison to Other States

The Evaluation Team conducted a comprehensive review of technical reference manuals (TRMs), publicly available evaluations, and other relevant sources to document the measure life estimates for RCx measures in other states. Many of the reviewed sources (e.g., the New York Technical Resource Manual and Vermont Technical Reference Manual) do not list measure life estimates for retro-commissioning and therefore were not included in the table below. Note that while some TRMs list individual RCx measures, many include only a single measure for “all retro-commissioning.”

Table 12: Comparison of RCx Measure Life Values from Various States

State	Measures Included	EUL Value
California (DEER)	Retro-commissioning and operational programs in non-residential buildings	3
Colorado (Xcel)	All retro-commissioning	7
Illinois	All retro-commissioning	8.6
Maine	All retro-commissioning	5
Massachusetts	O&M/Retro-commissioning, HVAC	1-5
	O&M/Retro-commissioning, non-HVAC	1-5
Minnesota (Xcel)	All retro-commissioning	7
Oregon	Industrial O&M	7
Utah (Pacifcorp)	All retro-commissioning	7
Wisconsin	Economizer Optimization	4
	Schedule Optimization	4
	Outside Air Intake Control Optimization	4

Appendix A | Detailed Methodology

A.1.1 Definition of Persistence

Retro-commissioning involves both the installation of energy-saving equipment (e.g., occupancy sensors) and the adoption of energy-saving operational and control strategies. Because of this, determining the persistence of RCx measures requires a more nuanced approach than simple energy efficient equipment.

As described in the Uniform Methods Project, the persistence of a measure incorporates two concepts:

- **Measure life or effective useful life (EUL)** - Following industry standard practice, we define EUL as the median length of time (in years) that equipment is in operation. The EUL, therefore, represents the length of time in which we would expect half of all installed measures to be still operating and the other half to have been replaced due to equipment failure or for any other reason. The EUL incorporates both the technical equipment life (how long the equipment will operate before it fails) and the measure persistence (how long the equipment will remain in place before it is removed or replaced due to early retirement, failure, business/resident turnover, or other reasons).
- **Savings persistence** – The savings of an energy efficiency measure (including both equipment and behavior or control-based measures) can change over time due to changed hours of use or equipment operation as well as degradation in efficiency relative to the baseline.¹⁷

While retro-commissioning persistence studies vary in their definition of persistence and their methodology to estimate persistence, most focus on the measure life rather than the savings persistence. Determining measure persistence for capital measures is simple: if the equipment is still in place and operating as expected, then the measure persists. When considering measures that are controls or behavior-based, these measures may be modified to meet comfort requirements or other needs, which may negatively affect savings. For this study, the Evaluation Team follows the approach of studies such as Slipstream (2019) and Roberts (2010) which determine that a measure persists if its energy savings is estimated to be equal to or greater than 50% of the original savings calculated.¹⁸

Taken together, the Evaluation Team defines the persistence of retro-commissioning measures as the median length of time that equipment or control strategies are in place and operational,

¹⁷ There are few studies of degradation in efficiency relative to baseline and this may be an area for future research.

¹⁸ In some studies, such as Friedman (2011), the definition of persistence was less clear for measures that were modified from their commissioned condition. That study states that “even if the original [commissioned control strategy] was more energy efficient, if the modified [control strategy] still significantly improved energy efficiency compared to the pre-commissioning operation, then we defined the measure to persist. If the [control strategy] had been disabled or modified to decrease energy efficiency compared to the pre-commissioning operation, then the measure did not persist.” In this case, the choice of the term “still significantly improved” can be read to indicate savings equal to at least 50% of the original savings, but the exact threshold is not defined.

with operational meaning functioning as originally intended and with energy savings equal to or greater than 50% of the original savings.

A.1.2 Utility Data Review

As an initial task, the Evaluation Team analyzed the utility program tracking data from 2015 to 2020 to identify the most implemented RCx measures in recent years. The Connecticut utilities combined to provide incentives for 76 RCx projects during that period, with Eversource accounting for the large majority (71).

After an initial data review and discussions with the utilities, the Evaluation Team found that the utilities' tracking databases could only provide high level measure data for most projects, such as "CNI Custom Cooling" and "CNI Custom Heating." The granular measure-level information required for our analysis was not stored in a central location and needed to be requested from the participating RSPs.

To reduce the burden on the utilities and RSPs, the Evaluation Team drew a random sample of projects and requested the full documentation for each of the selected projects. The RSPs were able to provide project files for 25 of the 31 sampled projects.

Table 13: Retro-commissioning Projects Analyzed

Year	Total Projects	Reviewed
2015	22	5
2016	12	4
2017	10	2
2018	12	4
2019	14	6
2020	6	4
Total	76	25

Once the Evaluation Team received the project files from the RSPs, we grouped measures of similar intent into common categories for better comparison across time and with other sources. For example, we grouped the measure described as "Implement an optimal start program for RTUs 1 & 2" into the "Air Handling Unit Scheduling" category.

A.1.3 Utility Staff Interviews

The Evaluation Team conducted interviews with program staff from Eversource and Avangrid. The topics covered in these interviews included past program offerings and measures, expected changes to the program and measure mix, and other elements that factor into persistence, such as the program's customer mix, the level of customer training, participation in other programs, and business turnover. Finally, we discussed the availability of program tracking data.

A.1.4 Market Actor Interviews

Between April and August 2022, Michaels conducted in-depth interviews with market actors with knowledge of RCx measure persistence. We interviewed the two participating retro-commissioning service providers (RSPs) operating in Connecticut at the time of the study.¹⁹ Additionally, we interviewed seven HVAC equipment and controls vendors. Three of these vendors operated in Connecticut and had experience with the Energize CT Retro-commissioning program and the other four provided a national perspective. The Evaluation Team selected these vendors using a convenience sampling approach. The sample frame included vendors that had been involved in participating RCx projects in Connecticut as well as vendors participating in similar RCx programs in comparable jurisdictions familiar to the Evaluation Team.²⁰

Table 14 provides a summary of the interviewed market actors.

¹⁹ In 2020, Eversource added an additional 6 RSPs to their program, but their activity in the program was limited at the time of the interviews.

²⁰ Due to low response rates from local and regional vendors, the Evaluation Team expanded our sample frame into other regions that were as similar to Connecticut and New England as possible.

Table 14: Breakout of Market Actor Interviews

Number	Market Actor Type	Geographic Focus*	Services Provided	Segments Served
1	RSP	CT	- Commissioning - Retro-commissioning - Energy engineering	- Education - Healthcare
2	RSP	CT	- Commissioning - Retro-commissioning	- Commercial - High-rise multifamily
3	Vendor	CT and Western MA	- Building automation controls - HVAC equipment inspection - Design services - Energy performance contracting	- Large commercial - Education - Hospitals - Laboratories - Small commercial
4	Vendor	CT and Western MA	- HVAC controls inspections	- Education - Manufacturing - Commercial
5	Vendor	NY, PA, OH	- HVAC design	- Education - Commercial - Hospitality - Municipal
6	Vendor	IA	- Controls - Mechanical service	- Commercial - Institutional - Manufacturing/industrial
7	Vendor	WI and MN	- Controls - Mechanical service - HVAC design	- Commercial - Industrial
8	Vendor	Midwest and Southwest US	- Energy engineering - HVAC controls	- Commercial - High-rise multifamily - Municipal - Education - Pharmaceutical - Industrial
9	Vendor	New England	- Process controls - HVAC design	- Industrial - Education - Healthcare

* Geographic focus indicates the territory of the respondent; in many cases, this only represented a subset of the firm's total territory.

These interviews explored market actors' in-field observations about the persistence of savings of the RCx measures, focusing on the measures targeted in this study. The interviews also investigated the reasons for failure and how best to increase measure and savings persistence, customer training, and the effect on COVID on their practices and their customers' uptake and

continuation of RCx measures. We provided an incentive of \$50 gift card to interviewees in appreciation of their time.

A.1.5 Literature Review

The Evaluation Team conducted a review of past RCx persistence research in the United States and Canada. By conducting a literature review, we sought to answer the following research questions:

- What is the best estimate of life for the RCx measures targeted in this study?
- Will the mix of RCx measures change in the next 5 years and, if so, how?
- What are the common reasons for the failure of RCx measures?
- How can persistence issues be remedied?
- What are the measurements and approaches needed for a field study?

The Evaluation Team's review prioritized recent research on RCx programs in the Northeast and with measures most similar to those targeted in this study. However, given the limited number of relevant studies, our scope broadened to include all of North America. Additionally, while the primary focus of our research was the persistence of RCx measures, the Evaluation Team also reviewed tangentially related studies to help answer the other research questions. For example, studies focusing on residential behavioral programs could provide insight into recommendations for increasing the persistence of behavioral measures.

In total, the Evaluation Team reviewed 43 sources in detail, collected from the following categories:

- RCx persistence studies
- Utility program evaluation-related materials (e.g., program evaluations, technical reference manuals, potential studies, stakeholder advisory group/technical advisory committee materials).
- Papers and conference proceedings (e.g., IEPEC, ACEEE Summer Study, and the National Conference on Building Commissioning)
- Studies and materials regional energy efficiency associations, (e.g., NEEP, NEEA, and MEEA)
- Materials from national laboratories (e.g., the Uniform Methods Project)

Appendix B | Measure Category Savings from Sampled Projects

The table below shows the savings by measure category for the 25 sampled projects from 2015 to 2020. The measure categories selected for this study are bolded. Note that projects with multiple measure categories listed together (e.g., AHU Scheduling/Economizers) were treated as unique measure categories. The Evaluation Team did not group these with their component measures because it was impossible to break out the savings into their components (e.g., AHU Scheduling and Economizers).

Table 15: Selected Measures' Share of Savings from Sampled Projects (2015-2020)

RCx Measure Category	kWh Savings	Summer kW Savings	Winter kW Savings	Natural Gas Savings (CCF)
AHU Scheduling and Optimization	3,090,544	682.7	117.8	138,123
CAV to VAV AHU Conversion	1,793,064	172.7	157.7	7,439
HVAC Occupancy Sensors	1,203,063	165.5	51.2	30,510
ChW Controls	961,754	58.8	70.3	1,632
Exhaust Fan Control	398,517	59.3	45.9	21,048
Lab Unoccupied AHU Control	349,103	12.6	17.5	17,157
HW Pumping Optimization	156,619	1.1	6.0	9,407
VAV Setpoint Adjustments	142,792	--	--	8,172
DAP Reset/Economizer	120,215	15.2	-	2,373
DCV/AHU Scheduling	96,348	73.5	11.8	4,448
Economizer	88,465	(13.1)	-	(506)
Demand Control Ventilation (DCV)	86,177	-	-	5,195
DCV/Occupancy Sensors	62,270	84.1	22.5	4,781
AHU Scheduling/Economizer	59,276	12.9	4.1	377
AHU Scheduling/Occupancy Sensors	50,814	13.2	9.4	161
CV to VV Pumping Conversion	35,856	-	-	-
HW Pumping Optimization/ ChW Controls	34,045	2.5	3.5	-
Boiler Controls	16,521	-	2.0	5,026
Cooling Tower Fan Control	14,550	-	-	(114)
Boiler Controls/ChW Control	10,785	2.0	-	5,619
Economizer/DCV	3,691			
HW Temp Reset	-	-	-	1,747
Total	8,774,469	1,354.7	519.7	264,337

Appendix C | Recommended Updates to 2022 PSD Values

The following table lists the effective useful life values of retro-commissioning measures in the 2022 Program Savings Document (PSD) and the recommended value from this study. In addition to HVAC controls, the PSD also lists lifetime values for lighting, refrigeration, and process equipment retro-commissioning measures. The Evaluation Team's review of these measures was very limited and therefore we recommend continuing to use the EUL values in the PSD for lighting, refrigeration, and process equipment retro-commissioning measures.

Table 16: Recommended Updated EUL Values for PSD

2022 PSD Measure Description	Value from 2022 PSD	Recommended Value
Lighting Systems		
Reprogramming of EMS controls	8	7
HVAC Controls		
Adjust scheduling	6	5
Controls to eliminate simultaneous heating and cooling	8	5
Demand control ventilation – single zone	8	7
EMS/linked HVAC controls	8	7
Modify HVAC controls	8	7
Reprogramming of EMS controls	8	7
Reset set-points	6	5
Refrigeration		
Adjust scheduling	8	8
Refrigeration control	10	10
Process Equipment		
Add regulator valves in compressed air system	10	10
Install compressed air compressor no-loss condenser drain	10	10
Interlock air system solenoid valves with machine operation	10	10
Interlock exhaust fans with machine operations	10	10

Appendix D | References

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Appendix E | Data Collection Instruments

Retro-commissioning Service Provider (RSP) Interview Guide

Thank you for taking the time to talk today. Michaels Energy has been contracted by the Connecticut utilities and the Connecticut Energy Efficiency Board to study how long savings from retro-commissioning measures last.

As part of this study, we are speaking to participating RCx service providers to understand the most common types of RCx measures they recommend and implement, the persistence of those measures, and how they help to ensure that savings last.

Do you have time to speak now? My questions should only take about 15-20 minutes.

Please note that although we will be discussing the specifics of your firm and projects, all information will be aggregated and anonymized prior to reporting.

In appreciation of your time, we can offer you a gift card of \$50.

Researchable Questions

1. What are the most common RCx measures installed?
2. Will the mix of RCx measures change in the next 5 years?
3. What is the best estimate of life for RCx measures expected to be installed during the next 5 years?
4. What are common reasons for the failure of RCx measures and recommendations on how to remedy persistence issues?
5. How has/might COVID affect programs and RCx strategies?

Introduction

1. What additional services relevant to RCx does your firm provide (e.g., controls, mechanical services, HVAC design)?
2. What markets or building types does your firm focus on?
3. In what geographic areas does your firm operate?
 - a. In what areas of CT?
 - b. In what areas outside of CT?
4. What is your role at the firm?
5. Can you describe your experience with the EnergizeCT Retro-Commissioning program?

- a. When did you first start working with the program?
- b. What share of your overall CT RCx projects go through the program?
 - i. (If not 100%) Why do some projects go through the program and not others?

RCx Process

6. Can you describe your firm's general process for identifying and prioritizing RCx measures?
7. Are there any measures that you do not propose to customers due to concerns about general measure persistence or risk around ROI due to measure persistence concerns?
8. Do you provide any kind of implementation support during or after the study?
9. How do you verify that measures have been implemented correctly?
10. Do you provide any customer training on RCx recommendations you make?

RCx Projects

11. What are the most common RCx measures you recommend?
 - a. What are the most common RCx measures that are typically implemented?
 - b. Does this differ by the major building types you serve? If yes, how so?
 - c. Do the RCx projects that go through the program differ at all from those that do not go through the program? If so, how do they differ? [Probe for differences in customer types, size of projects, measures, etc.]
12. Looking ahead, do you think the most common RCx measures you recommend and implement will change over the next five years?
 - a. If yes, what will be the most common measures in five years?
 - b. What, if any, currently common measures will become less common over the next five years?
 - c. What is driving the change in measure mix?

Measure Life

13. I'm going to list several measure types, and for each, please describe:
 - a. What is your best estimate for how long that measure will remain installed and functioning?
 - b. What are common reasons for the failure of the RCx measure and recommendations on how to remedy persistence issues?

Measure	Estimate of Measure Life	Common Reasons for Failure or Decrease in Savings
CAV to VAV AHU Conversion		
AHU Scheduling and Optimization		
Occupancy Sensors		
ChW Controls		
Exhaust Fan Controls		
Measure Identified by Interviewee 1		
Measure Identified by Interviewee 2		
Measure Identified by Interviewee 3		

14. Generally speaking, what, if any, are the ways to remedy persistence issues for these RCx measures?
- Do you communicate these recommendations to your customers? If so, how do you communicate these recommendations?
 - Do you find that measures have lower persistence where the owner has concerns or hesitancy towards implementing the measure but ultimately does implement it?

COVID Baseline Issues

15. Has COVID changed how you identify or implement RCx measures? If so, how?
16. To your knowledge, has COVID impacted the persistence of RCx measures installed over the last 5 years?
17. Do you have any challenges calculating savings and convincing customers of measure ROI as a result of COVID?
- If so, what challenges have you faced?
 - How do you help your customers overcome these challenges?

Wrapping Up

18. Thank you for your time today. Do you have any else to add that may help us better understand the savings persistence of RCx projects?

Thank you!

Controls Vendor Interview Guide

Thank you for taking the time to talk today. Michaels Energy has been contracted by the Connecticut utilities and the Connecticut Energy Efficiency Board to study how long savings from retro-commissioning measures last.

As part of this study, we are speaking to participating RCx service providers and Controls Contractors to understand the most common types of RCx measures identified and installed, how long those measures stay installed and operating correctly, and how to help to ensure that savings last.

Do you have time to speak now? My questions should only take about 15-20 minutes.

Please note that although we will be discussing the specifics of your firm and projects, all information will be aggregated and anonymized prior to reporting.

In appreciation of your time, we can offer you a gift card of \$50.

Researchable Questions

6. What are the most common RCx measures installed?
7. Will the mix of RCx measures change in the next 5 years?
8. What is the best estimate of life for RCx measures expected to be installed during the next 5 years?
9. What are common reasons for the failure of RCx measures and recommendations on how to remedy persistence issues?
10. How has/might COVID affect programs and RCx strategies?

Introduction

19. What additional products or services relevant to RCx does your firm provide (e.g., controls, mechanical services, HVAC design)?
20. What markets or building types does your firm focus on?
21. In what geographic areas does your firm operate?
 - a. In what areas of CT?
 - b. In what areas outside of CT?
22. What is your role at the firm?
23. Can you describe your experience, if any, with the EnergizeCT Retro-Commissioning program? [Skip follow-ups if no experience]
 - a. When was your first experience with the program?
 - b. How often do you typically interact with the program?

24. Are there any new technologies or processes you're aware of that may impact how RCx measures are installed or maintained?
25. Do you see differences in how RCx measures may be specified, installed, or maintained that would affect how long the measures will continue to operate at or above efficiency levels originally intended?
 - a. What are things done in the market which you perceive as helping measures continue to operate at a high level?
 - b. What are things done in the market which you perceive as hindering measures from continuing to operate as originally intended?
26. Regardless of whether you've seen them in the market, are there any procedures or practices that you believe would improve RCx measures persistence if broadly adopted by the market?

RCx Projects

27. What are the most common RCx measures you see recommended?
 - a. What are the most common RCx measures that are typically implemented?
 - b. Does this differ by the major building types you serve? If yes, how so?
 - c. Do the RCx projects that go through EnergizeCT's RCx program differ at all from those that do not go through the program? If so, how do they differ? [Probe for differences in customer types, size of projects, measures, etc.]
28. Looking ahead, do you think the most common RCx measures in the market will change over the next five years?
 - a. If yes, what will be the most common measures in five years?
 - b. What, if any, currently common measures will become less common over the next five years?
 - c. What is driving the change in measure mix?

Measure Life

29. I'm going to list several measure types, and for each, please describe:
 - a. What is your best estimate for how long that measure will remain installed and functioning?
 - b. What are common reasons for the failure of the RCx measure and recommendations on how to remedy persistence issues?

Measure	Estimate of Measure Life	Common Reasons for Failure or Decrease in Savings
CAV to VAV AHU Conversion		

Measure	Estimate of Measure Life	Common Reasons for Failure or Decrease in Savings
AHU Scheduling and Optimization		
Occupancy Sensors		
ChW Controls		
Exhaust Fan Controls		
Measure 1 Identified by Interviewee		
Measure 2 Identified by Interviewee		
Measure 3 Identified by Interviewee		

30. Generally speaking, what, if any, are the ways to remedy persistence issues for these RCx measures?
- Do you communicate these recommendations to your customers? If so, how do you communicate these recommendations?
 - Where the owner has concerns or hesitancy towards implementing the measure before implementing those measures, do you find that the savings last longer, shorter, or a similar amount of time than recommendations that are fully embraced?

COVID Baseline Issues

- Has COVID changed how the market identifies, installs, or maintains RCx measures? If so, how?
- To your knowledge, has COVID impacted the persistence of RCx measures installed over the last 5 years?
- Do you have any challenges calculating savings and convincing customers of measure ROI as a result of COVID?
 - If so, what challenges have you faced?
 - How do you help your customers overcome these challenges?

Wrapping Up

- Thank you for your time today. Do you have any else to add that may help us better understand the savings persistence of RCx projects?

Thank you!