Assessment of Persistence of Energy Savings under Wisconsin's Home Energy Plus Weatherization Program

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1.0 EXECUTIVE SUMMARY

This report analyzes the persistence of energy savings from the Wisconsin Weatherization Assistance Program (WAP), Home Energy Plus. Persistence is defined as the extent to which normalized annual energy consumption (NAC) savings are maintained over time. This report answers the question: does NAC stabilize at a new lower level following weatherization and for how long?

The Home Energy Plus (HE+) program provides weatherization services through 19 agencies across the state and serves households with a household income of 60 percent or less than the state's median income for a similar-size household. The Wisconsin weatherization program data management and reporting system has data in internally consistent systems extending back into the early 2000's, making this historical analysis possible.

The main objectives of the study are to understand the following questions:

- Can program-level gas and electricity savings be detected years after weatherization was completed?
- How persistent are the energy savings among different housing types? (e.g. manufactured homes, single family, and 2-4 unit multifamily)

METHOD

The analysis utilized 13 years of weatherization records from the Wisconsin Weatherization Assistance Program (WisWAP) and HE+ System databases as well as monthly utility billing data from six utilities in Wisconsin. The service territory of these utilities covers nearly the entire state of Wisconsin and the billing data spans from 2006 to 2018.

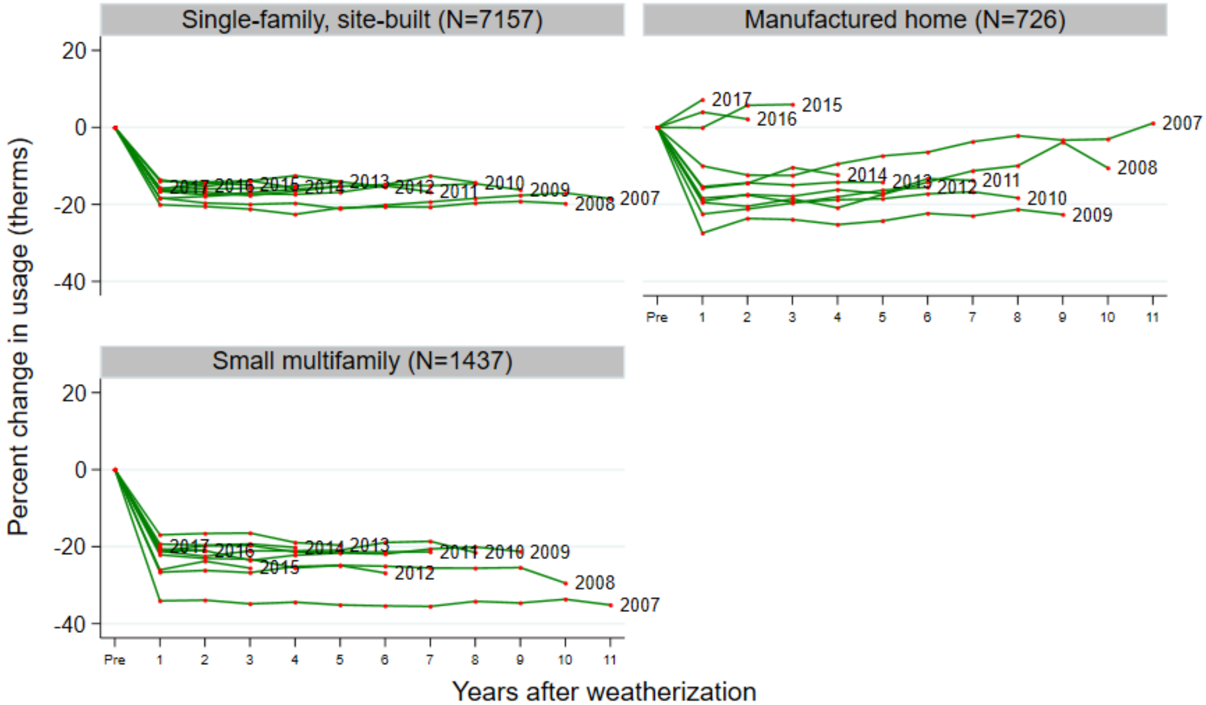
The analytic data set included only homes that had billing data for the entire 13-year billing history in order to avoid an unbalanced final data set. We weather normalized the billing data to develop NAC for each year in the study. Using that data, we calculated year-on-year changes in NAC to provide the general story of savings persistence. To address outlier influence and year effects, we used several regression modeling procedures, which are described in Appendix 6.0. Overall, we found the more in-depth modeling supported our less complicated assertions about savings persistence using NAC trends.

GAS SAVINGS

Estimates of natural gas consumption throughout the study period show that weatherization savings persist through time. Figure 1 illustrates this, showing the percent change in usage for each year post weatherization separated by housing type.

Single-family, site-built homes and small multifamily buildings show stable savings across the study period. However, manufactured homes show much more variation across weatherization-year cohorts. Manufactured homes weatherized in 2015 or later actually show a small but distinct increase in gas consumption following weatherization. This is a result of the change in program approach for gas-heated manufactured homes during that time period. Program years before the policy shift show relatively stable use across time.

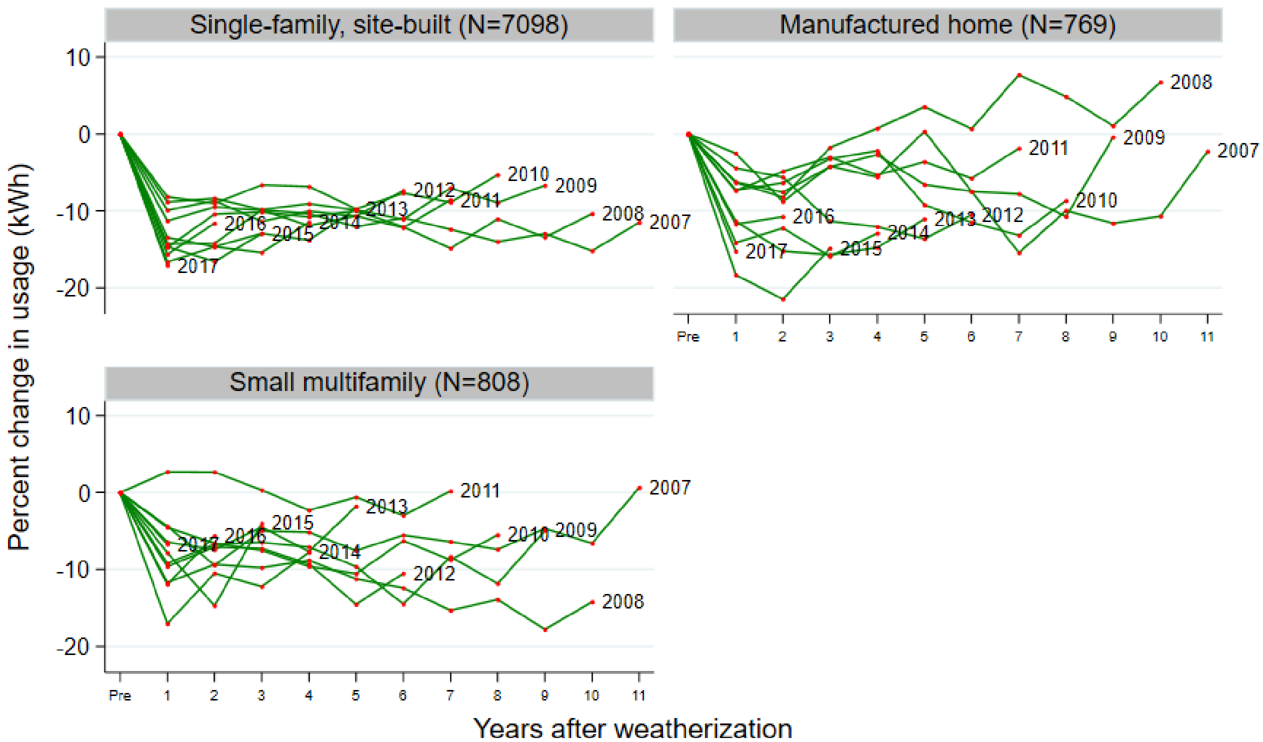
Figure 1. Percent change in mean NAC relative to pre-weatherization consumption by housing type and number of years after weatherization.



ELECTRIC SAVINGS

Electric savings are more ambiguous in terms of persistence across time compared to gas. Figure 2 examines the trend in percent electricity savings for the three housing types. For single-family homes, the overall trend for percent electricity savings shows a small erosion in savings over time. For example, project year 2007 changes from 14 percent savings in year 1 after weatherization to about 11 percent saving savings in year 11 after weatherization. Small-multifamily homes and manufactured homes exhibit a more variable pattern, with savings eroding somewhat over time for each project year. Overall, much of the increased volatility seen in small multifamily and manufactured homes is reflected in fewer homes weatherized.

Figure 2. Percent change in electricity usage compared to pre-weatherization



2.0 INTRODUCTION

This report examines the persistence of energy savings from Wisconsin's low-income Weatherization Assistance Program (WAP), Home Energy Plus. We define persistence of energy savings as the extent to which a decline in normalized annual energy consumption (NAC) in the year immediately following weatherization is maintained at the program level over time. This investigation of persistence seeks to answer the question: Does a reduction in NAC from weatherization stabilize at this new lower level and for how long?

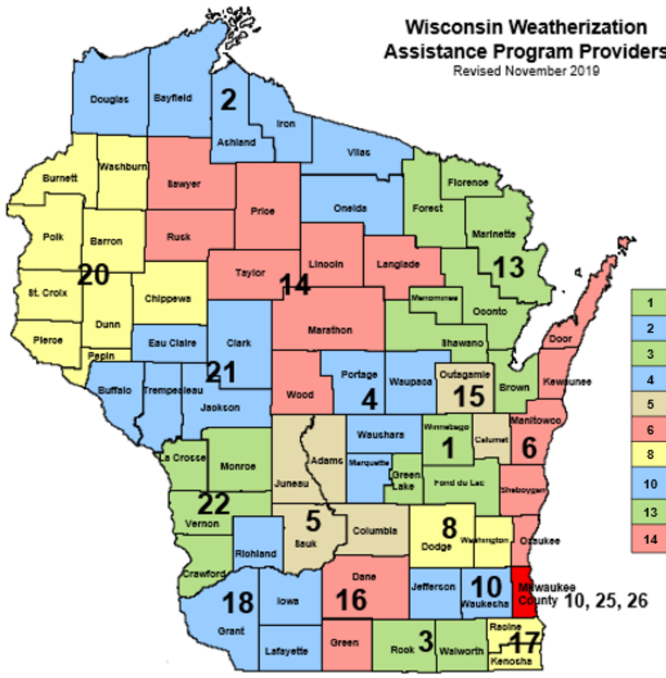
The results of the analysis demonstrate that natural gas savings are particularly stable year after year while electric savings are more variable in the years after weatherization and show some evidence of erosion. Single-family homes show the most stability across weatherization cohorts for both natural gas and electricity.

BACKGROUND

Examining the persistence of savings is important to understanding the benefits of energy efficiency and estimating the cost-effectiveness of upgrades. Most weatherization evaluations calculate first-year savings for a program and use assumed measure lifetimes to estimate lifetime energy savings as well as expected cost effectiveness of the upgrade. This assumption has direct implications for investment decisions regarding energy efficiency and weatherization.

This analysis is possible because Wisconsin's weatherization program, Home Energy Plus (HE+), has been evaluated annually since 2009 and has gathered extensive data in a consistent manner since the early 2000's. The program provides weatherization services through 19 agencies and 20 service areas across the state and is available to households meeting program eligibility requirements. This is defined as a household income of 60 percent or less than the state's median income for a similar-size household. The program targets homes with a high energy burden as well as those with elderly, very young, or disabled occupants. The main objectives of the HE+ program are to (1) reduce home energy bills, (2) save energy, and (3) make homes warmer in the winter and cooler in the summer.

The map below illustrates the geographic coverage of Wisconsin's weatherization service providers.



Weatherization Providers

1	ADVOCAP	15	Outagamie CHA
2	Ashland County Housing Authority	16	Project Home, Inc.
3	Community Action of Rock/Walworth	17	Racine/Kenosha CAA
4	CAP Services, Inc.	18	Southwestern Wisconsin CAP
5	Central Wisconsin CAC	20	West Central Wisconsin CAP
6	Partners for Community Development	21	Western Dairyland
8	Hartford CDA	22	Couleecap, Inc.
10	La Casa de Esperanza	25	Social Development Commission
13	Newcap, Inc.	26	Partners for Community Development
14	North Central CAP, Inc.		

To date, relatively few programs have been evaluated for persistence using utility billing data.[1] The persistence studies that have been conducted include measuring persistence from on-site analysis of equipment, technical studies based on laboratory testing, and billing analyses done with limited years of data.[2] In Wisconsin, the persistence of savings for up to eight years was evaluated in 1993 for participants in utility low-income weatherization programs.[3]

STUDY OBJECTIVES

This study takes advantage of the fact that the Wisconsin program maintains a detailed database of participants and regularly assesses actual energy savings based on obtaining and analyzing utility consumption histories. With some additional work to update consumption histories for prior participants, a relatively large sample size is available to examine overall persistence of savings for participants dating back to 2006.

The main objectives of this study are to understand the following questions:

(1) Can program-level gas and electricity savings be detected years after weatherization was completed?
(2) How persistent are the energy savings among different housing types? (e.g. manufactured homes, single family, and 2-4 unit multifamily)

[1] Vine, Edward. *Persistence of Energy Savings: What Do We Know and how Can It Be Ensured?* Berkeley, CA: Lawrence Berkeley National Laboratory, 1992. Accessed 4/5/2020. https://www.osti.gov/servlets/purl/10180664

[2] Violette, Dan. *Chapter 13: Assessing Persistence and Other Evaluation issues Cross-Cutting Protocols.* Golden, CO: national Renewable Energy Laboratory. 2013. Accessed 5/22/2020. https://www.energy.gov/sites/prod/files/2013/11/f5/53827-13.pdf

[3] Narum, David. Scott Pigg, Jeff Schlegel *Looking Past the First Year: Do the Savings Last? A Study of the Persistence of Energy Savings in Low-Income Wisconsin Residences.* Madison, WI: Wisconsin Energy Conservation Corporation, 1992. Accessed 4/4/2020. https://www.osti.gov/servlets/purl/7084606

The rest of this paper details the methodology for this study, the results for gas and electricity savings, and general implications of the results. Section 3.0 details the methods for this analysis, explaining in more depth the data used and how we estimated changes in energy consumption after weatherization to analyze persistence. Section 4.0 describes the results of our analysis. That section details the overall program impacts for gas and electricity as well as the impact on different housing types. It also explores how the program has changed over the last 12 years by exploring trends in first-year savings as well as the mix of measures installed. A detailed description of the modeling procedure and investigation into important measures accompanies this section in Appendix 6.0. Lastly, Section 5.0 concludes by providing an overview of the results.

3.0 METHODS

We define persistence at the program-level and as the examination of whether the savings achieved in the year following weatherization are maintained over time. This section describes our data set as well as the analysis methodology.

DATA PREPARATION AND ANALYSIS METHODS

This analysis utilized 13 years of weatherization records from the Wisconsin Weatherization Assistance Program (WisWAP) and HE+ System databases as well as monthly utility billing data from six utilities in the state of Wisconsin. Regular evaluations of first-year savings require participant billing data for a few years before and after weatherization. Because this year's evaluation included a persistence investigation in addition to the first-year savings analysis, we requested billing data for individual buildings as far back as utilities were able to provide. Alliant Energy, Madison Gas & Electric, We Energies, Wisconsin Public Service, and Xcel Energy all provided electric and gas data while WPPI Energy provided electric data only.

The service territories of the six utilities covers nearly the entire state of Wisconsin and the billing data spans from 2006 to 2018. We included all buildings with complete billing histories including those where changes in occupancy occurred. However, not all utilities provided data all the way back to 2006. This created a dataset that varied in completeness for individual buildings, so we removed jobs that did not have the entire 13-year history. Although this requirement decreases the total number of data points – and thus the statistical power of the results – it avoids using a less balanced set of data. This is important as having more (or less) data for some geographies across time could affect the results of this analysis as it relies on older data for later persistence and newer data for earlier persistence. During this stage, we also removed buildings with a treatment period longer than one year.

After all the data preparation steps, our data set included about 8,000 units heated with natural gas and about 8,700 units with electricity usage, with single-family homes making up over 80 percent of all units. It represents around 25 percent of all the units in the original data set, with the main impact on the number of units being the requirement that each unit had the entire 13-year history of billing data available. This data set provides a sufficient sample to analyze the impacts of persistence, however it is skewed towards service territories in which utilities were able to provide the full 13-year history for the majority of their buildings. For both gas and electric, this translates to homes treated by Newcap and Project Home being more heavily represented in this data set compared to the full sample of homes weatherized. The data is skewed towards these agencies and away from agencies serving Milwaukee and the western edge of the state. This corresponds with most of the billing data covering the 13-year history coming from Madison Gas & Electric and Wisconsin Public Service utility territories.

We then combined the billing data with information from the WisWAP and HE+ System databases to determine when weatherization occurred for each home and to categorize homes by housing type. We analyzed the consumption data by calendar year, grouped homes according to the year in which they were weatherized and then defined years relative to weatherization accordingly. Table 1 shows the basic data structure laid out by weatherization cohort and calendar year. For instance, all weatherization that occurred in calendar year 2007 includes a single year of pre- and 11 years of post-weatherization billing data. Note that for jobs that occurred early in the program, we are able to examine persistence of savings over a much longer time period.

Table 1. Basic data structure of analytic data set

Wx Cohort	Calendar Year												
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2007	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4	Post 5	Post 6	Post 7	Post 8	Post 9	Post 10	Post 11
2008	*Pre*	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4	Post 5	Post 6	Post 7	Post 8	Post 9	Post 10
2009	*Pre*	*Pre*	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4	Post 5	Post 6	Post 7	Post 8	Post 9
2010	*Pre*	*Pre*	*Pre*	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4	Post 5	Post 6	Post 7	Post 8
2011	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4	Post 5	Post 6	Post 7
2012	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4	Post 5	Post 6
2013	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4	Post 5
2014	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	**Wx**	Post 1	Post 2	Post 3	Post 4
2015	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	Pre	**Wx**	Post 1	Post 2	Post 3
2016	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	**Wx**	Post 1	Post 2
2017	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	*Pre*	**Wx**	Post 1

Wx = Weatherization; Pre = Pre weatherization; Post *x* = *x* years after weatherization

We then weather normalized the data at a unit-level to account for the influence of year-to-year weather variation on household energy use. The models disaggregate the energy use each calendar year into space heating, cooling (on the electric side) and non-space-conditioning components, and then adjust heating and cooling use to long-term average weather. Fitting the models to individual households versus the entire group of treated homes captures the unique energy-temperature relationship of each home and allows for a more accurate adjustment of observed energy use to long-term average weather conditions.

We analyzed the data by examining the time trend in average consumption for each weatherization year cohort, both in terms of calendar year and by years before and after the year of weatherization. We also calculated the percentage change for each post-weatherization year compared to the average pre-weatherization annual usage. Both methods provided a general view of how consumption patterns changed over the period from 2006 to 2018 for each weatherization cohort. This approach tells a basic story of the effect of weatherization on the population of weatherized buildings in the program over the study period.

Appendix 6.0 details the more complex regression modeling approaches we attempted in order to tease out persistence effects across cohorts. The models help control for non-weatherization influences and for the influence of extreme values of NAC. We found that the results can be sensitive to the fitting procedure, so we provide comparative results for four model-fitting procedures. In general, we found these approaches strengthened the more conceptually simple approach described above.

4.0 RESULTS

4.1 NATURAL GAS RESULTS

Estimates of natural gas consumption throughout the study period show that weatherization savings persist through time. Figure 3 shows NAC values over time for each weatherization-year cohort (with building types combined here). Each pane shows the average NAC over time for each weatherization-year cohort, with the red triangle marking the year weatherization occurred. Weatherization has an obvious and significant impact on annual gas consumption, with much smaller changes before and after weatherization, and no sign of significant erosion of savings for up to 11 years after weatherization. This view of persistence provides a portrait of the continuity of the program effect, suggesting that overall natural gas savings persist over the analysis' time period.

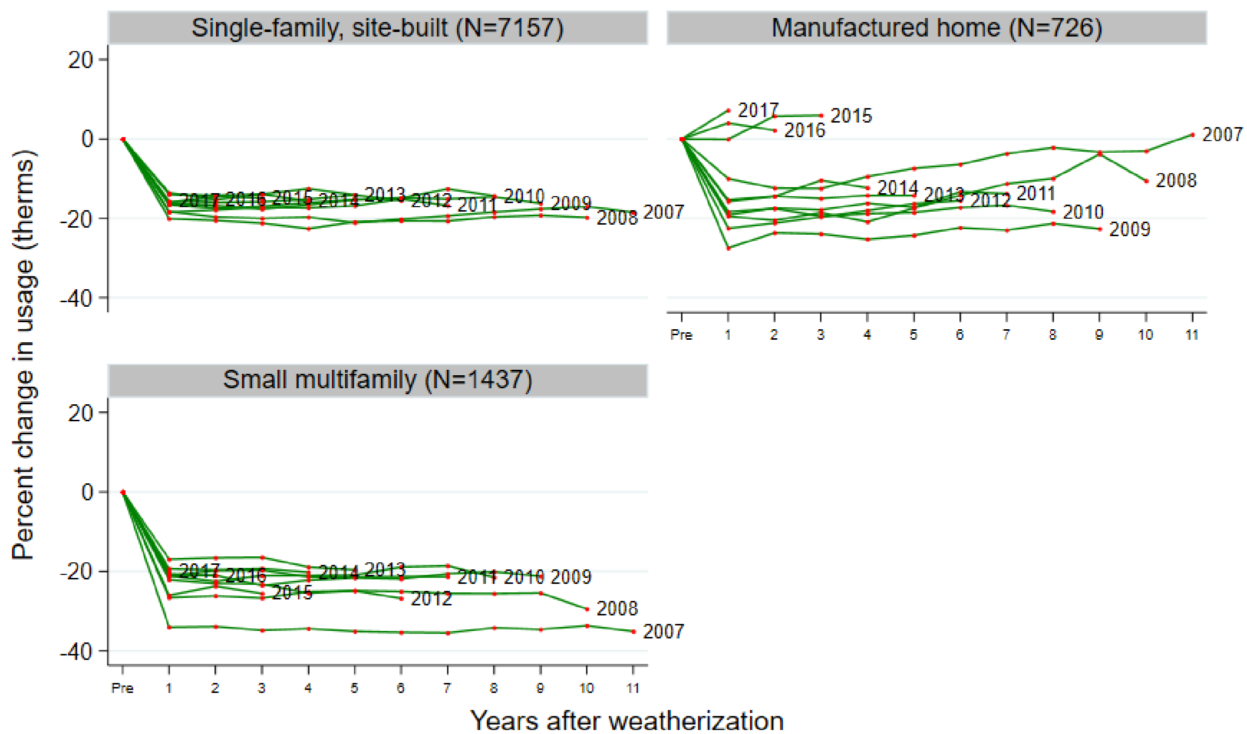
Figure 3. Normalized annual gas consumption (therms) by calendar year and year weatherized.

When plotted as a percent change relative to years since weatherization and separated by housing type, a slightly more nuanced picture emerges. Figure 4 illustrates this pattern, excluding 2006 as we do not have pre-weatherization data for the project year and 2018 as we do not have a full year of post-weatherization data for that year.

Single-family, site-built homes—which make up the bulk of the cases—show consistent and stable savings over time. Small multifamily buildings show a similar pattern, though with more variation in average savings across weatherization-year cohorts, perhaps due to the smaller number of cases in each cohort.

On the other hand, manufactured homes show much more variation across weatherization-year cohorts. Manufactured homes weatherized in 2015 or later actually show a small but distinct increase in gas consumption following weatherization. This is a result of the change in the program approach for gas-heated manufactured homes during that time period. Starting in 2015, the program switched from a computer-audit-driven approach that targeted major measures such as duct sealing and belly insulation to a prescribed measures-list that only called for minor gas measures—but that also allowed for fuel switching electric water heaters to natural gas. For the most part, homes weatherized prior to this program policy change show persistence of savings in the years following weatherization, with the 2007 cohort (of only *312* homes) standing as something of an outlier case.

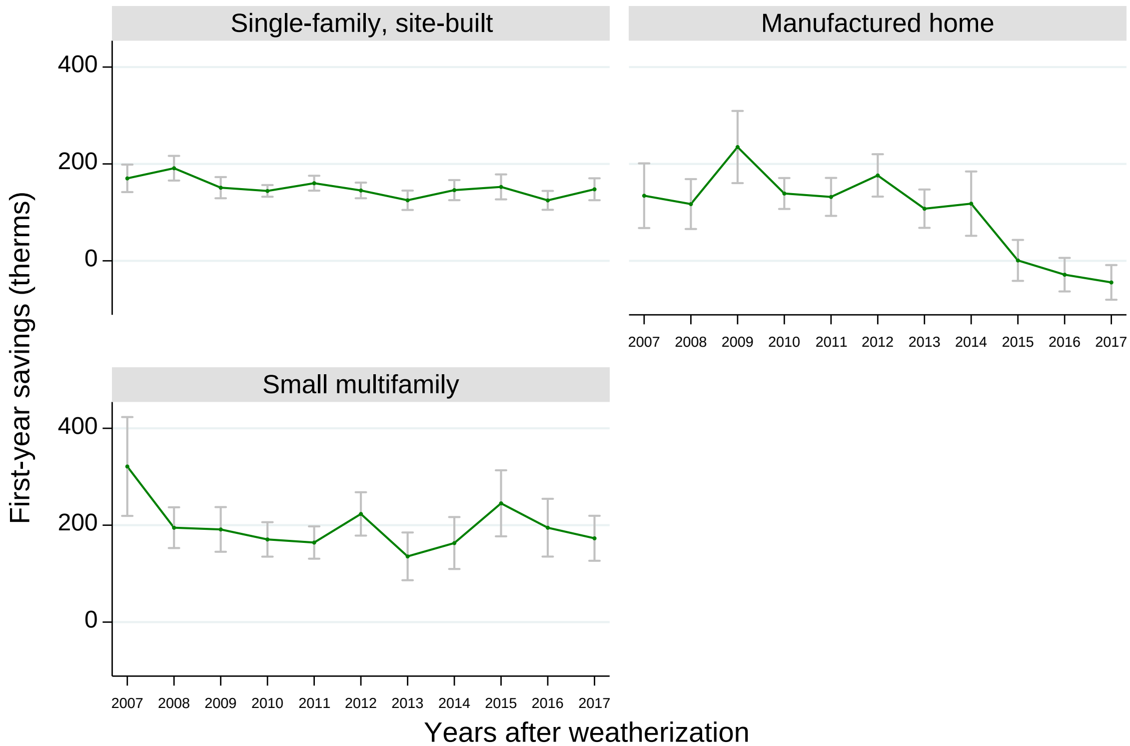
Figure 4. Percent change in mean NAC relative to pre-weatherization consumption by housing type and number of years after weatherization.



Figures 3 and 4 provide a story of the persistence of gas savings following program participation. To further flesh out the picture, we also examined how first-year savings, the mix of installed gas measures and their expected lifetimes has varied over time for the program.

Figure 5 illustrates the first-year natural gas savings across weatherization groups for each housing type with savings point estimates in green and 95 percent confidence intervals in gray. First-year average savings for single-family homes stay relatively stable across time, showing a small decrease in total therm savings from 2007 to 2016. Small-multifamily buildings show a similar pattern with early years achieving slightly larger savings than more recent years. Manufactured homes show a distinct drop in savings due to the policy shift in 2015. These patterns across the years mirror what Figure 4 shows in terms of weatherization cohorts achieving similar percent savings compared to the pre-weatherization period.

Figure 5. First-year natural gas savings by weatherization group



In addition to first-year savings trends across the program history, we also examined the trends in proportion of measures installed by both measure category and measure lifetime. Exploring trends in measure category incidence provides background on potential program shifts throughout the years while trends in measure lifetime incidence confirms that the savings results match expected savings based on assumed lifetimes.

Figure 6 illustrates the measure installation incidence broken out for four measure categories across the weatherization cohorts: water heating measures, shell measures, heating measures, and other measures. Appendix 7.0 provides details on what is included in each measure class and Appendix 6.0 provide savings results for individual measures.

Single-family and 2-4-unit buildings show similar patterns in measure incidence across the study period. Most notably, water heating measures have decreased across time while heating measures have increased across time in measure incidence. Shell measures show a slight increase in the early 2010’s but have since decreased in incidence back down to around 2006 levels. Similarly, the incidence of other measures decreased in the middle of the analysis period but have since increased back to 2006 levels. These changes in measure incidence seem to have a small impact on total savings as we see savings stay relatively stable over time.

Manufactured homes, on the other hand, have seen a sharp decline in shell measure and heating measure incidence while water heating and other measure incidence increased recently. The change in measure incidence coincides with the policy shift in 2015 and explains the recent decline in natural gas savings.

Figure 7 examines the incidence of measures broken out by measure lifetime. Looking at the expected lifetime of the measures offers insight into whether the savings patterns displayed in Figures 3 and 4 match expectations based on assumed lifetime. For detailed information on the corresponding lifetimes of measures, see Appendix 7.0.

The incidence of 2-year measure lifetimes is less than five percent for all years, meaning that most energy savings would be expected to persist for at least 10 years. At 10 years, we would expect to start to see energy consumption increase again as over 50 percent of measures have a lifetime of 10 years. As our study period is about 10 years, this generally matches what we see in the energy consumption graphs – with cohorts maintaining savings through at least 10 years.

Figure 6. Gas measure incidence across program

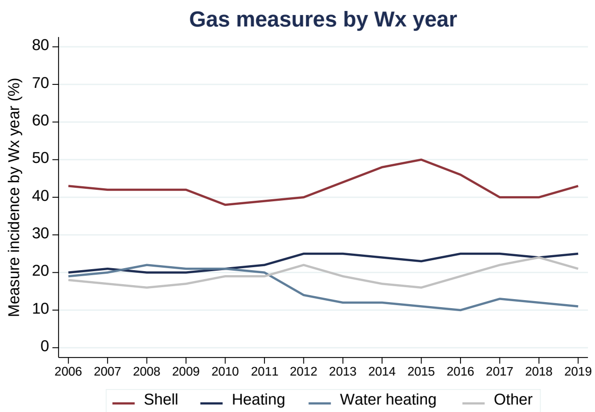
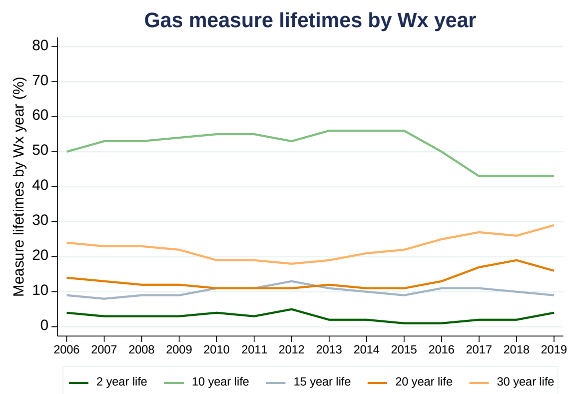


Figure 7. Gas measure lifetimes across program



Breaking out incidence by housing type identifies underlying differences not seen in the program as a whole. Figures 8 and 9 illustrate measure group incidence and measure lifetime incidence for each of the three housing types.

Figure 8 shows that single-family, site-built homes show no large-scale changes across the study period aside from about a 5 percent decline in the incidence of water-heating measures. Small multifamily residences experienced a similar decline. Manufactured homes mirror the noted policy shift starting in 2015 where the incidence of water heating and other measures increase sharply while heating and shell measures decline.

Figure 9 shows that measures lifetimes are similarly stable across the study period aside from the effect of the manufactured-home, measures-list lifetimes changing at the onset of that policy change. As in the overall case, the stability of measure incidence and lifetimes confirms the gas-savings-persistence patterns shown above.

Figure 8. Gas measure incidence across program life, by housing type

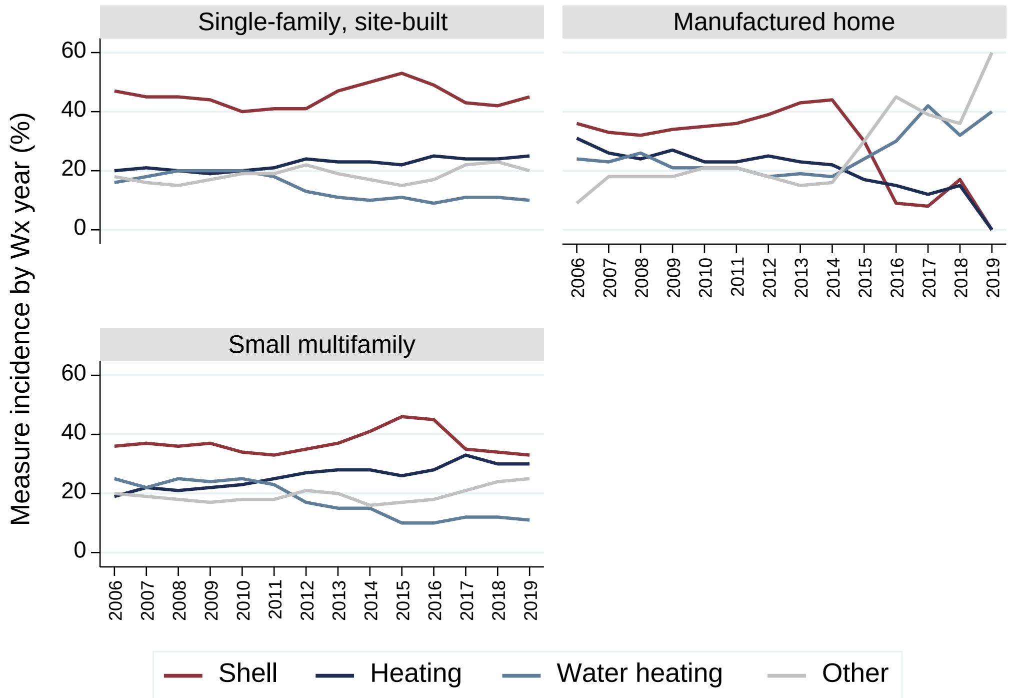
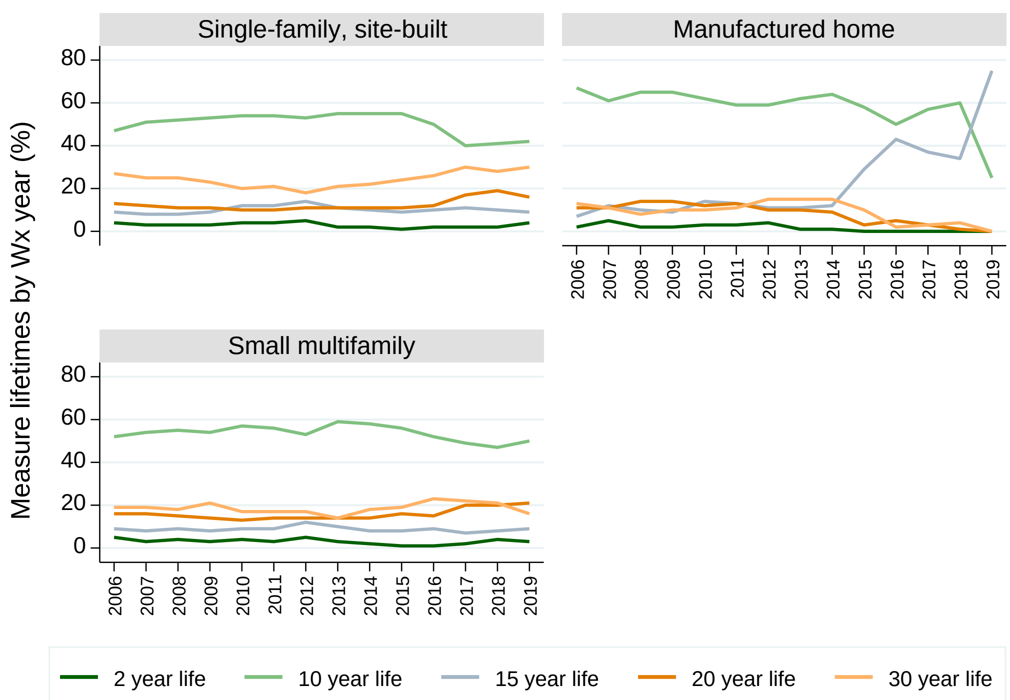


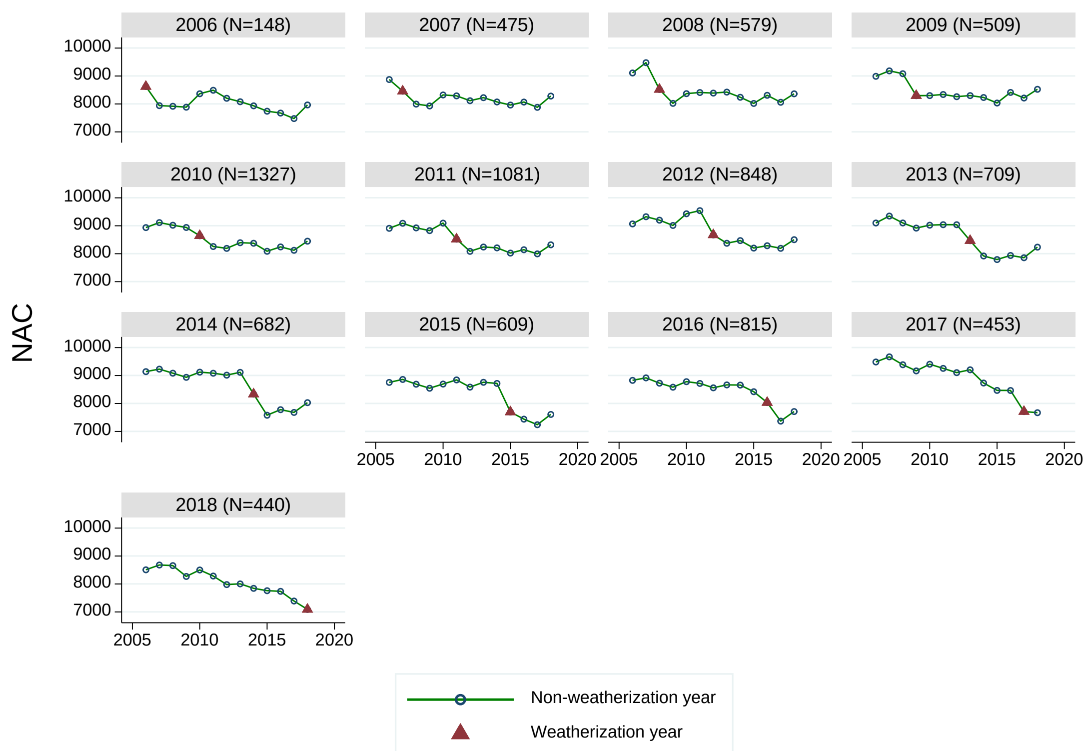
Figure 9. Gas measure lifetime across program life, by housing type



4.2 ELECTRICITY RESULTS

Our analysis finds that electric savings trends over time are less clear than gas savings trends, and that some cohort years appear to have underlying time trends in consumption unrelated to weatherization. Figure 10 shows the NAC for all 1 to 4-unit buildings, broken out by year of weatherization. The red arrow marks when weatherization occurred, allowing for easy pre-to post-weatherization comparison. The graphs generally show a large drop in consumption the year after weatherization, as expected based on the annual evaluations. Depending on the program year, the NAC then either stays relatively stable or increases slightly in the years following weatherization.

Figure 10. Normalized annual electric consumption by year weatherized for 1-4 unit homes



Cohort years starting with 2016 seem to show a significant trend of declining consumption in the years *prior to* weatherization. If this were true of all cohort years, then the flat consumption following weatherization for earlier cohorts would effectively point to a lack of savings persistence, since their consumption would have otherwise been expected to decline further. However, there is little evidence of pre-weatherization consumption declines for the majority of cohorts (roughly homes weatherized between 2007 and 2015). We therefore attribute the declining pre-weatherization-consumption trend for the later cohorts as an unexplained attribute of those later groups rather than a general phenomenon that would potentially affect our conclusion about electric savings persistence. This phenomenon exists in the full data set as well as when we filtered down to include only full consumption histories. Homes weatherized in 2018 show a particularly low pre-NAC leading up to weatherization on average but this trend does not represent a statistically significant difference.

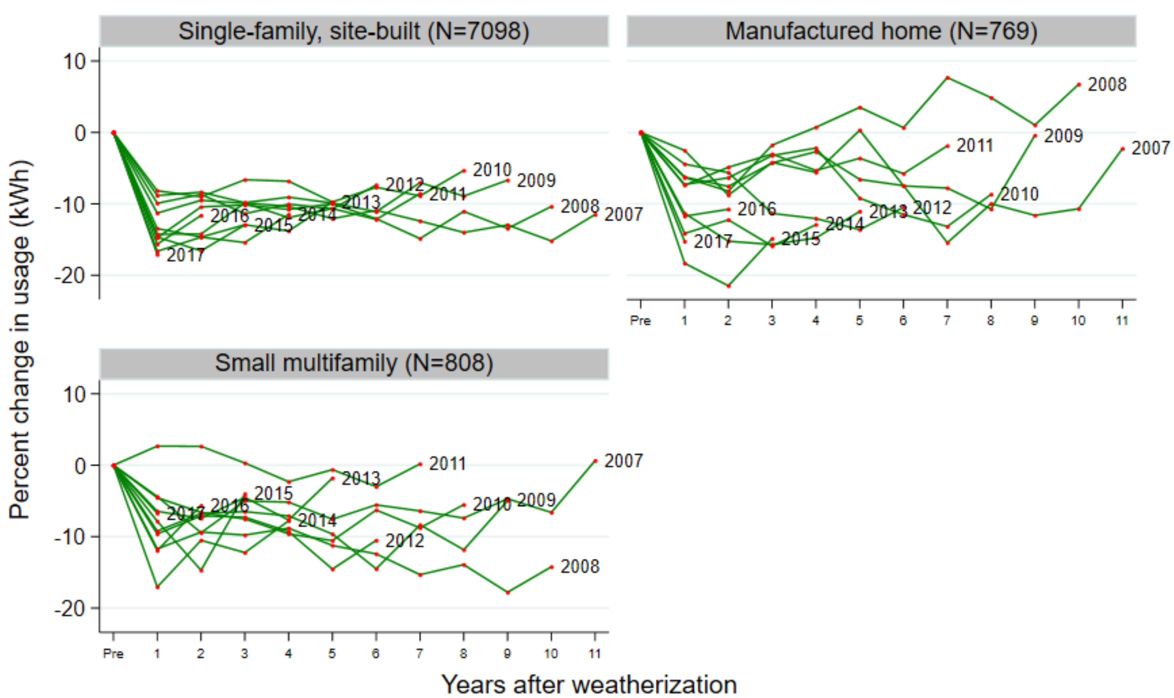
Figure 11 examines the trend in percent electricity savings for three housing types. This figure includes program years 2007 to 2017 – excluding 2006 as we do not have pre-weatherization data for the project year and 2018 as we do not have a full year of post-weatherization data for that project year.

For single-family homes, it appears that the percentage change bounces around from year to year and that the overall trend for percent electricity savings is different for each of the program years.[4] For example, project year 2007 changes from 14 percent savings in year 1 after weatherization to about 11 percent savings in year 11 after weatherization. Other project years similarly see a small erosion in percent savings over time, ranging from 2 percent to 5 percent. This pattern suggests that the savings from weatherization show a less clear pattern over time compared to gas. Appendix 6.0 provides more discussion on the savings patterns for electricity in the years after weatherization. The modeling procedures described there underline the clarity of the savings persistence for gas and lend additional support for the ambiguity of electricity savings persistence.

Small-multifamily homes exhibit a more variable pattern, but on average have a similar trajectory across time. The percent savings achieved also has a wider range than single family homes, with the extreme being 2011's increase in consumption after weatherization. Overall, much of the volatility seen in small multifamily is due to fewer homes being weatherized.

Lastly, manufactured homes show more year-to-year differences and cohorts 2007 to 2009 seem to lose most of their savings by the end of the time period. The volatility is again a direct result of the smaller sample of manufactured homes compared to single-family homes.

Figure 11. Percent change in electricity usage compared to pre-weatherization



[4] The sawtooth pattern in year-to-year savings is likely the result of calendar-year weather variation that is not adequately captured in the weather-normalization process.

In addition to examining changes in annual consumption for each cohort, we also looked at program changes across years, including achieved first-year savings and measure mixes. We examined trends in both the proportion of measures within distinct measure categories and the proportion of measures with certain lifetimes.

Figure 12 examines the first-year savings for each weatherization cohort by housing type with savings point estimates in green and 95 percent confidence intervals in gray. The graphs show that the first-year savings are relatively stable across time, with slight fluctuations across cohort groups. This pattern parallels what Figure 11 shows when comparing differences in percent savings for post year 1. The graph illustrates that the WAP program has achieved relatively constant first-year savings since 2006.

Figure 12. First Year Savings by Weatherization Cohort

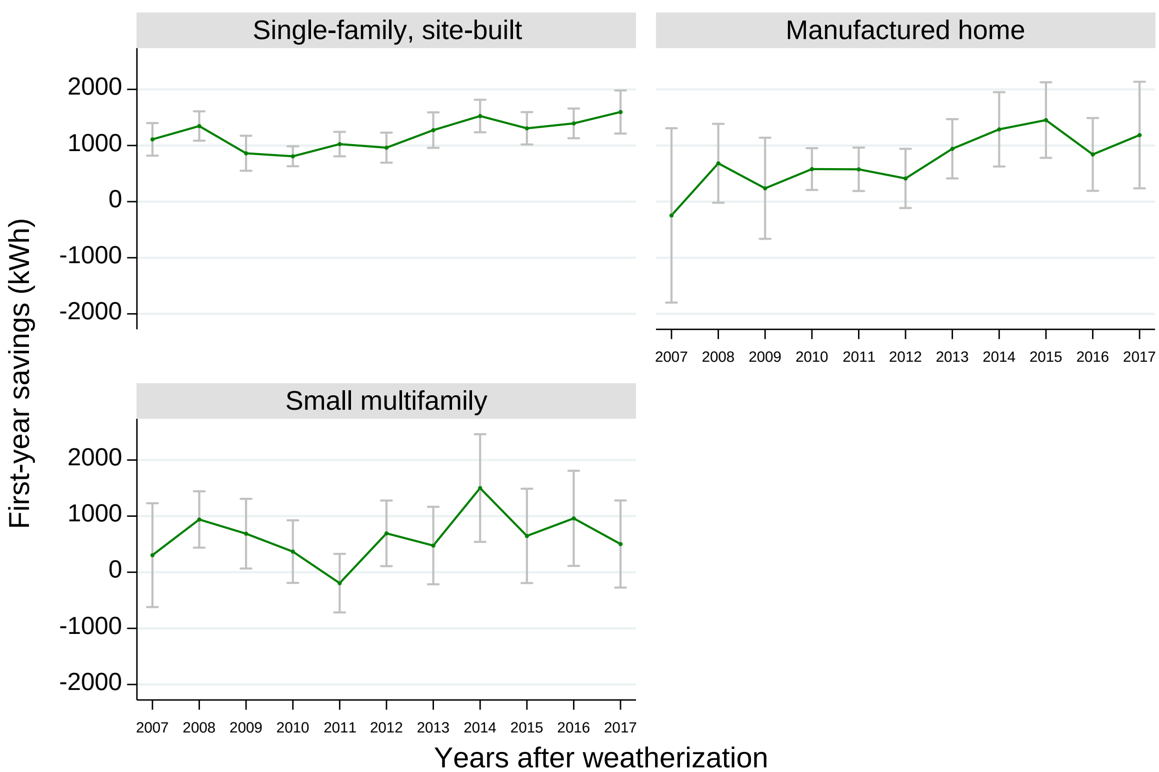


Figure 13 examines the trends across weatherization cohort in more depth. It illustrates the measure incidence across weatherization cohorts for four major groups of measures: shell measures, heating measures, water heating measures, and other measures. The figure illustrates that the mix of measures has varied across time for each housing type. See Appendix 7.0 for individual measures listed in each group.

Figure 14 looks at program trends in a slightly different way by showing the incidence of measures broken out by measure lifetime rather than measure group. The graph illustrates a decline in 10-year lifetime incidence and an increase in 20 and 30-year lifetime incidence in about 2015, but otherwise the incidence of measure lifetime has stayed relatively consistent across time. Appendix 8.0 provides detailed information on the lifetimes of specific measures.

Figure 13. Electric measure incidence across program

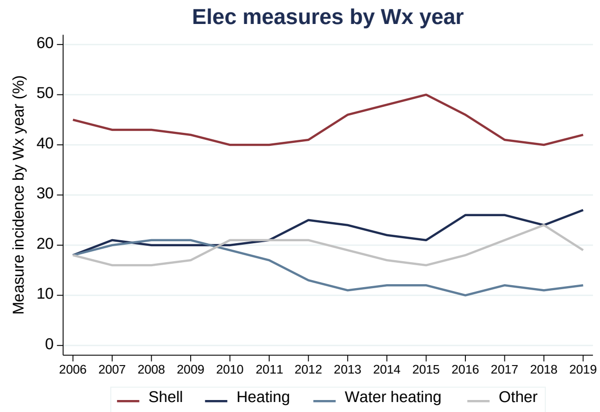
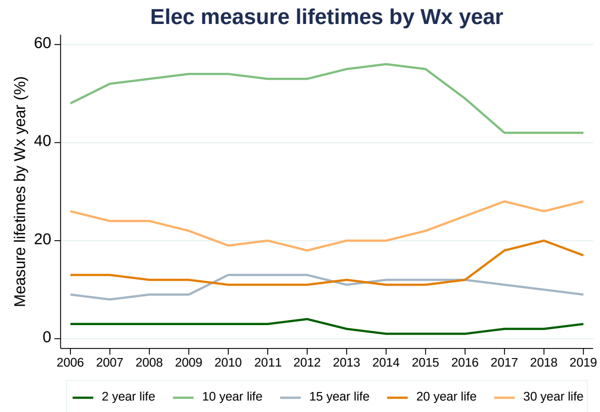


Figure 14. Electric measure life across program



Breaking measure incidence and lifetime out by housing type across the study period mirrors much of what is seen in gas jobs: shell measures are the most prevalent for all housing types except after the policy change to a measures-list approach in 2015 for manufactured homes and water heating measure incidence falls slightly in later years for both single-family and small-multifamily homes. Also, like gas persistence, electric measure lifetimes are relatively stable across the study period when broken out by housing type with 10-year measures being the most numerous measure lifetime.

Figure 13. Electric measure incidence across program, by housing type

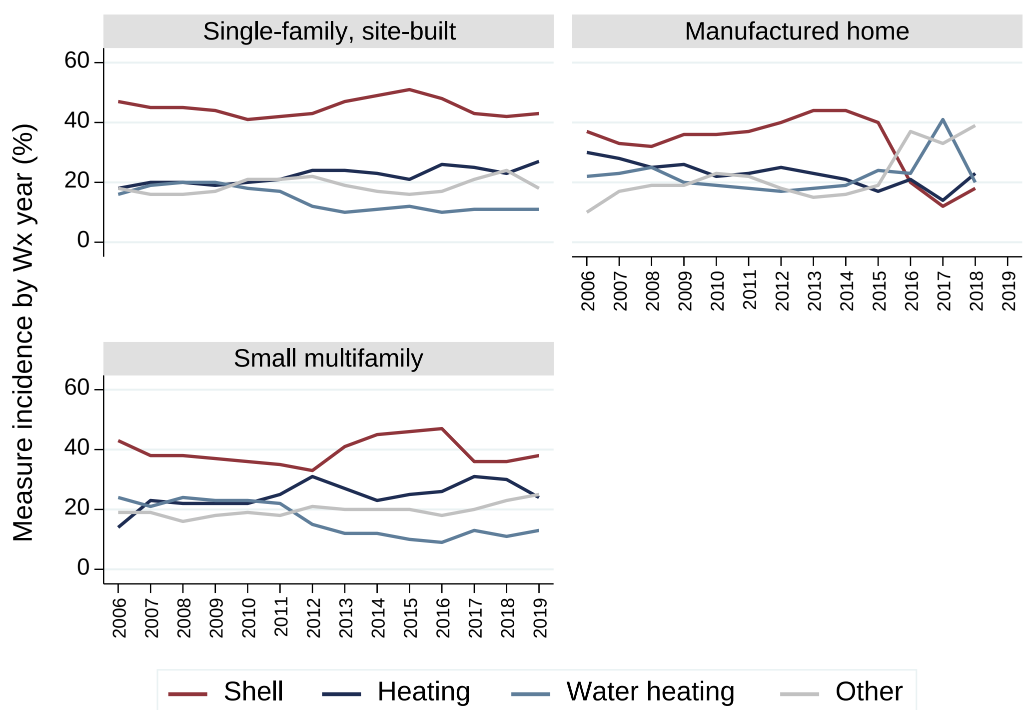
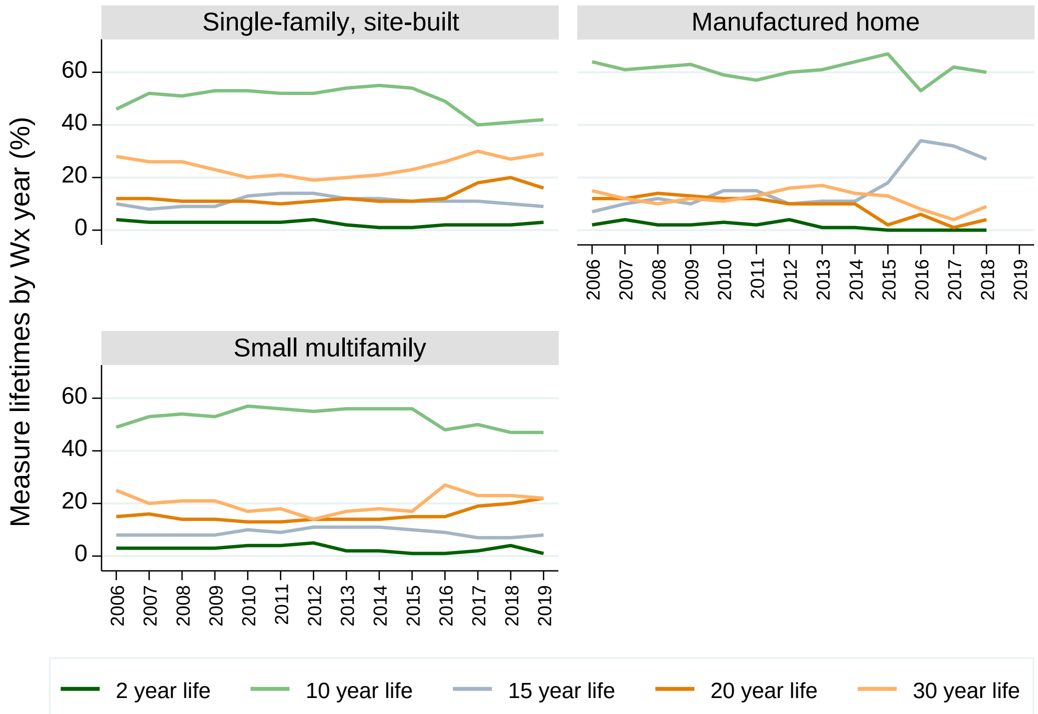


Figure 14. Electric measure lifetime across program, by housing type



5.0 CONCLUSION

The results from this analysis demonstrate that natural gas savings persist for at least ten to twelve years after weatherization. However, the persistence narrative for electric savings is less clear. Single-family homes show the most stability across weatherization cohorts for both natural gas and electricity.

This is an important finding for low-income energy efficiency programs as it supports life-cycle cost-effectiveness calculations that presume longevity of installed gas measures, particularly mechanical system and shell measures. While the study provides no direct evidence of savings beyond the first dozen years or so, the fact that little erosion is seen after even 11 years for gas suggests that substantial savings are likely to be seen beyond the first dozen years.

6.0 APPENDIX REGRESSION MODELS

This appendix describes more detailed regression modeling that was undertaken to better tease apart various influences on the observed persistence of savings. This appendix describes our general approach to the modeling of overall natural gas and electricity savings and shows results from various model-fitting methods that screen data. We also extend these concepts to estimates of persistence for selected individual measures.

Modeling Overall Persistence of Savings

The persistence models are all based on the year-to-year change in weather-normalized annual consumption (ΔNAC) both before and after weatherization. Analyzing consumption *changes* instead of consumption *levels* in each year eliminates some tricky issues associated with different homes or entire weatherization-year cohorts having different levels of consumption and focuses the analysis more directly on the goal of the analysis, which is to estimate how savings change over time. (Note that because we calculate the change in consumption here as NAC_{yr2} minus NAC_{yr1}, savings from weatherization are negative numbers in our analysis.)

The main predictor in the model is the number of years after weatherization (PostYr), which we represent as a series of indicator variables that are set to 0 or 1, with $PostYr_1$ taking a value of 1 for ΔNAC values associated with the first-year impact from weatherization, $PostYr_2$ representing the change between the first and second years after weatherization, etc.[5]

When the model is fitted, the coefficients associated with each PostYr term (β_{yr1}, β_{yr2}, etc.) thus capture the average change in NAC between two post-weatherization years, with β_{yr1} representing the average first-year impact of weatherization on usage, β_{yr2} representing the average change in savings from post-weatherization Year 1 to Year 2, etc. The cumulative persistence of savings for any given number of years after weatherization can then be calculated as the sum of the PostYr coefficients. For example, the overall persistence of savings in post-weatherization Year 5 is calculated as:

$$\text{Year 5 cumulative impact} = \beta_{yr1} + \beta_{yr2} + \beta_{yr3} + \beta_{yr4} + \beta_{yr5}$$

In addition to the main PostYr coefficients of interest, several additional variables are included to help control for non-weatherization influences on ΔNAC. These include indicator variables for:

- Calendar year
- Weatherization-year cohort
- Grantee

There are several ways to fit this type of model and we found that the results can be sensitive to the fitting procedure, so we provide comparative results for four model-fitting procedures:

- Ordinary least-squares (OLS)
- Robust regression
- Quantile regression

[5] Note that in order for the first-year savings from weatherization to be properly represented, the ΔNAC associated with $PostYr_1$ is calculated somewhat differently as the difference in NAC between the year immediately following weatherization and the year immediately preceding weatherization, thus skipping the one to two years associated with weatherization itself.

- Mixed-effects model

Ordinary least-squares is what is typically employed in statistical regression modeling. It fits the model by minimizing sum of the squared differences between the observed data and the model.

Robust regression is a variant of OLS that is implemented in the Stata software package and seeks to identify and downweight outliers in the data.

Quantile regression is another way of dealing with outliers. Instead of modeling average (mean) effects, quantile regression models medians, which are more resistant to extreme datapoints.

Mixed-effects modeling considers some predictors as “fixed effects” and others as “random effects,” the former being predictors of interest to the analysis and the latter being considered factors that, while systematically influencing the data, are random influences that are not of interest to the analysis. Here we treat PostYr as the sole fixed effect, and consider Calendar Year, Weatherization Year and Grantee as random effects in the context of measuring overall average persistence of savings. For the mixed-effects model, we also included weatherization job as a random effect to help control for time trends in consumption associated with individual homes.[6]

In addition to the fitting procedure, there is also the question of what data to include or exclude from the analysis. We considered two variants of the dataset and looked at results for these with and without screening for outliers. The two dataset variants are: (1) all available data; and (2) only weatherization jobs with NAC values for the full 14-year time span of the analysis.

Using all available data increases the number of available data points—and thus the statistical power for the results—but it also represents a less balanced set of data, because some utilities were able to provide more data than others and for different time periods. Having more (or less) data for some geographies and time periods could affect the results of an analysis like this that relies on older data for later persistence and newer data for earlier persistence.

Restricting the analysis to homes with a full 14-year period of data avoids these problems but also potentially skews the results towards the service areas of the utilities with the most complete data. Note that here we used the entire 14 year-period (2006-2019) without removing 2019 as was done above. Removing 2019 in the less complicated analysis above was done because 2019 does not include a full year of billing records. We assumed that these more complex models have a better ability to control for extreme values or outliers, which 2019 is likely to include because it does not include a full year of consumption data.

In addition to the two dataset choices, we also implemented the analysis with and without screening for outliers. The outlier screening involved dropping individual data points where the year-to-year change in consumption exceeded 40 percent for ΔNAC years that did not involve weatherization itself or 75 percent for the ΔNAC associated with weatherization (since weatherization itself can have a significant impact on consumption). These screens eliminated about 4 percent of the gas data and 7 percent of the electric data. Note that we did not run the robust or quantile models on the outlier-screened data, since those fitting procedures are already intended to be resistant to outliers.

[6] Mixed effects models also allow for specifying a hierarchy of effects. We treated Calendar Year, Weatherization-Year Cohort and Grantee as overall random effects (Level 1), and Weatherization Job as a Level 2 random effect within Grantee.

Overall, the four fitting procedures, two dataset selections and two options for outlier screening yield 12 sets of results each for natural gas and electricity, as shown in the table below:

Fitting Procedure	**All Available Data**		**Full-Span Data Only**	
	Untrimmed	**Trimmed**	**Untrimmed**	**Trimmed**
OLS	Model 1	Model 2	Model 3	Model 4
Mixed Effects	Model 5	Model 6	Model 7	Model 8
Robust	Model 9		Model 10	
Quantile	Model 11		Model 12	

Figures on the following pages summarize the results for the two fuels for each housing type. Comparing across the various model runs (Figure 17 and Figure 18), it is clear that outliers can affect the results fairly strongly (e.g. Model 1 vs. Model 2 for natural gas in single-family homes). The general effect of outliers is to implausibly suggest that savings increase strongly over time.

After discounting such results, the gas model runs generally suggest no erosion of savings over the analysis time period, except for manufactured homes where a number of the models suggest savings erosion within the first 13 years following weatherization.

The results for electricity, on the other hand, are more ambiguous, with single-family homes in particular having some models indicative of erosion of savings and others indicative of no erosion.

Generally, we favor Model 8, as the mixed-effects approach has conceptual appeal, the full-span dataset avoids issues with unbalanced data and the outlier trimming helps make the results more robust. Plots of Model 8 with associated confidence intervals (Figure 19 and Figure 20) strongly suggest persistence of gas savings for single-family and small multifamily homes and some evidence of erosion for manufactured homes. For electricity, Model 8 strongly suggests erosion of savings for single-family homes, though this is subject to the ambiguity from the varied results across models. Persistence of electricity savings for small multifamily and manufactured homes is also ambiguous under Model 8 due to the wide confidence bands for these housing types.

for

Figure 15. Estimated gas persistence, by housing type and model number.

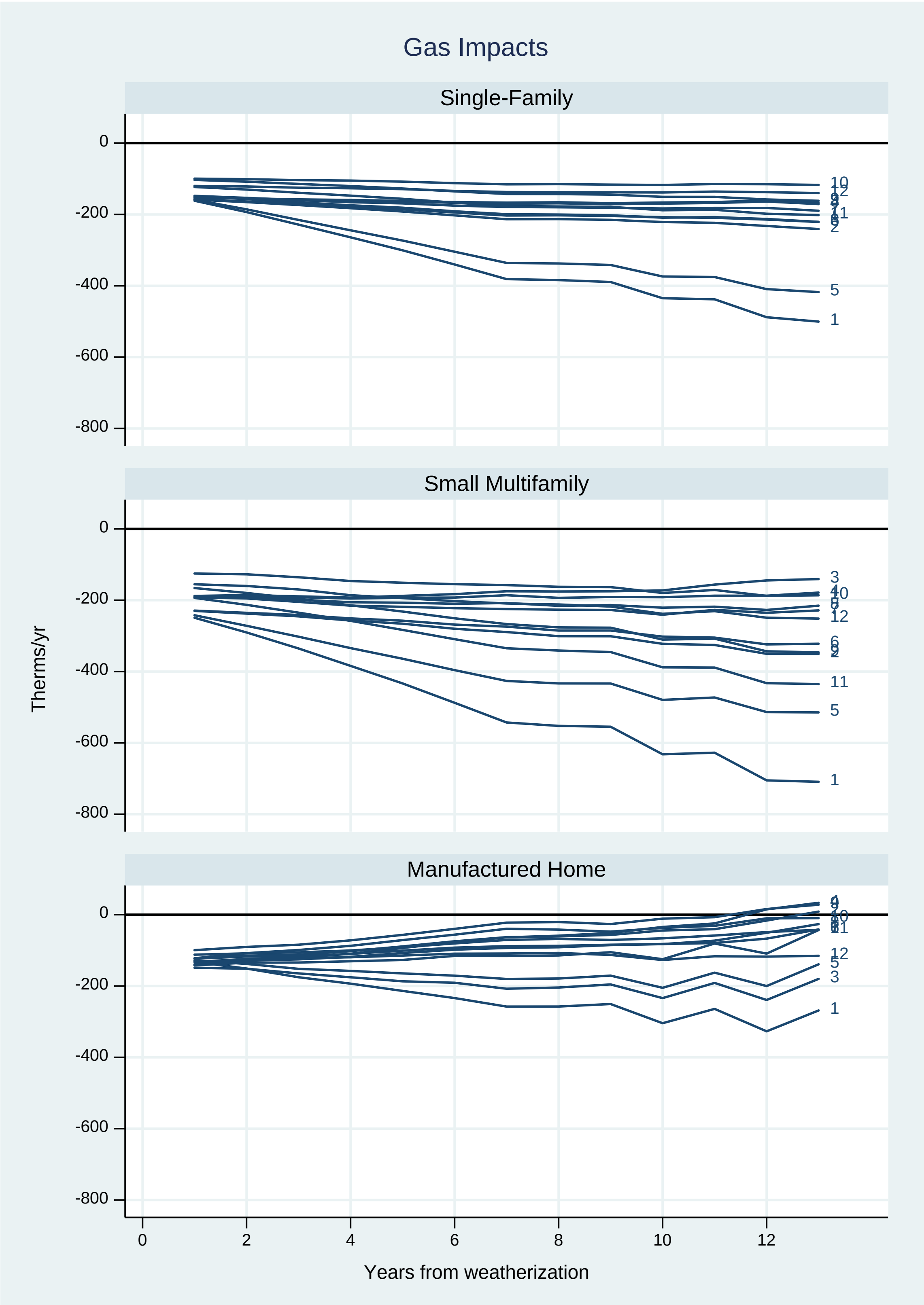


Figure 16. Estimated electricity persistence, by housing type and model number.

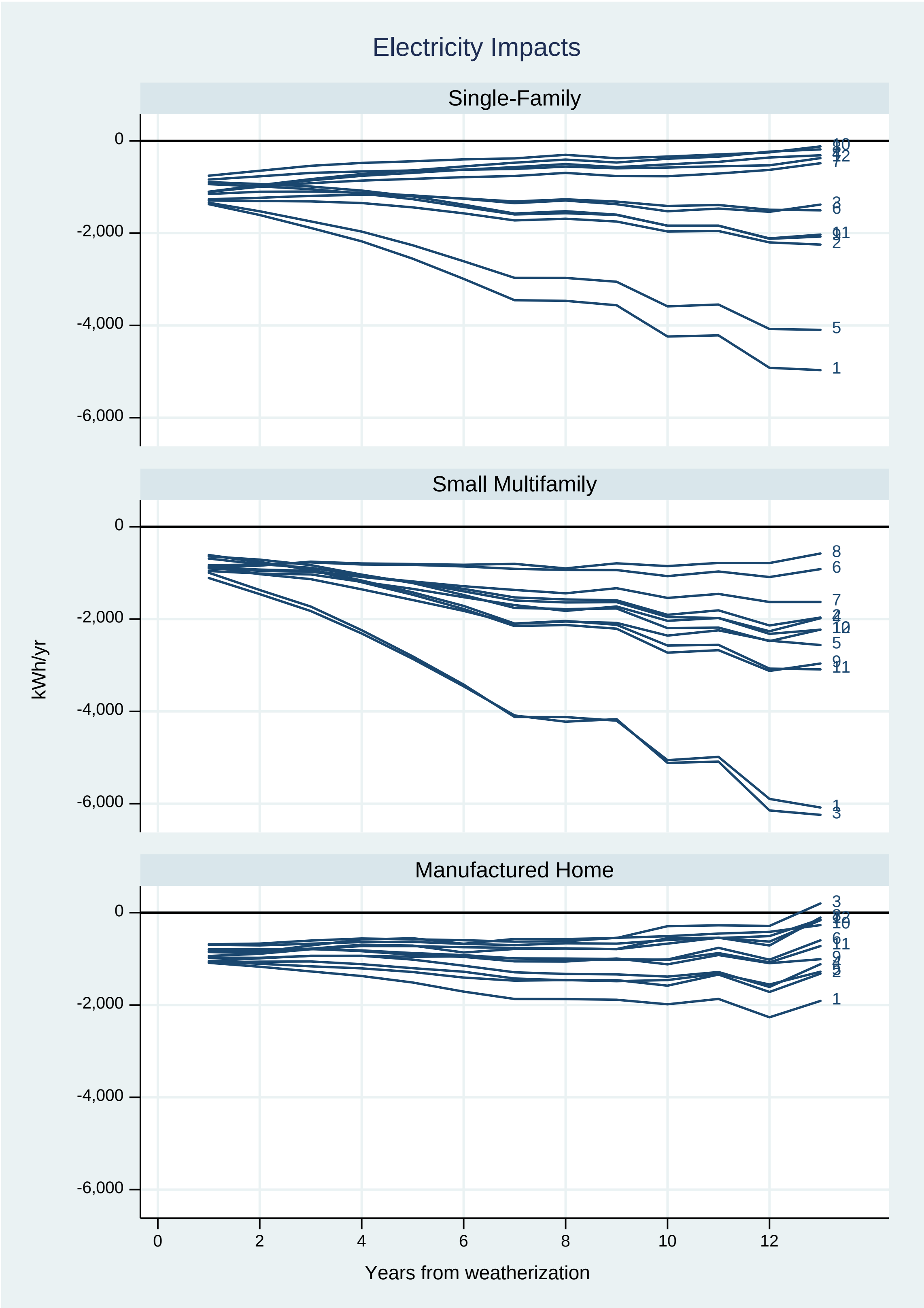


Figure 17. Estimated gas persistence for Model 8, by housing type.

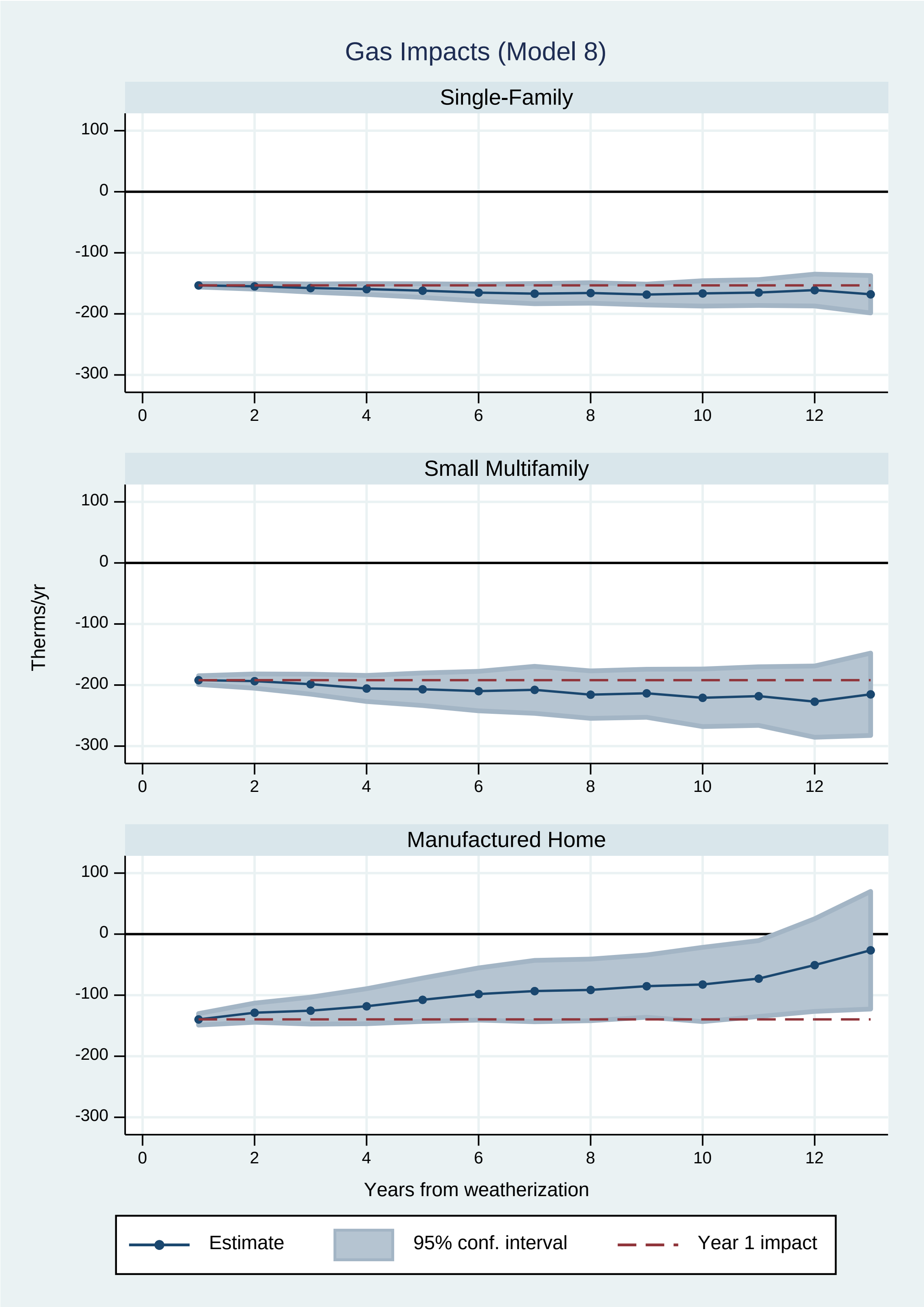
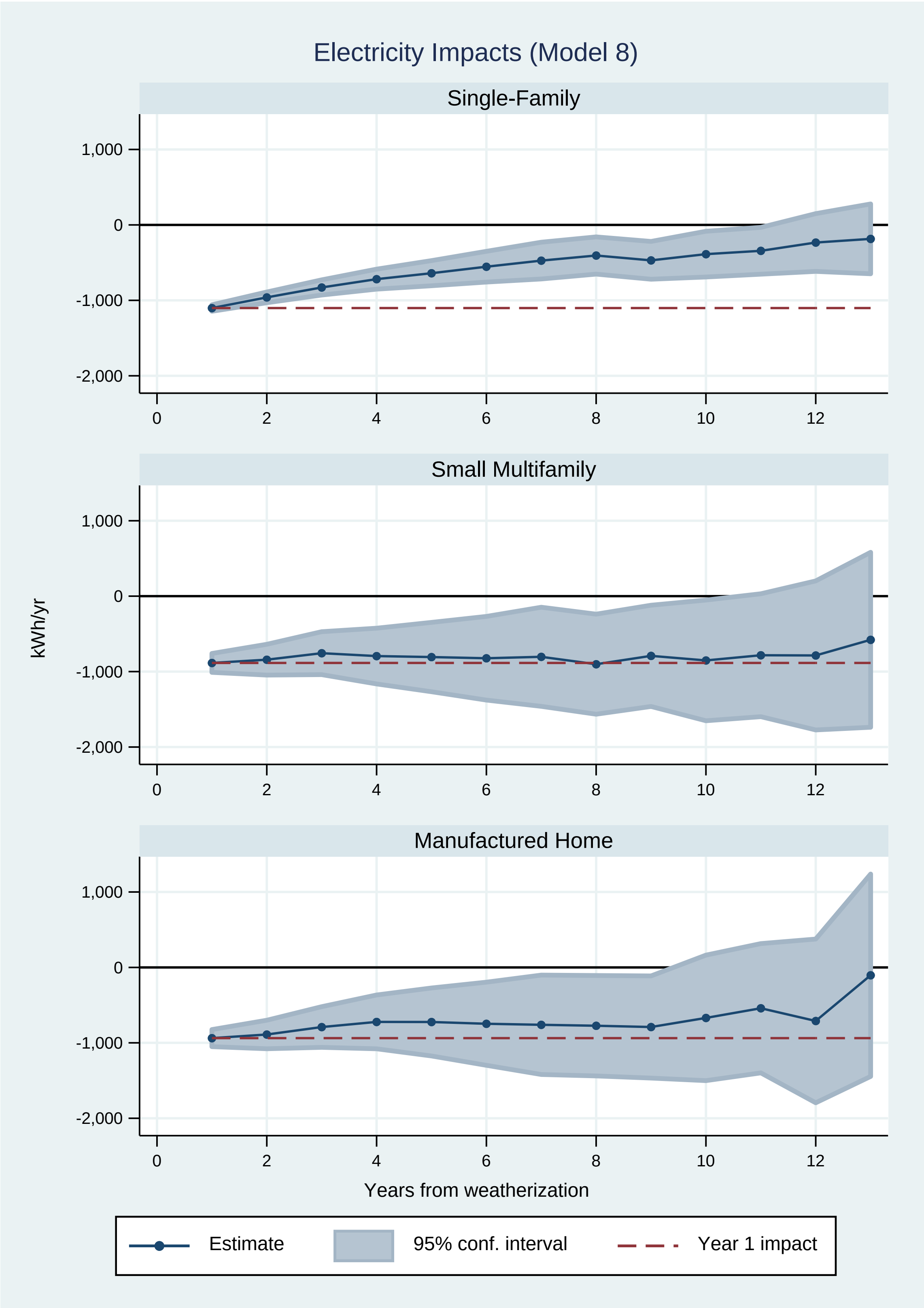


Figure 18. Estimated electricity persistence for Model 8, by housing type.



Measure Level Persistence of Savings

Finally, we examined variants of Model 8 that included binary predictors for selected individual measures installed under the program. The measures selected included those known to be key contributors to impacts from the program as well as measures such as water heater temperature reduction that have a short measure life and/or are easily disabled. Measure-level estimates of the persistence of impacts over time are obtained by including terms that interact the measure indicators with the PostYr indicator variables.

For the most part, the results (Figure 21 and Figure 22) are either statistically ambiguous due to wide confidence intervals or show stable savings over time. The exceptions are faucet aerators—where the results implausibly indicate strongly increasing savings over time—and the gas heating penalty associated with the installation of continuous mechanical ventilation, where the results suggest a decline over time.

The gas results for mechanical ventilation could be explained by gradual clogging of the installed exhaust fans–though field measurements made in 2019 suggest that this is not the case for at least the first 7 to 8 years of operation—or by an increasing fraction of households that disable the ventilation as time goes on. However, another phenomenon could create the false appearance of a decline in gas impacts: if the average cfm of installed ventilation has increased over the years, it would manifest as an apparent decline in gas impacts, since later persistence is strongly determined by early program participants.

Figure 19. Estimated persistence of natural gas impacts for selected measures.

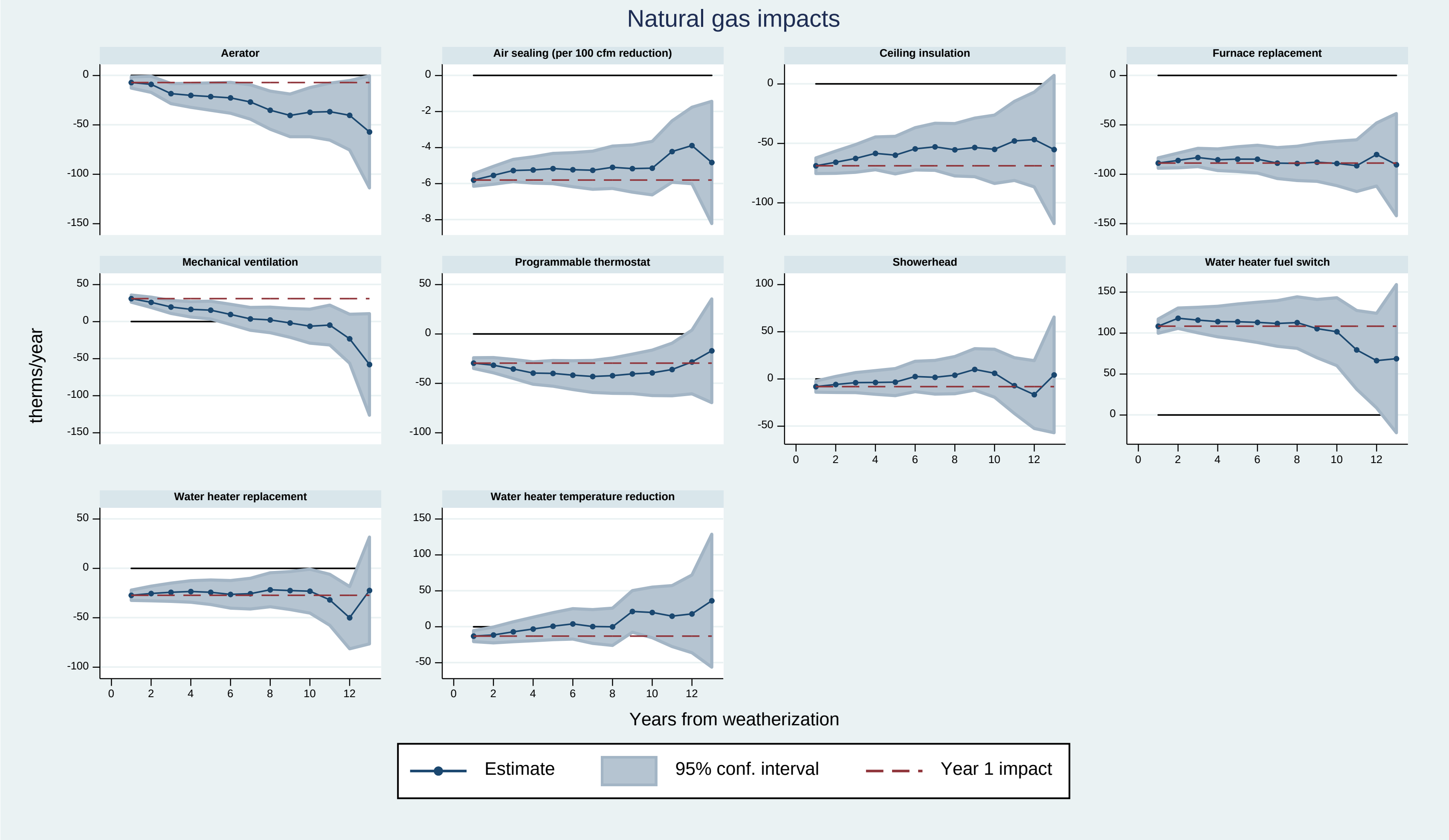
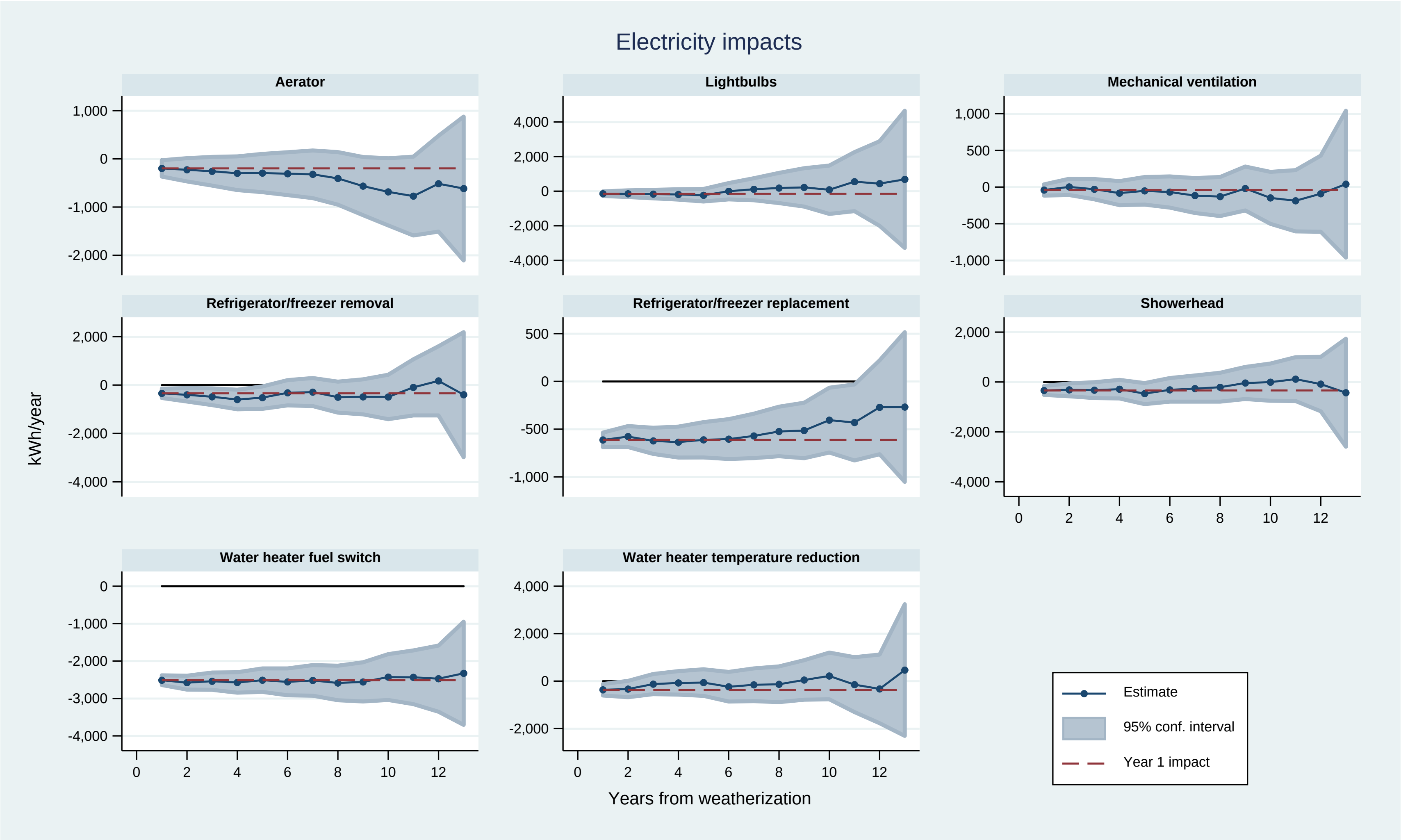


Figure 20. Estimated persistence of electricity savings for selected measures.



7.0 APPENDIX MEASURE CLASS

Heating	Water heating	Shell	Other
Automatic Fill Valve	Electric Upgrade	2 Part Foam	CFL 3-Way Bulb
Backflow Preventer	Flow Restrictors	2 Part Foam - R12	CFL 3-Way Bulb - Mobile Home
Clean and Tune	Flow Restrictors - Mobile Home	2 Part Foam - R19	CFL Bulb
Cleanable Filters	Gas power vent from conventional gas	2 Part Foam R19	CFL Bulb - Mobile Home
Compression Tank	Gas power vent from electric	7/1/16 Non-Guideline Sealing - MHML	Exterior
Disposable Filters	Gas, Mobile Home Direct Vent	Air Sealing	Exterior - Mobile Home
Disposable Filters - Mobile Home	Gas, Mobile Home direct vent from elec	Air Sealing - Mobile Home	Fixture Replacement - TDWG Pilot
Distribution Pipe Insulation	Gas, conventional from electric	Attic Prep - No Attic Insulation	Halogen Torchiere Replacement
Distribution System Modifications	Indirect Fired Water Heater	Blower Door Setup	Halogen Torchiere Replacement - Mobile Home
Electric Conversion	Pipe Insulation	Blower Door Setup - Mobile Home	LED Bulb
Electric Vent Damper	Pipe Insulation - Mobile Home	Blown Cellulose - Enclosed R11	LED Bulb - Mobile Home
Gas Boiler	Reduce Temperature	Blown Cellulose - Enclosed R19	LED Can Light Insert - TDWG Pilot
Gas Boiler - Energy Star	Showerhead	Blown Cellulose - Enclosed R30	Remove Additional Unit (include $100 Incentive)
Gas Forced Air 90%	Showerhead - Mobile Home	Blown Cellulose - Enclosed R38	Remove Additional Unit (include $100 Incentive)-MH
Gas Mobile Home	Tank insulation	Blown Cellulose - R11	Remove Additional Unit (include $100 incentive)
Gas Mobile Home 90%		Blown Cellulose - R13	Replacement
Gas Space Heater or Wall Furnace		Blown Cellulose - R19	Replacement - Mobile Home
Heating System Modifications - JHSM016		Blown Cellulose - R30	
Insulate Ducts		Blown Cellulose - R38	
Modulating Aquastat		Blown Cellulose - Unfloored R11	
Outdoor Reset		Blown Cellulose - Unfloored R19	
Radiator New or Replacement		Blown Cellulose - Unfloored R30	
Radiator Valves		Blown Cellulose - Unfloored R38	
Repair/Replace/Add Ductwork - First Floor		Blown Cellulose - Unfloored R50	
Repair/Replace/Add Ductwork - Second Floor		Blown Fiberglass - R30	

Repair/Replace/Add Ductwork-First Floor-MH		Blown Fiberglass - Enclosed R11	
Seal Ducts		Blown Fiberglass - Enclosed R19	
Seal Ducts - Mobile Home		Blown Fiberglass - Enclosed R30	
Setback Thermostat		Blown Fiberglass - Enclosed R38	
Setback Thermostat - Mobile Home		Blown Fiberglass - Enclosed R50	
Zone Valves		Blown Fiberglass - Mobile Home R11	
		Blown Fiberglass - Mobile Home R19	
		Blown Fiberglass - Mobile Home R30	
		Blown Fiberglass - Mobile Home R38	
		Blown Fiberglass - R11	
		Blown Fiberglass - R19	
		Blown Fiberglass - R38	
		Blown Fiberglass - Unfloored R11	
		Blown Fiberglass - Unfloored R19	
		Blown Fiberglass - Unfloored R30	
		Blown Fiberglass - Unfloored R38	
		Blown Fiberglass - Unfloored R50	
		Blown fiberglass - Mobile Home R11	
		Fiberglass Batt - Mobile Home R11	
		Fiberglass Batt R11	
		Fiberglass Batt R11 - Mobile Home	
		Fiberglass Batt R19	
		Fiberglass Batt R19 - Mobile Home	
		Minor Infiltration - Non Blower Door Guided	
		Mobile Home Insider Storm	
		Non-Guideline Sealing	
		Polyisocyanurate Insulation Board R7	
		Polystyrene Insulation Board R10	
		Rigid Insulation Board, Exterior R5	

		WCEG Guided Sealing	
		WCEG Guided Sealing - Mobile Home	
		Window Replacement Energy Star Rated	

8.0 APPENDIX MEASURE LIFETIMES

2 Year	10 Year	15 Year	20 Year	30 Year
Clean and Tune	7/1/16 Non-Guideline Sealing - MHML	CFL 3-Way Bulb	CFL Bulb	2 Part Foam
	Air Sealing	CFL 3-Way Bulb - Mobile Home	Electric Conversion	2 Part Foam - R12
	Air Sealing - Mobile Home	CFL Bulb - Mobile Home	Gas Boiler	2 Part Foam - R19
	Blower Door Setup	Electric Upgrade	Gas Boiler - Energy Star	2 Part Foam R19
	Blower Door Setup - Mobile Home	Exterior	Gas Forced Air 90%	Attic Prep - No Attic Insulation
	Cleanable Filters	Exterior - Mobile Home	Gas Mobile Home 90%	Blown Cellulose - Enclosed R11
	Disposable Filters	Fixture Replacement - TDWG Pilot	Gas Space Heater or Wall Furnace	Blown Cellulose - Enclosed R19
	Disposable Filters - Mobile Home	Gas power vent from conventional gas	Halogen Torchiere Replacement	Blown Cellulose - Enclosed R30
	Flow Restrictors	Gas power vent from electric	LED Bulb	Blown Cellulose - Enclosed R38
	Flow Restrictors - Mobile Home	Gas, Mobile Home Direct Vent	LED Can Light Insert - TDWG Pilot	Blown Cellulose - R11
	Insulate Ducts	Gas, Mobile Home direct vent from elec		Blown Cellulose - R13
	Minor Infiltration - Non Blower Door Guided	Gas, conventional from electric		Blown Cellulose - R19
	Mobile Home Insider Storm	Halogen Torchiere Replacement - Mobile Home		Blown Cellulose - R30
	Non-Guideline Sealing	Indirect Fired Water Heater		Blown Cellulose - R38
	Pipe Insulation	LED Bulb - Mobile Home		Blown Cellulose - Unfloored R11
	Pipe Insulation - Mobile Home	Replacement		Blown Cellulose - Unfloored R19
	Reduce Temperature			Blown Cellulose - Unfloored R30
	Repair/Replace/Add Ductwork - First Floor			Blown Cellulose - Unfloored R38
	Repair/Replace/Add Ductwork - Second Floor			Blown Cellulose - Unfloored R50

	Repair/Replace/Add Ductwork-First Floor-MH			Blown Fiberglass - R30
	Seal Ducts			Blown Fiberglass - Enclosed R11
	Seal Ducts - Mobile Home			Blown Fiberglass - Enclosed R19
	Setback Thermostat			Blown Fiberglass - Enclosed R30
	Setback Thermostat - Mobile Home			Blown Fiberglass - Enclosed R38
	Showerhead			Blown Fiberglass - Enclosed R50
	Showerhead - Mobile Home			Blown Fiberglass - Mobile Home R11
	Tank insulation			Blown Fiberglass - Mobile Home R19
	WCEG Guided Sealing			Blown Fiberglass - Mobile Home R30
	WCEG Guided Sealing - Mobile Home			Blown Fiberglass - Mobile Home R38
	Window Replacement Energy Star Rated			Blown Fiberglass - R11
				Blown Fiberglass - R19
				Blown Fiberglass - R38
				Blown Fiberglass - Unfloored R11
				Blown Fiberglass - Unfloored R19
				Blown Fiberglass - Unfloored R30
				Blown Fiberglass - Unfloored R38
				Blown Fiberglass - Unfloored R50
				Blown fiberglass - Mobile Home R11
				Fiberglass Batt - Mobile Home R11
				Fiberglass Batt R11
				Fiberglass Batt R11 - Mobile Home
				Fiberglass Batt R19
				Fiberglass Batt R19 - Mobile Home
				Polyisocyanurate Insulation Board R7
				Polystyrene Insulation Board R10
				Rigid Insulation Board, Exterior R5