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# Window Inserts and the People Adopting Them: Building Sustainable Communities in Maine

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# WINDOW INSERTS AND THE PEOPLE ADOPTING THEM: BUILDING SUSTAINABLE COMMUNITIES IN MAINE

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Residents of Maine face a large monetary expense to heat their homes in the winter. In Maine it takes 540 gallons of heating oil each year to heat a typical home [1]. Interior window inserts may be a practical solution to improve comfort, save money, and consume less environmentally harmful fossil fuels during cold winter months. The window inserts discussed in this paper are custom measured to fit into a window and consist of a wooden frame that is wrapped in two layers of polyolefin film and weather stripped for a snug fit. Commercial inserts cost $20-$36/square foot, or approximately $300-$540 for a 36” by 60” window [2]. However, there is a growing movement in Maine to reduce costs by harnessing the power of community volunteers. WindowDressers is a non-profit organization in Rockland, Maine that helps community organizers in towns throughout the state provide inserts for one-tenth of the price ($1.65-$3.68/square foot) of commercial inserts. In addition, 25% of inserts are allocated to low-income customers for a reduced rate ($10 for 10 inserts). Customers that purchase inserts also volunteer time to work to build and assemble them with other members of the community. This is part of a growing movement of community energy that works through grassroots movements as opposed to traditional “top down” approaches to achieve energy related goals.

Survey data are used in this thesis to show customers are participating to conserve energy, live comfortably, save money, benefit the environment, and because they value the sense of community with the project. Volunteers are participating to help others achieve the same goals. Ninety-six percent of participants reported being satisfied with their overall experience, and 68% of volunteers report having a better experience than they were expecting. Survey data are also used to demonstrate that most customers are not reporting a direct rebound effect, or lower than expected energy savings from an energy efficiency improvement. After the inserts are installed in a home, more customers reportedly turn their thermostats down rather than up. The ability for the inserts to reduce drafts and make rooms feel warmer are credited for this.

We also predict the cost, energy, and emissions savings: a typical home with ten 36” by 60” inserts is estimated to save 35 gallons of heating oil per year, which results in $105 per year in savings and a simple payback period of 3.9 years on their investment for full price customers. The typical Maine home is also predicted to save 357 kilograms of carbon dioxide, 14 grams of methane, and 3 grams of nitrous oxide per home, per year. Historical fuel oil consumption data are used from three WindowDressers customers to estimate the median of their annual fuel oil energy savings to be 17% as a result of window inserts. The historical heating fuel analysis shows a median of 128 gallons of heating oil being saved per household during the winter of 2016 - 2017, resulting in an estimated $326 of household savings 1,300 kilograms of carbon dioxide, 52.5 grams of methane, and 10.2 grams of nitrous oxide per household. Finally, this thesis compares historical consumption for two customers to the predicted energy savings model designed for their homes. We find that their consumption falls along the same range of predicted savings.

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# CHAPTER 1

# COMMUNITY BUILT WINDOW INSERTS

## 1.1. Introduction

In 2017 America, it is hard to deny the facts presented by climate change researchers and those that do are considered to be a minority [3]. While great programs exist for individuals to reduce their carbon footprint, they are often underutilized [4]. One large contributor to greenhouse gas emissions in the northern United States is heating our buildings during the cold winter months. Not only does this practice require a large amount of polluting fossil fuels, it can also be a large monetary expense. This is especially true in the state of Maine, where the average household uses the equivalent of 540 gallons of heating oil every year [1]. Using pricing data since 2004, 540 gallons of heating oil can safely be assumed to cost over $800 (2016 USD) a year and is the most common heating source in Maine [5]. In 2010, a grassroots program led by WindowDressers began helping Maine residents make a difference in their heating cost and energy consumption. According to their website, "WindowDressers is a volunteer-driven non-profit organization dedicated to helping Maine residents reduce heating costs, fossil fuel consumption, and $CO_2$ (Carbon Dioxide) emissions by minimizing heat loss through windows. Inserts offer an inexpensive alternative to window replacement. With 30% of home heat loss through windows alone, inserts reduce home heating fuel use and $CO_2$ emissions simultaneously… There are 557,000 homes in Maine, and over 90 percent of them need weatherization. We're here to help" [6]. The volunteer-driven approach to improve energy efficiency in the local areas makes WindowDressers part of a growing movement toward community energy. Community energy relies on grassroots movements to support issues like human rights, affordability, and environmental protection, related to renewable energy, energy efficiency and conservation as an alternative to the traditional "top down" approach [7].

### 1.2. Background

WindowDressers operates primarily using volunteers to organize a “build” in their own community. A “build” happens when volunteer organizers find customers in that community who wish to order window inserts; measure each of the windows that will be receiving inserts; coordinate a large available space for the inserts to be assembled (i.e. a church or community center); pick-up all materials needed from WindowDressers headquarters in Rockland; organize times for customers and other volunteers to assist in the build; and train all volunteers to complete each stage of the window insert assembly. WindowDressers began in the single community of Rockland, but grew steadily to 17 different communities in 2016. The growth in both number of communities and number of total inserts can be seen in Figure 1. This research team had a special interest in the Bangor 2015 and 2016 builds as we acted as two of the volunteer coordinators for those builds. Bangor builds will be mentioned separately in Chapter 2 for this reason.

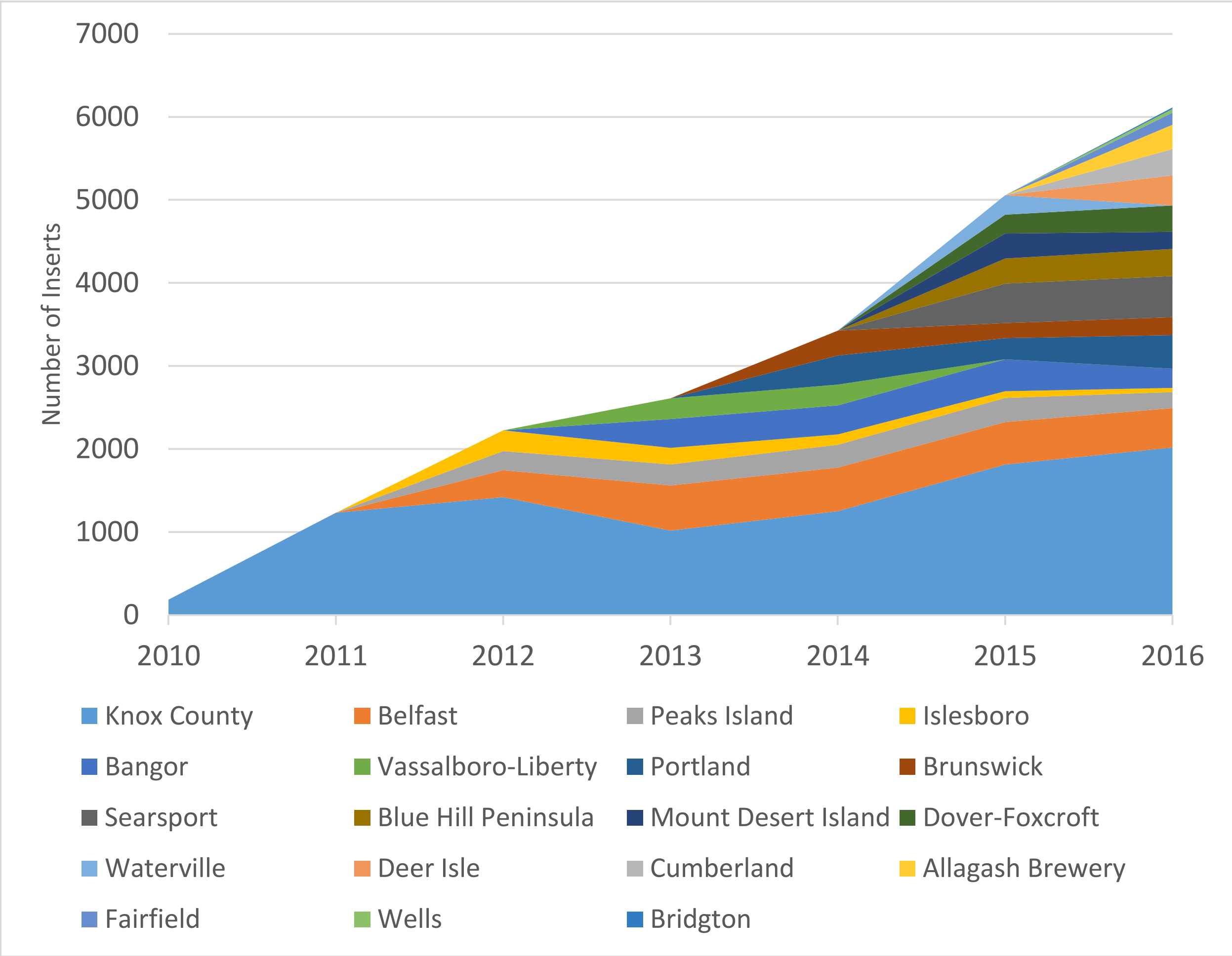


*Figure 1 – Growth of WindowDressers*

The window inserts built with WindowDressers are constructed of locally-sourced pine wood. When customers order inserts, their windows need to be precisely measured in order to construct the pine frame to fit appropriately in each window. Their frames can either be left as natural pine wood, or painted a white color for an added price. The wood for the frames is cut at the WindowDressers headquarters in Rockland, Maine using a computerized system that is designed to use their resources as efficiently as is possible. Twelve-foot sticks of frame wood are inserted into the machine by hand, and each length is cut to minimize wood use. Any insert that has a length longer than 46 inches also receive a thin, matching wood strut to prevent the frame from bowing. All of the window insert frames are constructed using screws and wood glue at either the Rockland headquarters and sent out to the local community builds (called a phase 1 build), or sent out in unassembled bundles to be constructed at the local community build site (called a phase 2 build). Each community can choose between these two options for their own build, however the work is being completed by volunteers in both build options. After the frames are constructed, they all undergo a wrapping process at the community build site. Here members of the community volunteer to:

1. Wrap the outside perimeter of the insert frame with double-sided tape.
2. Pull a sheet of polyolefin plastic tightly along one face of the insert, and press down firmly to the double-sided tape. Cut away the excess plastic.
3. Wrap the outside perimeter of the insert again with double-sided tape.
4. Pull a sheet of polyolefin plastic tightly along the opposite face of the insert, and again press firmly to the double-sided tape. Cut away the excess plastic.
5. Shrink the polyolefin on each side using a heat gun to remove all of the wrinkles in the plastic.

6. Tape the outside of the insert with a clear packing tape, adding durability to the insert.
7. Finally, weather strip the outside of the frame with 90 degree angles at the corners to provide a tight fit when placed in the customers' window.

These steps are repeated for every window insert, which are taken home and installed by the customers as soon as they are ready. Installation is usually as simple as placing the insert inside the window frame. In some cases, window blinds, casement window cranks, or other objects that would impede the insert from fitting in the window must first be removed. The installation process can be seen in Figure 2.

Insert being installed　　Insert in place

*Figure 2 – Interior Window insert installation (image courtesy of Steve Shaw, WindowDressers)*

Inserts bought through WindowDressers affiliated builds are unique from other home weatherization purchases. Customers who purchase these inserts are also asked to volunteer at their community build to help assemble them with other members of their community. A customer is typically asked to volunteer for one 4-hour shift for every seven inserts they purchase. Volunteerism is not strictly enforced, and customers who do not participate in the build will still receive their purchased inserts. However, the norm is that most customers do volunteer in addition to other members of the community who are not customers themselves. Window inserts can be purchased for two different price rates: full price or a special rate. Full price covers the cost of all materials for those inserts as well as part of the special rate material cost. The special rate is designated to 25% of every build to allow low-income customers to purchase 10 natural pine inserts for the flat rate of $10. The special rate does not allow low-income customers to purchase more than 10 inserts or to purchase white painted frames. The special rate was designed to provide an affordable method of home weatherization to the low-income community who needs it most.

In addition to WindowDressers, there are three other organizations in Maine who build these inserts. Unity College in Unity, Maine has been conducting their own window insert building workshop since 2008. They work with the Neighbor-Warming-Neighbor program to run workshops showing members of the community how to build window inserts identical the ones in this study [8]. The Midcoast Green Collaborative in Damariscotta, Maine also holds window insert workshops for customers to build their own inserts [9]. They also offer material kits (either with or without the wood frames) that can be picked up or shipped right to a home. Again, these window inserts are identical to the inserts in this study. Finally the Island Institute in Rockland, Maine also conducts community window insert builds in island and coastal communities [10]. The Island Institute learned how to conduct their builds from the Midcoast Green Collaborative and they build identical inserts [11]. The research provided in this study focuses on WindowDressers because it was the organization we worked with directly. However, the findings would also apply to other organizations, researchers, or policy makers trying to understand the social, economic, and technical aspects of community built window inserts.

There are also commercially available window inserts. Indow Window is a company out of Portland, Oregon that sells inserts that are constructed from a single layer of acrylic (as opposed to a double layer of polyolefin) and a patented locking mechanism that allows the inserts to be flexible and provide tight fit in the window [12] (see Figure 3). These inserts are roughly ten times more expensive than the full price WindowDressers inserts [2], however customers are not asked to volunteer time as part of the purchase. In addition to their standard inserts, Indow Windows also offers a number of specialty inserts designed to reduce outside noise levels, prevent outside visibility, prevent light infiltration, or decrease UV radiation coming through the windows [12]. These attributes will not be considered in this study, but they do highlight some additional potentials of window inserts. Indow Window standard inserts will be used as a comparison to the WindowDressers community built inserts.

*Figure 3 – Indow Window installation process [12]*

### 1.3. Objectives

This study analyzes data collected from participants in WindowDressers community window insert builds. The data consists of surveys, interviews, models, and utility bills. There are five main objectives in this paper:

1. Identify social motivations and perceptions of participating in the window insert builds.
2. Identify whether behaviors change after participating in a window insert build, including any reported rebound effect or decrease in expected energy savings after window insert adoption.
3. Predict how much money, energy, and emissions window inserts could save.
4. Determine how much money, energy, and emissions window inserts actually save.
5. Compare predicted savings to actual savings, including assessment of possible rebound effect.

Chapter 2 addresses the first and second objectives using data from survey responses from build participants. Chapter 3 addresses Objective 3 using heat loss calculations to estimate the impact of window inserts. Chapter 3 addresses Objective 4 by using utility bills to observe changes in consumption before and after three participants installed their window inserts. Chapter 3 addresses Objective 5 by comparing the modelled and actual savings for two participants who installed window inserts.

# CHAPTER 2

# WINDOW INSERTS IN COMMUNITIES: CLOSING THE ENERGY EFFICIENCY GAP

## 2.1. Introduction

In order to fully understand the WindowDressers builds, it is important for us to know the social perceptions and behaviors associated with them. This research will provide WindowDressers, and other community energy movements, better insight to why people participate in community energy efficiency projects and how they feel about their experience once they do. Grassroots energy movements are growing, and people are participating for more reasons than a monetary incentive [7]. We need to better understand how the people participating in these movements think and feel to help capitalize on their potential, and learn about how participation affects them. This chapter aims to build on that understanding and examines survey data to identify stated preferences and behaviors of WindowDressers community build participants, to answer two research questions:

1. Why do people choose to participate in community window insert projects and how satisfied are they with the overall experience of participation?
2. How do behaviors change after participation in a window insert project? Are participants likely to continue participating in the project; are they likely to recommend that others participate in the future; are there any signs of a rebound effect?

Question 1 will be answered shows that participation is influenced by monetary savings, energy savings, emissions savings, as well as community influence. Question 2 assesses changes in behavior, and whether participants will continue to be involved in the projects future.

## 2.2. Background

### 2.2.1. Motivations for Participation

Rational Choice Theory in economics states that individuals make decisions to maximize their utility depending on their individual goals and preferences. Every decision is weighed against alternatives, and the individual picks the choice that will provide the most utility. It is the basic building block in the field to why any decision is made. Even in group actions, there is a methodological individualism that all group actions are the result of individual decisions to participate [13]. There has long been an ongoing debate amongst economists, sociologists, anthropologists, and psychologists about the validity of the theory. Anthropologist Dr. Michael Chibnik wrote *Anthropology, Economics, and Choice* in 2011, which analyzed the different approaches anthropologists, economists, psychologists, and sociologists took in order to answer the same problems. Chibnik acknowledged that economics carries the most influence among the social sciences, and pointed out some of the flaws in the assumptions that many economists make. Chibnik did not agree with the assumption that the economy is filled with rational actors [14]. In his words, "The application of rational choice models has been questioned (Gladwell, 2005 for example) for the many situations in which people make decisions without consciously and systematically weighing the costs and benefits to alternative actions" [7, page 12]. Sociologists and other social scientists tended to see their work as an alternative to rational choice theory due to its simplicity and the homogeneity of the supposedly rational actors [16]. An alternative method of understanding human decision-making is the anthropologic theory of social embeddedness developed by Karl Polanyi [17] and further clarified by Mark Granovetter [18]. Granovetter argues that behavior is influenced by ongoing social relationships and should not be construed with the independent rationality of separate actors. He believed that most neoclassical economists who subscribe to rational choice theory were "undersocializing" human behavior. The problem with social embeddedness is that its effect cannot be quantified, just observed. Social embeddedness continues to be relevant in the field of anthropology, however no research has yet been conducted specifically about social embeddedness in residential energy efficiency. There is research however, on the social embeddedness of volunteerism on a non-profit organization. Research suggests that more volunteer focused organizations seem to ward of the threat of closing down over time [19]. The authors did not pin down an exact cause for this, but they had a theory that "volunteers maintain their efforts with an organization long after they have served their initial purpose" [18 page 183]. This suggests that a volunteer-led organization like WindowDressers may have a better chance of existing long-term compared to a similar non-volunteer led organization due to repeat participation of community volunteers.

There is evidence that customers are failing to implement cost-saving energy efficiency investments, even when it is the rational decision to do so – in other words, there is an "energy-efficiency gap" [20]. Part of the "energy efficiency gap" also be attributed to the lack of necessary information. Environmental and social psychologists use the Information Deficit Model show explain that people may not be adopting simply because they do not have the necessary information [21]. But this "energy-efficiency gap" also exists in large part due to "hardware bias," which is the tendency to "see energy efficiency as primarily about technology and economics, rather than also about human behavior and psychology" [20 page 24]. In other words, the social aspects of a project carry a significant importance in the success of a project in addition to the economic benefits. This is why it is important to focus on community energy projects, which have the unique benefit of using social behaviors to promote economic benefits.

There is literature to support low-income residents wanting to act more pro-environmental than they are able to achieve, relative to their higher income peers. Michael Redcliff and Ted Benton described this phenomenon in *Social Theory and the Global Environment*: "One of the most important insights which the social scientist can offer in the environmental debate is that the eminently rational appeals on the part of environmentalists for 'us' to change our attitudes or lifestyles, so as to advance a general 'human interest' are liable to be ineffective. This is not because ... 'we' are irrational, but because the *power* to make a significant difference, one way or the other, to global or even local environmental change is immensely unevenly distributed" [19 pages 7-8]. In other words, no matter how environmentally conscious you are, impactful pro-environmental actions – even at the local level - are far easier to participate in if you have money. If in fact lower-income members of society are environmentally motivated, community energy projects that focus on low-income participant like WindowDressers would be able to provide the opportunity for their actions to make a difference.

### 2.2.2. Changes in Behavior

This research is interested in whether community window insert build participation can change environmental behaviors through a spillover effect. A positive spillover effect is described as "a person's inclination to engage in other sustainable behavior increases after engaging in prior sustainable behavior" [22 pages 2-3]. Positive spillover can be attributed to the idea that increased familiarity with energy efficiency behaviors may make it easier to repeat them [25] or environmental attitudes may change as a result of a pro-environmental behavior [26]. In the case of community built window inserts, repeat participation in a future window insert build would qualify as one example of a positive spillover.

A negative spillover effect is when individuals participate in negative environmental behavior after participating in a positive one [24]. In the case of community built window inserts, an example of a negative spillover would be a rebound effect. The rebound effect is generally considered to be when monetary savings from energy efficiency improvements are used to increase energy or maintain the same level overall [27]. Existing studies highlight the potential for rebound effects as a result of energy efficiency adoption. In economics, rebound effect can be explained due to a relative decrease in the price of energy; when the price of a good decreases, consumption generally rises [28]. The rebound effect can be either direct or indirect [28]. An example of a direct rebound effect related to energy efficiency would be if a home owner installs added insulation to their home, thereby saving money on heating costs, and then uses the monetary savings to purchase additional heating fuel (e.g., raises the thermostat in the winter) to keep the home warmer than before. An example of an indirect rebound effect in this case would be if the home owner spent the monetary savings on something else that consumes energy (an additional appliance, additional travel, or something less obviously related to energy like new clothes or other material goods). There are studies that quantify a rebound effect in home heating [29] that will be addressed in Chapter 3 where actual costs and savings will be addressed.

No existing studies use survey data to assess residential home weatherization rebound effect. Survey data would not be likely to give an accurate representation of changes in energy consumption behavior because they are entirely self-reported. Existing research uses historical household energy consumption data to observe changes in energy consumption after an energy efficiency improvement. Historical home energy consumption data will be used in chapter 3 of this study; however self-reported survey data can provide insight to whether customers believe they are changing their energy consumption behavior or not. This can be used in future research to analyze the difference between reported and actual rebound effects. Other sectors have used survey data specifically to support that a rebound effect exists. Survey studies have been conducted in the residential transportation sector in China [30] and the United States [31]. In China, 320 households were surveyed and a 13.98% direct rebound effect was found by finding the increase in total vehicle miles driven after residents switched to more fuel-efficient cars. In the United States, data from the 2009 National Household Transportation Survey (sample size not specified) was used to estimate a direct rebound of between 11% and 19% when also looking at vehicle miles driven after switching to more fuel-efficient vehicles. Surveys have also been used for the residential lighting sector in Germany [32], where 6,409 German households where surveyed on how often they change their light bulbs and found a 6% rebound effect in electric consumption by looking at changes in replacement bulb luminosity and how long residents left their lights on after switching to more energy efficient light bulbs.

Whether or not participants are changing their consumption behaviors after they buy window inserts will affect how much energy the customer is able to save. There is only one existing study that includes a predictive model for energy savings of window inserts and compares it to actual consumption [33]. David Sailor's model suggested that the average household in Oregon/Washington should expect around 10% energy savings during the winter season after installing Indow Window inserts. However, Sailor actually observed an average savings of 19% across the 4-household sample – nearly double what they expected. Sailor hypothesized that the inserts decreased thermal drafts and made the homes feel more comfortable, leading to the residents decreasing their thermostats due to increased comfort, rather than increasing them due to a reduced heating cost. Sailor's observations suggest a positive rather than negative spillover effect.

Sailor's research is the only study to touch on the change in energy consumption behaviors associated with window inserts specifically. The lack of research conducted on the direct rebound effect associated with window insert adoption, coupled with the precedent of prior research examining rebound effect through survey data, motivate the research approach presented in this chapter.

**2.3. Methods**

We sent out three surveys in total with the active dates, target communities, number of responses, and target population size visible in Table 1. The target population includes all coordinators (volunteers who organized the builds), customers (people who ordered inserts), and volunteers (people who helped build inserts but were not coordinators) who took part in any WindowDressers build. While respondents from each of these roles received the same survey, there were blocks designed specifically for customers and/or volunteer/coordinators that would not be asked unless the respondent indicated that they fulfilled that role. Note that any respondent may have played multiple roles and received the questions for each role they indicated. There were additional introductory questions, energy knowledge questions, energy consumption behavior questions, and demographics questions that every respondent was presented with, regardless of their role in participation (full surveys can be found in the supplemental materials, see Appendix A). All of these surveys were sent out sometime after each of the builds had been completed. The first survey specifically targeted the Bangor 2015 build participants. This research team acted as coordinators for this build and had the contact information to email every participant the survey directly. However we wanted to include all of the other communities in our research, so we created a second 2015 survey which targeted every other WindowDressers build participant. This second survey was sent out as a web link by WindowDressers directly to the coordinators of the other 11 build sites. The coordinators were asked to distribute the survey amongst their own participants. We hoped to gather responses from not only 2015 participants, but also participants from previous years dating back to the project's 2010 inception. We do not know the exact size of the target population outside of Bangor, however we do know that around 5,000 inserts were built by other builds through 2015. Using Bangor as a reference, 385 inserts were built among 56 participants – or about one participant for every 7 inserts – we can estimate that there were more than 700 participants outside of Bangor through 2015. The third survey was sent after the 2016 builds and hoped to gather responses from both new participants and past respondents. We distributed the survey in the same manner as the 2015 surveys, however we distributed the same survey to everyone. We emailed it to all of the Bangor participants individually, and WindowDressers distributed a web link to the other 16 builds that took place in 2016. With the third survey, we gathered responses from new participants as well as at least 20 participants who indicated they had taken one of our 2015 surveys (14 indicated they were not sure). There were over 6,000 inserts built through 2016. Using the same logic of one participant for every seven inserts, we estimate our target population for the 2016 survey was over 850.

*Table 1 – List of surveys*

| Survey Name | Target Communities | Active Dates | Number of Responses | Target Population Size |
|---|---|---|---|---|
| 2015 Survey (Bangor) | Bangor | Nov 2015 - Mar 2016 | 27 | 56 |
| 2015 Survey (Other) | All Other | Nov 2015 - Mar 2016 | 129 | >700 |
| 2016 Survey | All | Nov 2016 - Apr 2017 | 181 | >850 |
| Total | | | 337 | >850 |

All survey questions that will be discussed in this paper were asked in all three surveys and the results combine all available data.  Any respondent to the 2016 survey who indicated they had also taken the 2015 survey, were not asked any questions that will be mentioned in this paper a second time (assured using skip logic in the survey).  Most of the questions were presented as a Likert scale, allowing respondents to rate to which degree the question applied to them.  An example of a 5-point Likert scale question is seen in Figure 4.

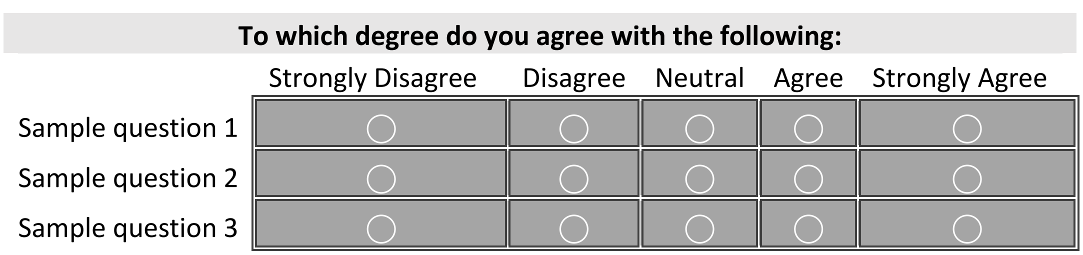


*Figure 4 – Sample Likert scale question*

### 2.3.1. Motivations and Impressions

To determine why customers purchased window inserts, we asked all respondents to the three surveys who indicated they were customers a Likert scale question which asked: "Please indicate to what degree you agree with the following statements. I ordered window inserts…

- … to save money.

- … to benefit the environment
- … to conserve energy
- … to improve comfort
- … because I value the sense of community associated with the project."

To determine why volunteers and coordinators volunteered their time for the builds, we asked all respondents in the three surveys who identified themselves as a customer a Likert scale question which asked: "Please indicate to what degree you agree with the following statements. I am participating in this Window Insert Build…

- … to benefit the environment.
- … to help others conserve energy.
- … to help others live more comfortably.
- … because of the sense of community associated with the project."

In the 2015 surveys, these questions were presented as a 5 point Likert scale with the options of strongly disagree, disagree, neutral, agree, or strongly agree, with two additional options of not sure, and not applicable. For the 2016 version of the survey, we also presented them as a 5 point Likert scale, but dropped the not sure and not applicable options. The graphs presenting these data will include all neutral, not sure, and not applicable selections together. WindowDressers has a specific focus towards low-income customers, allocating 25% of inserts at each build to them. Therefore, these questions will also be analyzed through an independent sample t-test, comparing the responses of participants who indicated their household income was $25,000/year or less, to responses from all other respondents. Each t-test in this thesis has been tested for equality in variance using Levene's Test (Appendix B). T-tests assume equality in variance, therefore all statements that violate the equal variance assumption were adjusted using the

Welch-Satterthwaite method built into SPSS [34]. The income level of $25,000/year was chosen as the threshold because of the survey structure. We asked respondents to select the range of their household income, the lowest options being $25,000/year or less and the second lowest being $25,000 to $50,000/year. $50,000/year is higher than the median Maine household income ($49,331/year), and would not be considered a low-income household. To simplify this analysis, responses of Agree and Strongly Agree were both re-coded as a 1, and any other response was re-coded as a 0. The reasoning was that it was more relevant to answering the research question to observe what percent of respondents found each statement to be either influential or not influential. The percentage of each population that agreed to any degree with any of the statements will be presented along with a p-value representing statistical significance between the two options.

To determine the satisfaction in the overall project, we asked every respondent, "How satisfied were you with the overall window insert experience?" This was presented as a five point Likert Scale with very satisfied, somewhat satisfied, neutral, somewhat dissatisfied, and very dissatisfied presented as options in all three surveys. We also asked any who identified themselves as volunteers and/or coordinators to rate their volunteer experience, asking "Overall my experience as a volunteer was…

- Much better than expected.
- A little better than expected.
- The same as expected.
- A little worse than expected.
- Much worse than expected."

This question was presented the same in all three surveys. A t-test was conducted to again compare a difference in response between lower (<$25,000/yr) and higher incomes, however no statistical significance was found. Therefore, another t-test was completed to determine if there was any statistical difference in volunteers who volunteered a substantial amount of time (more than eight hours), compared to volunteers who gave less time. The number of hours was set at eight because the typical volunteer shift was 4 hours. Respondents who reported volunteering eight hours or less were assumed to participate in one or two build shifts, but respondents who volunteered for more than 8 hours were assumed to have taken a bigger role (more volunteer shifts, additional outreach, helping to coordinate, etc.). For this question, the scale to which degree a respondent felt about their experience was important because we are trying to determine how highly each group ranked their experience. All responses indicating their experience was re-coded in order; from much better than expected coded as 5, to much worse than expected coded as 1. The mean response from each of the volunteer groups will be presented along with a p-value denoting the statistical significance between the two.

### 2.3.2. Changes in Behavior

All survey participants were asked about their likeliness to continue participating in future WindowDressers builds: "Please indicate how likely you are to…

- … volunteer for a future Window Insert Build.
- … help initiate a future Window Insert Build.
- … recommend a friend order window inserts.
- … recommend a friend volunteer for a Window Insert Build."

This question appeared in all three surveys as a 4 point Likert scale, with the options of Not Likely, Somewhat Likely, Likely, or Very Likely. The percentage of respondents who reported being Likely or Very likely to each question will be reported. Observations were made between respondents who volunteered time at a build (volunteers and coordinators), and respondents who did not volunteer time (just customers) using a t-test. The reasoning was to compare how volunteering in this project might potentially change future behaviors relative to not volunteering. Each response was converted to a 1-4 scale were Very likely was coded as a 4 and Not likely was coded as a 1. The mean response in the volunteer and non-volunteer groups will be reported, along with a test for statistical significance.

All customer respondents were asked whether they changed the temperature in their homes after they installed their inserts. This question will be used to hypothesize the reported likeliness of a direct rebound effect. The question read, "Now that the window inserts are installed, have you changed the temperature at which you set your thermostat in the winter?" In the 2015 version of the survey, the respondent answered either yes or no. If they responded yes, they were prompted with a text entry field which asked them to state how their temperature setting has changed. The goal was to determine if customers were raising or lowering the temperature in their homes, and responses that provided this information were manually sorted accordingly. However, 10 of the 27 respondents left this text entry blank. To remedy this, the answer options were changed in the 2016 version of the survey to read "no – it has not changed"; "yes, I have raised the temperature"; or "yes, I have lowered the temperature". The text entry prompt was still included for respondents selecting either of the "yes" options with a request for more information.

### 2.4. Results and Discussion

#### 2.4.1. Why do People Choose to Participate in Community Window Insert Projects and how Satisfied are they with the Experience?

When we asked customers why they purchased inserts, we expected a strong response for money and energy savings as these inserts are marketed as “one of the lowest cost energy efficiency improvements a homeowner can invest in, offering the shortest payback with a high return on […] investment that improves home weatherization” [6]. From all the customers who responded to any of the three surveys, 207 out of 225 respondents either agreed (68) or strongly agreed (139) that monetary savings contributed to their decision and 220 out of 226 either agreed (55) or strongly agreed (165) that conserving energy contributed to their decision (Table 2, Figure 5). Indow Window studies reported that inserts decreased drafts and increased thermal comfort [33]. We also see that 212 out of 226 customers agreed (67) or strongly agreed (145) that they purchased their inserts to increase their own comfort. As stated in their mission statement, WindowDressers believes their window inserts are a tool that everyday people can use to help reduce their impact on climate change [35]. From our survey results, 180 out of 221 respondents agreed (75) or strongly agreed (105) that they ordered window inserts to benefit the environment, and 193 out of 223 respondents agreed (72) or strongly agreed (121) that they purchased inserts to reduce dependence on fossil fuels. Finally, the main difference between this project and other window weatherization methods is the community involvement in this project. Anthropologists might argue that there is some level of social embeddedness involved in a community project like this one. We asked survey participants whether the sense of community associated with this project influenced their decision to purchase inserts, and found that 146 out of 218 either agreed (88) or strongly agreed (58) that it did. While this response is not as strong as any of the other metrics, 67% of customers still reported it influenced their decision.

*Table 2 – Motivation for purchasing window inserts*

| Motivation for Purchase | Indicated Agree or Strongly Agree | Total Responses | Percentage |
|---|---|---|---|
| To conserve energy | 220 | 226 | 97% |
| To improve comfort | 212 | 226 | 94% |
| To save money | 207 | 225 | 92% |
| To reduce dependency on fossil fuels | 193 | 223 | 87% |
| To benefit the environment | 180 | 221 | 81% |
| Because they valued the sense of community associated with the project | 146 | 218 | 71% |

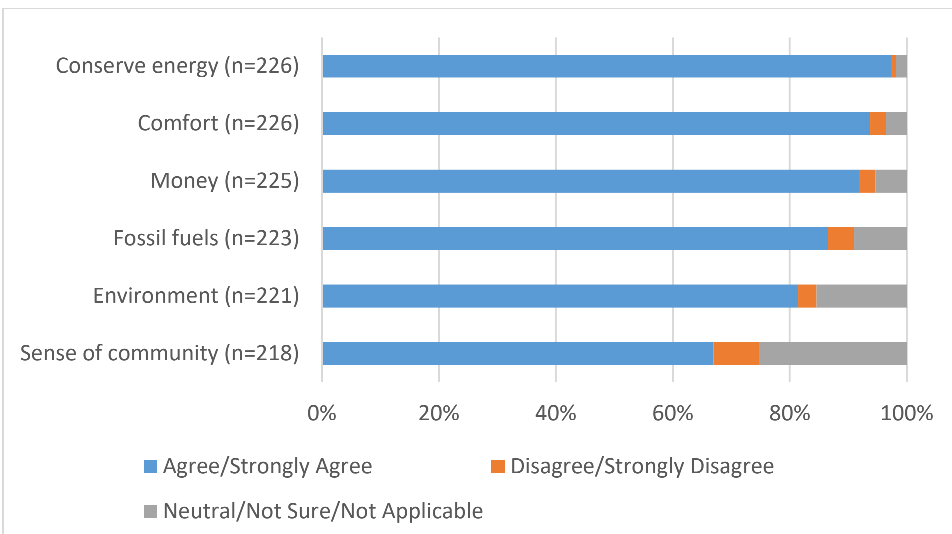


*Figure 5 – Motivation for purchasing window inserts*

WindowDressers has an emphasis for low-income households to purchase inserts; therefore, we compared the lower-income (<$25,000/year household income) responses to the responses of everyone else. Unfortunately, there were only 26 survey respondents who reported themselves as low-income customers. A t-test was still completed out of interest of the result; however the small sample size should be noted. Table 3 shows the percentage of lower-income and higher-income respondents that agreed or strongly agreed with each motivation, as well as the p-value from the t-test. According to the t-test, lower-income households were more likely to buy inserts to save money and improve the comfort of their homes than higher-income respondents. This may be because higher income customers have been able to afford keeping their houses comfortable before purchasing inserts in a way that low-income customers could not. There was no statistical significance between low-income or higher income customers purchasing inserts to conserve energy, reduce dependency on fossil fuels, benefit the environment, or because they valued the sense of community associated with the project.

*Table 3 – Comparing motivation for purchasing inserts by income*

| Motivation for Purchase | Lower-income (Agree or Strongly Agree) | Higher Income (Agree or Strongly Agree) | T-Statistic | Degrees of Freedom | p-value |
|---|---|---|---|---|---|
| To conserve energy | 100% (n=26) | 97% (n=155) | -0.926 | 179 | 0.356 |
| To improve comfort | 100% (n=26) | 92% (n=155) | -3.755 | 154 | 0.000*** |
| To save money | 100% (n=26) | 90% (n=154) | -4.063 | 153 | 0.000*** |
| To reduce dependency on fossil fuels | 92% (n=24) | 89% (n=155) | -0.388 | 177 | 0.699 |
| To benefit the environment | 83% (n=24) | 85% (n=155) | 0.148 | 177 | 0.883 |
| Because they valued the sense of community associated with the project | 61% (n=23) | 72% (n=153) | 1.078 | 174 | 0.283 |

**** indicates statistical significance at (α=0.01)*

*Grey cells have been adjusted using the Welch-Satterthwaite method*

When observing the reported motivations for volunteering, the order of the statements from most to least influential is identical to the motivations customers reported for buying their inserts (Table 4, Figure 6). The exception is that we did not ask volunteers if they participated to help others save money or not. Note, there was some overlap in the responses as respondents who indicated themselves as both a customer and a volunteer/coordinator would have answered both the motivation for purchase and motivation for volunteering questions. 87 out of 94 respondents reported that they agreed (24) or strongly agreed (63) that they were volunteering to help others conserve energy, and 83 out of 91 respondents reported that they agreed (25) or strongly agreed (58) that they were volunteering to help improve the comfort of others. 82 out of 90 respondents reported they agreed (21) or strongly agreed (61) that they were volunteering to help reduce dependency on fossil fuels, and 81 out of 89 respondents reported that they agreed (21) or strongly agreed (60) that they were volunteering in order to benefit the environment. Finally, 79 out of 90 respondents agreed (32) or strongly agreed (47) that they were participating because of the sense of community associated with the project.

*Table 4 – Motivation for volunteering*

| Motivation for Volunteering | Indicated Agree or Strongly Agree | Total Responses | Percentage |
|---|---|---|---|
| To help others conserve energy | 87 | 94 | 93% |
| To improve comfort of others | 83 | 91 | 91% |
| To reduce dependency on fossil fuels | 82 | 90 | 91% |
| To benefit the environment | 81 | 89 | 91% |
| Because they valued the sense of community associated with the project | 79 | 90 | 88% |

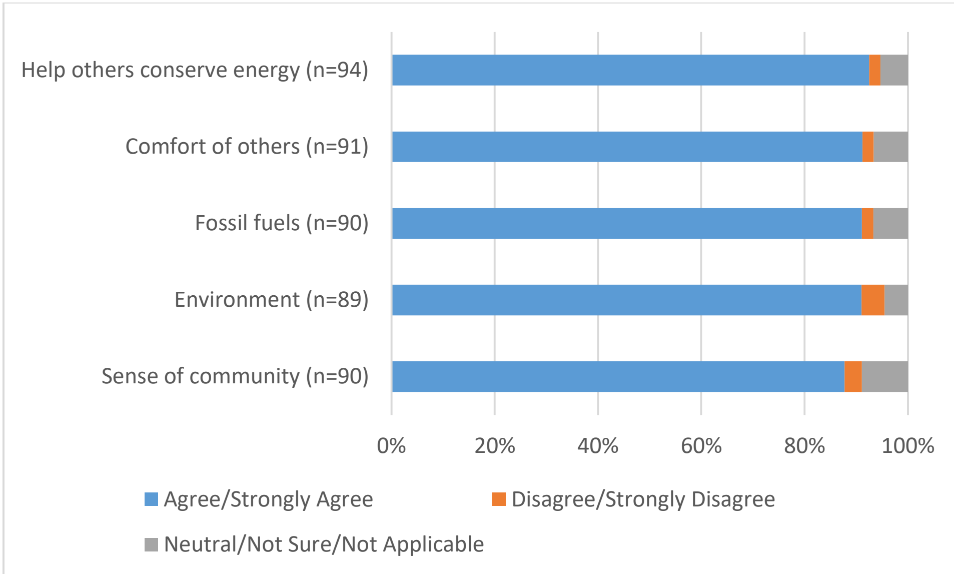


*Figure 6 – Motivation for volunteering*

Again comparing income level responses, we tested if low-income participants (<$25,000/year household income) volunteered for any different reasons compared to everyone else. Unfortunately, there were only 12 survey respondents who reported themselves as low-income volunteers. A t-test was completed out of interest, but the small sample size should be noted. However, there was no statistical difference between low-income and higher-income statements for volunteering to help others conserve energy, improve the comfort of others, reducing dependency on fossil fuels, benefiting the environment, or because they valued the sense of community (Table 5).

*Table 5 – Comparing motivation for volunteering by income*

| Motivation for Volunteering | Lower-income (Agree or Strongly Agree) | Higher Income (Agree or Strongly Agree) | T-Statistic | Degrees of Freedom | p-value |
|---|---|---|---|---|---|
| To help others conserve energy | 83% (n=12) | 94% (n=66) | 0.913 | 12.569 | 0.379 |
| To improve the comfort of others | 83% (n=12) | 94% (n=64) | 0.895 | 12.668 | 0.388 |
| To reduce dependency on fossil fuels | 83% (n=12) | 95% (n=64) | 1.037 | 12.264 | 0.320 |
| To benefit the environment | 75% (n=12) | 95% (n=64) | 1.524 | 11.931 | 0.153 |
| Because they valued the sense of community associated with the project | 92% (n=12) | 89% (n=63) | -0.282 | 73 | 0.779 |

*Grey cells have been adjusted using the Welch-Satterthwaite method*

When all survey respondents are asked about their overall satisfaction with their participation in the project as a whole, we see very high satisfaction reported. 269 out of 279 respondents reported being satisfied (40) or very satisfied (229) with the project experience overall. However, 6 were reportedly dissatisfied with one of those indicating very dissatisfied. The additional 4 respondents reported neutral feelings. When we asked volunteers how the overall experience of just the volunteer portion of the project was, respondents reported overall good experiences. Of 183 respondents, 89 reported the volunteer experience to be much better than expected, 36 reported it to be slightly better than expected, 54 reported it was as they expected, and 4 reported the volunteer portion of the project to be slightly worse than expected. There was no statistical difference between low-income (<$25,000/year household income) and higher income responses for overall volunteer experience. However, we can see a statistical difference in a respondent's overall volunteer experience by how much time they reported volunteering. In Table 6 we see that volunteers who participated for over 8 hours reported a slightly (0.25 out of 5) better overall volunteer experience than those who volunteered for 8 or less.

*Table 6 – Comparing satisfaction in the volunteer experience by time spent participating*

| Metric | 8 or Less Hours of Volunteerism | More than 8 Hours of Volunteerism | p-value |
|---|---|---|---|
| Overall volunteer experience (rated 1-5) | 4.02 (n=84) | 4.27 (n=94) | 0.071* |

** indicates statistical significance at (α=0.1)*

### 2.4.2. How do Behaviors Change After Participation?

Supporting the literature, there is evidence in the survey responses that participants may continue to play an active role in the future of this project [19]. 188 out of 272 people said they were likely (45) or very likely (55) to volunteer in a future window insert build, and 205 out of 271 people said that they were likely (83) or very likely (122) to recommend their friend volunteer in a future build (Table 7). Comparing the responses from people who actually volunteered time in any capacity (volunteers and coordinators), to those who participated solely as customers, we can observe a strong statistical difference in a respondent's interest in participating, or recommending others participate in future projects (Table 8), with volunteers being statistically more likely to volunteer in a future build, more likely to initiate a future build themselves, and more likely to recommend a friend volunteer than non-volunteers. There is no statistical difference in recommending a friend to purchase inserts in a future build.

*Table 7 – Likeliness of future participation*

| Future Participation | Indicated Likely or Very Likely | Total Responses | Percentage |
|---|---|---|---|
| Recommend a friend purchase inserts in a future build | 255 | 273 | 93% |
| Recommend a friend to volunteer in a future build | 205 | 271 | 76% |
| Volunteer in a future build | 188 | 272 | 69% |
| Initiate a future build | 60 | 254 | 24% |

*Table 8 – Comparing the likeliness of future participation of volunteers and non-volunteers*

| Future Participation | Volunteers or Coordinators | Non-volunteers | T-Statistic | Degrees of Freedom | p-value |
|---|---|---|---|---|---|
| Recommend a friend purchase inserts in a future build (1-4) | 3.63 (n=195) | 3.68 (n=74) | 0.552 | 267 | 0.582 |
| Recommend a friend to volunteer in a future build (1-4) | 3.36 (n=195) | 2.63 (n=72) | -5.348 | 97.392 | 0.000*** |
| Volunteer in a future build (1-4) | 3.34 (n=195) | 2.09 (n=74) | -8.867 | 110.091 | 0.000*** |
| Initiate a future build (1-4) | 1.93 (n=181) | 1.43 (n=70) | -3.496 | 149.503 | 0.000*** |

**** indicates statistical significance at (α=0.01)*

*Grey cells have been adjusted using the Welch-Satterthwaite method*

Finally, there is still a concern about rebound effects for customers. The literature supports the idea that increased energy efficiency may lead to a rebound effect. However, research is minimal in looking at a self-reported rebound effect for home weatherization. According to our survey, 50 out of 177 respondents claimed that they changed the temperature of their home after installing inserts. However, 32 respondents reportedly lowered their temperature, only 8 reportedly raised it, and 10 did not specify the change. Overall, it appears that most customers left their homes at the same temperature (or lowered it), which would not suggest a reported direct rebound effect. One low-income respondent who raised their thermostat stated "I've increased [the thermostat]… Just tired of being cold." A higher-income respondent who lowered their thermostat stated "I [lowered the thermostat]… and am still comfortable in the bedroom." Research into the Indow Window suggested that customers may have reduced their thermostat settings due to increased thermal comfort and reduced drafts [33]. 96 out of 99 of our surveyed customers reported being satisfied (30) or very satisfied (66) with their inserts' ability to reduce drafts (Table 9), with 1 reporting a neutral response and 2 reporting a very dissatisfied response. 93 out of 98 respondents were reportedly satisfied (39) or very satisfied (54) with their inserts contribution to warmer rooms, with 2 reporting neutral, 1 dissatisfied, and two very dissatisfied responses. These survey data support the perspective from Indow Window research that improved comfort may encourage residents to leave their thermostats lower than they normally would [33].

*Table 9 – Customer satisfaction with inserts ability to reduce drafts and warm rooms*

| Window Insert Quality | Indicated Satisfied or Very Satisfied | Total Responses | Percentage |
|---|---|---|---|
| Less drafts | 96 | 99 | 97% |
| Warmer rooms | 93 | 98 | 95% |

## 2.5. Conclusions

Question 1 aimed to determine why people are participating in this project and how satisfied they are once they do. Literature tells us that participating is a rational, utility maximizing decision [13], but the community aspect of this project also creates a social influence. 97% of Customers agreed they purchased to conserve energy, 94% to save money, 92% to reduce dependency on fossil fuels, and 87% to benefit the environment, and 71% that they valued the sense of community associated with the project. However, low-income customers were more likely to be participating to save money and improve comfort than a higher income customer. A low-income customer who reported raising his thermostat after purchasing his inserts, stated the reason was that he was "tired of being cold". It would make sense that low-income customers who cannot as easily afford to live as comfortably as higher income-customers, would be more motivated by financial savings and an increase in comfort. 93% of volunteers agreed that they participated to help others conserve energy, 91% to reduce dependency on fossil fuels, 91% to benefit the environment, and 88% because they valued the sense of community associated with the project. There was no statistical difference between why low-income volunteers participated to why higher-income volunteers participated. However, the small sample size of low-income volunteers (12) should be noted. The fact that low-income participants were statistically equal to both purchase inserts, or volunteer for environmental reasons as higher-income participants, supports the notion that they have same interest to make an environmental difference, despite the ability for either group to do so being unevenly distributed [19]. WindowDressers and other community energy movements that focus on low-income participants have a unique ability to provide lower-income members of society with that opportunity. The people are taking advantage of that opportunity are enjoying it; 96% of all participants were overall satisfied with their experience. Amongst volunteers, 68% of them noted that their volunteer experience was some degree better than they had expected it to be. Volunteers who participated for more than eight hours rated their experience better overall than volunteers who participated eight hours or less. It is unclear whether these volunteers report a better satisfaction as a direct result of volunteering more, or if they volunteered more because of their higher satisfaction in doing so.

Question 2 was aimed to determine how behaviors changed after participation in a window insert project. Most respondents where likely to recommend a friend purchase inserts (93%), recommend a friend volunteer (76%), and volunteer in a future build themselves (69%). Most respondents were not likely to initiate a build in the future, but 24% still were. Literature shows that non-profit organizations that depend on volunteers last longer than those that do not [19]. This is observed in our survey responses when we compare likeliness of future participation amongst volunteers and non-volunteers. The volunteers were more likely to recommend a friend volunteer, volunteer in a future build themselves, and initiate a build in the future compared to non-volunteers. Literature shows that a rebound effect is typically found after an energy efficiency improvement [28]. There is no previous research using survey data to determine a rebound effect in residential home heating. A direct rebound effect would be evident if a respondent raised the temperature in their home after installing window inserts. Evidence from our survey shows that 28% of customer respondents did reportedly change their thermostat after installing inserts. Eight respondents did report raising their temperature, showing a rebound effect may be attributed to window inserts in some cases. However, most respondent did not report changing their thermostat (127) and more reportedly lowered their temperature (32) instead of raised it. This does not suggest a likely direct rebound effect associated with adoption (note that 10 respondents did not specify how they changed their thermostats after installing inserts).

Limitations in this study included a low number of low-income respondents. While WindowDressers does not define a low-income household, they focus their efforts towards this demographic and allocate 25% of their inserts to these customers for a reduced rate. This study defined a low-income customer to have a household income of $25,000 or less, and only 14% of our respondents qualified into this category. Either customers earning a household income of more than $25,000 a year are qualifying themselves as low-income customers, or there is a disproportionate number of low-income participants responding to the survey. WindowDressers does not have a defined standard for a low-income customer, they depend on customers to self-identify. A limitation with the survey was that it did not ask the customers which pricing option they paid, rather it asked customers to pick the household income bracket that defined them (<$25,000/year, $25,000-$50,000 per year, $50,000-$70,000 per year, etc.). Future work should identify the customers who actually paid the low-income rate from the group of respondents. The second limitation is a lack of non-participant information. The information provided in this chapter is useful to understanding WindowDressers participants, but nothing is done to determine what makes them different from non-participants. Future work should include a concise survey for a sample of Maine residents that included both WindowDressers participants and non-participants, to identify what really motivates participation over non-participation. The third limitation is a lack of previous research on community energy efficiency. It is difficult to place this research into the context of previous work because very little applicable work has been done before. If community projects like this one continue to grow into the future, more research may follow.

These results are important for WindowDressers and other organizations like it to better understand their participants. The results are also important for homeowners are looking for an affordable alternative to window replacement. However, these results more importantly build upon the limited body of literature for any researchers of any discipline looking to identify the motivations, perceptions, and changes in behavior resulting from community energy efficiency participation. There is an amount of social embeddedness involved in participation that is overlooked in energy efficiency adoption, as well as a possible "positive spillover" from the participants staying involved in the future. There is reason to suggest that window inserts could even defy the expected "negative spillover" of a rebound effect that should follow an increase in energy efficiency which should be looked into further. Finally, government agencies and utility companies interested in decreasing the "energy-efficiency gap" that prevents people from increasing their energy efficiency, even when it is in their financial interest, should take notice of community built inserts.

# CHAPTER 3

# ANALYZING THE COSTS AND BENEFITS OF WINDOW INSERTS

## 3.1. Introduction

Heating a home is expensive in cold states like Maine. 540 gallons of #2 fuel oil (also referred to as heating oil or fuel oil) are used every year to heat a typical Maine household [1]. Thirty percent of heat loss in a home goes through the windows [6]. Replacing residential windows to increase energy efficiency can range from $200 -$1500 per window, and may even have a payback period longer than 100 years [37]. WindowDressers and several other organizations have been building window inserts as an alternative to increase window energy efficiency. This chapter aims to determine how effective these inserts can be at reducing energy consumption. There are three main objectives for this chapter:

1. Predict how much money, energy, and emissions window inserts can save.
2. Determine how much money, energy, and emissions window inserts have actually saved.
3. Compare predicted savings to actual savings, including an assessment of rebound effect.

The first objective requires a model to determine the estimated change in heat loss through a window as a result of inserts. A sensitivity analysis is also conducted to account for the uncertainty in the parameters of the model. Estimated energy, money, and emissions savings will all be reported. The second objective requires an analysis of the change in energy, money, and emissions for three WindowDressers customers in years before and after installing window inserts. A sensitivity analysis is again conducted to account for the uncertainty in the parameters. The third objective will compare the modelled and actual savings for two of these customers.

### 3.2. Background

There is very little available literature on the savings of window inserts. However, there are a few scientific studies. In 1997, Andrew Shapiro, an energy engineer, and Brad James, a master's degree student at the University of Vermont wrote a thesis on heat loss through windows associated with similar window inserts [36]. All numbers presented in their paper have been inflation adjusted into 2016 dollars in my thesis. They observed the financial and energy savings attributed to two different types of window inserts that were placed inside 14 typical windows, sized 36" by 60", in Burlington, VT. They presented all of their energy and financial savings estimates using the assumption of fuel oil being used for heating; an assumed cost of $1.35 per gallon of fuel oil; and an assumed furnace efficiency of 75%. The first type of insert they tested was constructed of Plexiglas and used magnetic strips to lock the insert in place inside the window frame. With this type of insert they projected a $4.42/insert annual savings (3.27 gallons of fuel oil) when placed inside the typical performing windows. When this same insert was placed inside looser fitting window frames, they projected the savings to jump up to $24.40/insert per year (18.07 gallons of fuel oil). However, when it was placed inside tighter fitting window frames that included an exterior storm window, the expected savings dropped to $2.13/insert per year (1.58 gallons of fuel oil). When they tested a spring loaded insert with a metal frame, they found this insert would save $3.86/insert per year (2.85 gallons of fuel oil) when placed in typical windows; $23.94/insert per year (17.73 gallons of fuel oil) when placed on looser windows; and $1.68/insert per year (1.24 gallons of fuel oil) when placed in tighter windows with an exterior storm window. The authors estimated that 84% of total heat loss through the window is from non-infiltration processes (conduction, convection, or radiation). The other 16% of heat loss could be attributed to infiltrative processes (unchecked air flow through the window opening). It should be noted that each of these inserts differ from the primary insert in this research study, however research on these inserts remains relevant as one of the few similar technologies that have been studied.

Two studies were done in Washington/Oregon by Portland State University and the Pacific Northwest National Laboratory (PNNL), each in 2013. They both conducted studies on window inserts sold by Indow Windows, which "are made of sheets of acrylic glazing edged with a patented spring bulb made out of silicone and filled with urethane foam. The spring bulb holds the insert in place by expanding and pressing against the window frame" [38]. The first was conducted by Portland State University [33]. Researchers monitored three homes in Oregon, and one home in Washington, which had all installed Indow Window inserts. The goal of the study was to develop a model to estimate energy savings and compare it to the actual observed results. They set up a testing facility where they conducted u-factor and noise abatement performance tests on a single insert. They concluded the insert would reduce noise by 10-20 dB inside the home, and that the average R-value (inverse of u-factor) of a single-pane window with an insert was 1.87, compared to 1.0 without. The R-value is a measure of how well an object prevents heat flow – the higher the R-value of an object, the more effective of an insulator it is. Researchers also tested air infiltration using a blower door test for each home after the inserts were installed. These tests found that the inserts reduced air infiltration by 3.7-7.7%, depending on the home. Researchers took the area of windows that inserts covered, as well as the area of glass that remained uncovered (windows without inserts and sliding glass doors), temperature estimates for the calendar year, and developed their estimated savings model; further details of which were not specified. Over the course of the year they discovered the annual natural gas usage (used for heating) of the homes decreased by an average of 19%, however their model suggested the reduction should have been closer to 9.8%.

Several months after the Portland State University study, PNNL conducted a study on a single Seattle, Washington home. The home was built in 1916, and had recently gone through alternative weatherizing retrofits, including a heat pump installation, installing a new duct system, additional insulation, and air sealing the basement. However, after these retrofits were complete, the owner noticed condensation gathering on his windows due to a combination of the reduced air exchange, water use inside the house (cooking, bathing, washing, etc.), and from an air pump being located directly below windows in the sunroom. To remedy this, the owner installed window inserts on all 27 single-pane windows of the home, which solved his condensation problem and allowed PNNL to meter the electric use and estimate his energy savings. After normalizing energy use by using heating degree days (a measurement for how much heating is needed to keep a home at a baseline temperature given the corresponding outside temperature for that period of time), they determined this individual consumed 21.1% less energy than they would have without inserts during the winter months. After determining the change in energy consumption, they estimated the payback period for this home to be 80.6 years, due to the cost of the inserts and abundance of prior weatherization. However, the researchers estimated that if the home had not previously undergone the other weatherization retrofitting and solely installed inserts, the payback period would have been 9.9 years. PNNL also monitored electric consumption during the summer, cooling months however found no significant savings. Additionally, the author measured the room temperature throughout the day to determine if inserts reduced temperature variance (stable temperatures are more comfortable), however these results did not find a conclusive difference to the variance before inserts were installed. The authors also monitored the envelope of the building using a blower door test and found that air leakage was reduced by 8.6% after the inserts were installed; this may have led to the owner's claim of increased thermal comfort [38].

Another window insert project has been conducted by Unity College in Maine since 2008. The college works with the Neighbor-Warming-Neighbor program to build window inserts like the ones in this study. However, in this case participants build only their own inserts (as opposed to WindowDressers builds where volunteers help build each other's inserts in addition to their own). Participants must measure their own windows, pre-register their measurements, and pay $1.25 per square foot of insert they wish to build for themselves [8]. They advertise that their inserts each save roughly one gallon of heating oil per square foot of window covered [39]. Their methods used to come to these conclusions were not specified.

### 3.2.1. Rebound Effect in Residential Heating

A brief review of the literature on rebound effect from window insert adoption is presented in Section 2.2.2. This section will expand this discussion to explore studies that have tested for a direct rebound effect in residential heating. Indirect rebound effect is beyond the scope of this paper.

In 2000, Richard Haas and Peter Biermayr measured the direct rebound effect for residents of Austria [40]. They measured the electric heating consumption for 12 large multi-family dwellings before and after each were retrofitted to be more energy efficient. Haas and Biermayr calculated a theoretical change in energy consumption and compared it to the actual change in energy consumption. Through this comparison, Haas and Biermayr found an average rebound effect of 30% of the expected efficiency savings from the retrofitting. In other words, these 12 buildings collectively only achieved 70% of their theoretical energy reduction. Haas and Biermayr are the only study prior to ours to observe direct rebound effect as a result of home weatherization efforts. All other studies that report a rebound effect in residential heating consumption do so by modelling the price elasticity of demand to simulate a direct rebound effect, but is not based upon an energy efficiency upgrade. Using price elasticity as an estimate for rebound effect is a standard practice used in the available literature; however it should be noted that Sorrell and Dimitropoulos argue that price elasticity may overestimate rebound effect due the “asymmetry of price elasticity estimates; the anticipated positive correlation between energy efficiency and other categories of input costs, notably capital costs; the role of price induced efficiency improvements; the endogeneity of energy efficiency; and the anticipated negative correlation between energy efficiency and time efficiency” [26 pages 645-646].

In 2001, Runa Nesbakken used a discrete continuous approach model with 551 households in Norway [41]. Their model estimated price elasticity for different fuels used for home heating; electricity, electricity and oil, electricity and wood, electricity and oil and wood. Employing a cross sectional analysis, she found an average energy price elasticity of 21% for all households. She also calculated the income elasticity associated with space heating and determined that for every 1% increase in income, heating consumption increases by 0.06%.

In 2003, Chantal Guertin et al. also used an econometric model and cross-sectional data to estimate a rebound effect in 440 households in Canada [42]. Their econometric model used a deterministic frontier analysis to determine the efficiency of different heating sources. They then used cross-sectional data to observe changes in behavior with changes in price. They broke their data into a low-income class (average income Can$19,000), middle income class (average income Can$44,000), and a high income class (average income Can$82,000) and found an estimated price elasticity for space heating of 43%, 33%, and 25%, respectively. The price elasticity is seemingly much higher for low-income individuals than those of a higher income.

In 2011, Reinhard Madlener and Maximilian Hauertmann used panel data and a fixed effects model in order to observe how price elasticity varies across home owners and renters, as well as across income among 11,000 German households as the price of energy (€/kWh) changed [43]. They found that the price elasticity was about 12% of energy savings for all home owners, compared to 40% of energy savings for all renting tenants. When comparing the rebound effect of different income levels, they found that both higher income (>€2710/month) and lower income (<€2710/month) home owners had a similar price elasticity with 14% and 13% respectively. However, when comparing the same two income brackets for renters, they found a sizable gap between 31% (higher income) and 49% (lower income) respectively.

The limited research analyzing rebound effect as a direct result of an energy efficiency improvement motivates the work presented in this chapter. Most studies that determine a rebound effect associated with residential heating do so by looking at the price elasticity of demand. This method has been questioned, and this thesis will instead look at rebound effect directly through comparing predicted and actual savings.

### 3.3. Methods

This thesis uses a predictive model to estimate energy savings from window inserts as well as an analysis of customer utility bills to calculate actual savings. The predictive energy savings model accounts for non-infiltration heat losses only (i.e., convection, conduction, and radiation through the glass). The predictive model uses measurements from a customer's home to estimate annual energy savings that would be achieved by installing inserts, including: 1) a simple payback period on their investment based on the cost of inserts, annual energy savings, and historical prices for heating fuel; and 2) a total simple payback period, which includes a basic opportunity cost valuation, assuming they participate in the requested 4- hour volunteer shift per seven inserts and abated emissions as a result of the modelled energy savings. The analysis of actual energy consumption uses historical heating fuel purchase data obtained from the fuel providers of three WindowDressers customers to compare the winter energy use before and after window insert installation, while accounting for differences in heating degree days each winter. The historical data from two of these customers are compared to the energy savings model output based characteristics specific to their homes.

### 3.3.1. Predicted Energy Savings Model

The predicted energy savings model uses Equation 1 to estimate the annual non-infiltrative heat loss through a window [44]. Equation 2 calculates the difference in heat loss between a window without an insert and the same window with an insert ($Q_{savings}$). The R-value of the window with an added insert is the sum of the R-value of the window and the R-value of the insert. Equation 3 estimates the monetary value of annual energy savings based on the price of heating oil (Table 10). The price of oil is determined by analyzing inflation adjusted prices since 2004 to find a median ($3.10), minimum ($1.79) and maximum ($4.09) price (2016 USD) [1]. Equation 4 estimates the cost of an insert from WindowDressers pricing structure (Table 11) [45]. Equation 5 uses the monetary cost and savings estimates to estimate the simple payback period for the investment. A simple payback period is used because it is straightforward and easy to understand compared to a discounted payback period that accounts for the time value of money. This is important because the model is presented to prospective WindowDressers customers, many of whom have not studied economics or been exposed to the concept of discount rate.

$$Q = \frac{A \cdot d \cdot h}{R} \quad (1)$$

$Q$ = heat loss (Btu/yr), $A$ = area ($ft^2$), $h$ = hours/day, $d$ = heating degree days. $R$ = R-value, see Table 10 for additional parameters

$$Q_{savings} = Q_{window+insert} - Q_{window} \quad (2)$$

$Q_{savings}$ = energy savings (MMBtu/yr), $Q_{window+insert}$ = energy lost through a window with an insert (MMBtu/yr), $Q_{window}$ = energy lost through a window alone, see Table 10 for additional parameters

$$S = \frac{Q_{savings}}{E_{oil} \cdot \eta} \cdot P_{oil} \quad (3)$$

$S$ = monetary savings ($/yr), see Table 10 for additional parameters

$$C = P_{insert} \cdot A_{insert} \cdot (1 + t) \quad (4)$$

$C$ = total upfront cost of inserts ($); t = sales tax (5%), see Table 10 for additional parameters

$$PBP = \frac{C}{S} \quad (5)$$

$PBP$ = simple payback period (years), see Table 10 for additional parameters

*Table 10 – Parameter values of the energy savings model*

| Symbol | Description | Minimum | Default | Maximum |
|---|---|---|---|---|
| $P_{oil}$ | Price of #2 fuel oil ($/gal) [46] | $1.79 | $3.10 | $4.09 |
| $d$ | Heating degree days (oF day/yr) [47] | 5,812 | 6,758 | 7,148 |
| $R_{insert}$ | R-value of inserts (F-ft2-h/Btu) [33] [48] [49] | 0.92 | 2.30 | 3.00 |
| $R_{win}$ | R-value of windows (F-ft2-h/Btu) [50] | 0.91 | 2.61 | 4.34 |
| $\eta$ | Efficiency of furnace/boiler [51] | 0.78 | 0.82 | 0.85 |
| $P_{insert}$ | Price of inserts ($/ft2) [45] | $1.65 | $2.67 | $3.68 |
| $E_{oil}$ | Energy content of #2 fuel oil (MMBtu/gallon) [51] | *N/A* | 0.13869 | *N/A* |

*Table 11 – WindowDressers pricing [45]*

| Sample Window Size | Hgt | Width | Sq. Ft | 2016 Pine | White |
|---|---|---|---|---|---|
| Small | 36” | 20” | 5.0 | $15.39 | $18.39 |
| Medium | 52” | 30” | 10.8 | $23.22 | $27.74 |
| Large | 68” | 36.5” | 17.2 | $28.50 | $34.32 |

A sensitivity analysis examines the effect on model results of variability and uncertainty from key parameters in Equations 1-5 by assigning a maximum value, minimum value, and distribution to each of the parameters to more accurately determine the full range of possible results (Table 10). Annual heating degree day data represent Bangor, Maine and an assumed base temperature of 65 degrees Fahrenheit [52]. The minimum efficiency of the furnace/boiler (.78) is the estimate of a standard oil furnace, the maximum efficiency (.85) is from one that is Energy Star rated, and the default value (.82) is the average of the two [51]. The price of the inserts was determined from WindowDressers minimum ($1.65), maximum ($3.68), and average ($2.67) price per square foot of insert (Table 11). The energy content of fuel oil is 0.13869 MMBtu per gallon [51]. The minimum R-value of a window without an insert is from a standard single pane window (0.92), the maximum R-value is from a triple insulating glass window with 1/2" of air space between panes (4.05), accompanied by insulating tight fitting drapery which adds to the R-value (0.29) [50]. The default window R-value is the median possible window configuration that could be determined (between a single pane with and without a storm window; a double pane window with 3/16”, 1/4”, 1/2”, or 3/4” airspace, with and without suspended film, with two suspended films, with suspended film and low-e coating; and a triple pane window with 1/4”, or 1/2” air space) with and without drapery (2.61) [50]. The R-value of the window insert is still unknown to us. The designer of the insert estimates the value to be 2.3 [48]. WindowDressers claims that the insert has an R-value closer to 3 [49]. These are the only two sources estimating the R-value of these inserts, and therefore represent our default and maximum values. The Indow Window, while built of different materials, is the only insert with an R-value that has been tested (see Section 3.2). The average measured Indow Window R-value was 0.92, and represents the minimum value in our analysis [33]. It is reasonable that the R-value the WindowDressers inserts may be higher than the Indow Window inserts, as WindowDressers inserts contain an area of dead air space between the two layers of film and the Indow Window does not.

The primary output of the predicted energy savings model is a “typical” customer, which uses the default input values (Table 10) and assumes an area of 150 square feet, or ten 36” by 60” windows [53]. Due to the uncertainty and variability in the parameters, 10,000 Monte Carlo simulations using the probability distributions identified in Table 12 are also included in the results. The simple payback period is calculated using the full-price and special rate pricing (10 inserts for $10, described in Chapter 1). WindowDressers community approach to building inserts also requires customers to commit to volunteer to build inserts for a certain amount of time, which bears an opportunity cost. Equation 6 calculates a flat opportunity cost based on the median Maine household income ($49,331/year) from the most recent available estimate (2014 data), valuing an hour of customer volunteer time at $23.71 per hour based on this wage [54]. Customers are asked to volunteer for one 4-hour volunteer shift for every 7 inserts that they order; while this rule is not strictly enforced by the community builds, it is applied to our “typical” customer. The opportunity cost is not included in the Monte Carlo simulation as the added cost would take away from the primary focus of energy savings from the model. Equation 7 estimates the total payback period for a typical customer accounting for a flat opportunity cost in participation. Predicted greenhouse gas emission savings are also calculated for carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) from the abated heating oil (Table 13) [55]. The calculated emissions saved are based on the amount of heating oil saved by the “typical” customer. It is difficult to place a value on environmental pollutants because they are not market goods; however this paper will provide a simple estimate from the EPA’s valuation on greenhouse gas emissions [56]. The EPA estimates that $CO_2$ has a social impact of $24.05

per ton (2016 USD) assuming a 3% discount rate (which was the average of their three integrated assessment models). $CH_4$ and $N_2O$ are valued using a Global Warming Potential value to convert environmental damage caused by $CH_4$ and $N_2O$ into a $CO_2$ equivalent. $CH_4$ has a Global Warming Potential of 25 times $CO_2$, per ton, and $N_2O$ has a Global Warming Potential of 298 times $CO_2$ per ton [56]. Equation 8 calculates a total payback period that includes a valuation for the annual emissions savings.

*Table 12 – Predicted energy savings model Monte Carlo input values*

| **Parameter** | **Probability Distribution** | **Mean** | **Median** | **Mode** | **Standard Deviation** | **Min** | **Max** |
|---|---|---|---|---|---|---|---|
| $P_{oil}$ | Triangular | \$3.13 | **\$3.10** | \$2.71 | \$0.62 | \$1.79 | \$4.09 |
| $d$ | Triangular | 6573 | **6758** | N/A | 280 | 5812 | 7148 |
| $R_{insert}$ | Triangular | 2.07 | **2.3** | N/A | 0.43 | 0.92 | 3.00 |
| $R_{win}$ | Triangular | 2.66 | **2.615** | N/A | 0.93 | 0.91 | 4.34 |
| $\eta$ | Triangular | 0.82 | 0.82 | 0.82 | 0.01 | 0.78 | 0.85 |
| $P_{insert}$ | Triangular | \$2.62 | \$2.59 | **\$2.52** | \$0.42 | \$1.65 | \$3.68 |
| $A_{insert}$ | Normal | 150 | 150 | 150 | 15 | -∞ | ∞ |

$$C_{opportunity} = \frac{I * N}{H_{work} * 7} \quad (6)$$

$C_{opportunity}$ = opportunity cost; $I$ = median Maine annual household income; $N$ = number of inserts; $H_{work}$ = number of hours worked in a year based on a 40-hour work week

$$TPBP = \frac{C+C_{opportunity}}{S} \quad (7)$$

$TPBP$ = total payback period (years)

$$TPBP_2 = \frac{C+C_{opportunity}}{S+S_{emissions}} \quad (8)$$

$TPBP_2$ = total payback period including emissions (years); $S_{emissions}$ = annual value of emissions savings (\$)

*Table 13 – Greenhouse gas pollutants from combustion of #2 fuel oil*

| **Factor** | **per MMBtu of Fuel Oil No. 2** [55] | **per gallon of Fuel Oil No. 2** [55] | **Social Cost Per Ton** [56] |
|---|---|---|---|
| $CO_2$ (kg) | 73.96 | 10.21 | \$24.05 |
| $CH_4$ (g) | 3.0 | 0.41 | \$601 |
| $N_2O$ (g) | 0.60 | 0.08 | \$7,160 |

### 3.3.2. Actual Energy Savings Analysis

The actual energy savings analysis uses historical heating purchases from window insert customers. Customers either agreed to share their consumption information through one of our surveys (see methods of chapter 2) or if our research team measured their windows, they were asked if they wanted to participate after their measurements were completed (this research team coordinated the Bangor community build in 2015 and 2016, addressed in Chapter 1). Once they agreed, they received a waiver (Appendix C) either by hand, postal mail, or email allowing us to contact their utility company directly to retrieve up to five years of their past purchases. We received 24 waivers in total from WindowDressers customers that we sent to each of their utility providers. From those 24 consenting customers, we were able to obtain the historical consumption data directly from their utility provider for 13 of them. The consumption data for the other 11 customers was not gathered due to either the utility company not accepting our waiver; the utility company accepting the waiver, but never providing the information; or in the case of cord wood for heating, no provider was contacted. 10 of the 13 customers we did gather data for, were not used in our analysis because either the utility company was not able to provide us with the consumption data for at least one full winter before and after they installed their inserts (leaving nothing to compare their consumption to), or they reported in the survey (Chapter 2) that they made a weatherization or other home improvement (e.g., replaced windows, added insulation, replaced/changed heating source, put an addition on their home, etc.) before the same winter they installed window inserts. Each of these changes would have altered the heating consumption of the customer in a way that would not allow us to separate out the effect of the inserts. When these cases were removed, three out of the original 24 customers remained with usable data (referred to as Customer A, B, and C).

All three customers installed their inserts during the winter of 2016-2017 and use #2 fuel oil (heating oil) as their primary heating source. To complicate things, each of these customers also supplement their heating (Customer A and B with wood, and C with an electric space heater). Since we do not have data on supplementary heating purchases, we assume supplemental fuel consumption remains constant across all of the years in the analysis. Heating oil purchases were obtained from their providers in May 2017 after the winter heating season ended. We were provided with six full winters (November through April) of fuel consumption and pricing data for Customer A; however we only use the last two winters because this customer added a wood stove before the winter of 2015-2016. We were provided with three full winters of fuel consumption and pricing data for Customer B, all of which are used in the analysis. We have six full winters of consumption and pricing data for Customer C; however only use two winters worth of data because additional insulation was installed in the home before the winter of 2015. All three customers reported having single pane windows in their home; however, Customer A also reported exterior storm windows and tight fitting drapes on all of their windows, while Customer C reported also having some additional double pane windows (exact number was not reported). The presence of tight fitting drapes and the number of panes a window has are used to determine its R-value, which is needed to estimate heat loss (Equation 3). Customer A and C each bought 10 inserts for their home, while Customer B bought 15 inserts.

Equation 9 determines the amount of heating oil a customer used each year while accounting for the outside temperature. The amount of heating degree days changes every winter, which is why it is important to determine the amount of oil per heating degree day used, as opposed to total consumption. The heating degree day information is gathered from the weather station closest to each customer's location [47] and uses a default base temperature of 65 degrees Fahrenheit for Customer’s A & B, and a reported base temperature of 68 degrees for Customer C (reported in a survey, see Section 2.3.; Customer’s A & B did not take the survey which is why the default value is used). Equation 10 calculates the percent change in temperature dependent gallons (TDG) consumed after inserts were installed. Equation 11 estimates the number of gallons saved per household during the winter of 2016 to 2017 when the inserts were installed. Equation 12 estimates the number of gallons saved per insert per household in winter 2016-2017. Results are also reported in temperature dependent energy (TDE) by converting gallons of heating oil to MMBtu, based on a conversion factor of 0.13869 MMBtu per gallon of heating oil [51]. Emissions savings per home and per insert are also calculated in the same manner as the predicted energy savings model (Table 13).

$$TDG = \frac{G}{d} \tag{9}$$

*TDG* = temperature dependent gallons used; *G* = gallons of Fuel Oil #2; *d* = heating degree days in the winter season (November – April)

$$TDGS = \frac{TDG_{base} - TDG_{inserts}}{TDG_{base}} \tag{10}$$

*TDGS* = temperature dependent gallons saved; $TDG_{base}$ = temperature dependent gallons used in years without inserts (average of all appropriate years with data before inserts installed); $TDG_{inserts}$ = temperature dependent gallons used in year with inserts

$$GS_{2016-2017} = TDGS * d_{2016-2017} \tag{11}$$

$GS_{2016\text{-}2017}$ = actual change in gallons consumed during the winter of 2016 to 2017 as a result of inserts; *TDGS* = percent change in temperature dependent gallons used; $d_{2015\text{-}2016}$ = heating degree days in the 2016-2017 winter season (November – April)

$$GSpi_{2016-2017} = \frac{DGS * d_{2016-2017}}{N} \tag{12}$$

$GSpi_{2016-2017}$= estimated change in gallons consumed per insert during the winter of 2016 to 2017 as a result of inserts; *TDGS* = percent change in temperature dependent gallons used; $d_{2016\text{-}2017}$ = heating degree days in the 2016-2017 winter season (November – April); *N* = number of inserts

It is difficult to assess the exact time that heating oil is consumed after it is delivered to a customer. Unlike electricity or natural gas which is metered monthly, heating oil deliveries do not follow a set pattern and differ between each customer. In addition, customers may not consume their entire tank between deliveries and may not fill it completely on each delivery. We define the heating season as November through April; however, a delivery of fuel oil in April may be used partially that year and partially saved for the following year as heating oil is not used for anything other than home heating. For that reason, each customer's fuel use was identified in three different ways: 1. Default - half of each April delivery is used during the same heating season in which it was delivered and half the following season; 2. Case 2 - each April delivery is used entirely the following heating season; and 3. Case 3 - each April delivery is used entirely within the heating same season as when it was delivered. The temperature dependent gallons are determined for each customer specific to their gallons of oil consumed and heating degree days. We will use the average default case among the three customers to create a "typical customer" (Table 14). Given the uncertainty in consumption, a sensitivity analysis will be conducted using the default, case 2, and case 3 results. For our sensitivity analysis, the lowest temperature dependent gallons value among all three customers serves as our minimum; and the highest temperature dependent gallons value among all three customers serves as our maximum. The minimum fuel cost is the lowest cost per gallon reported across all three customer energy bills; the maximum is the highest reported cost per gallon; and the default value is the average purchase cost per gallon (all prices are inflation adjusted to 2016 USD). Heating degree data is specific to each customer (depending on their base temperature and location), we will also use a minimum, maximum, and average total winter season (November-April) heating degree data amongst all three participants to estimate the number of gallons saved per home. The heating degree days here are different than the predicted model as they are specific to these individual customers.

*Table 14 – Actual energy consumption data*

| Symbol | Description | Minimum | Default | Maximum |
|---|---|---|---|---|
| $TDG_{base}$ | Gallons of heating oil used per heating degree day before inserts are installed | 0.070 | 0.109 | 0.170 |
| $TDG_{inserts}$ | Gallons of heating oil used per heating degree day after inserts are installed | 0.058 | 0.094 | 0.139 |
| $P_{oil}$ | Price of #2 fuel oil (2016$/gal) [46] | $1.68 | $2.29 | $3.65 |
| $d$ | Heating degree days ($^{o}$F day/yr) | 5,900 | 6257 | 7220 |
| $N$ | Number of inserts | 10 | 11.7 | 15 |
| $E_{oil}$ | Energy content of #2 fuel oil (MMBtu/gallon) [51] | *N/A* | 0.13869 | *N/A* |

We ran 10,000 Monte Carlo simulations using the triangular distributions in Table 15. The bold-face value represented the most likely value of the distribution for each parameter. The output of this analysis provides a probability distribution for how much heating oil and MMBtu these three homes saved as a result of their inserts.

*Table 15 – Triangular distributions for actual energy consumption*

| Parameter | Mean | Median | Mode | Standard Deviation |
|---|---|---|---|---|
| $TDG_{base}$ | **0.109** | 0.087 | 0.086 | 0.036 |
| $TDG_{inserts}$ | **0.094** | 0.076 | 0.139 | 0.034 |
| $P_{oil}$ | **$2.29** | $2.15 | N/A | 0.482 |
| $d$ | 6379 | **6257** | N/A | 511 |
| $N$ | **11.7** | 10 | 10 | 2.89 |

### 3.3.3. Comparing Predicted and Actual Savings

The predicted savings model outlined in this paper was applied to the homes of Customers A & B when they purchased their inserts, using household-specific data (R-value and area of current windows, heater efficiency, and price they paid for inserts) to reduce uncertainty compared to the "typical" customer model represented in the main predicted model results. All measurements were taken by our research team in the home of the customer when they were having their windows measured for inserts (Only for the Bangor build participants; that was the build this research team coordinated). The results of the model were also shared with the customer as a range of values from the lowest predicted savings (worst case) to the highest predicted savings (best case) and included a best guess scenario. Customer C was a participant in a build this research team was not coordinating, meaning we did not visit their home to apply the model and will not be included in this section. The results of the predictive and actual energy savings models for Customers A and B will be compared. Customer A paid the special rate of 10 inserts for $10 and customer B paid the full price of $432 for 15 inserts (Tables 16 and 17). Customer A purchased 155 square feet of inserts and Customer B purchased 192 square feet. Customer A has single pane windows with exterior storm windows and tight fitting drapes (R=2.29), while Customer B just has single pane windows (R=0.91). Both customers have standard oil furnaces ($\eta$=0.78). The predicted energy model is completed for both customers individually using the equations in section 3.3.1, using the known values to decrease uncertainty, and therefore a Monte Carlo analysis will not be used in this section. Instead the same range of the lowest (worst case) and highest (best case) case scenarios that were provided to the customer will be presented. The range was due to the uncertainty that still existed in the price of heating fuel, heating degree days, and the R-value of the inserts before the heating season (Table 16 & 17).

*Table 16 – Predictive model parameters for Customer A*

| Symbol | Description | Low | Default | High |
|---|---|---|---|---|
| $P_{oil}$ | Price of #2 fuel oil ($/gal) [46] | $1.79 | $3.10 | $4.09 |
| $d$ | Heating degree days ($^oF$ day/yr [47] | 5,812 | 6,758 | 7,148 |
| $R_{insert}$ | R-value of inserts (F-ft$^2$-h/Btu) [23] [44] [45] | 0.92 | 2.3 | 3 |
| $R_{win}$ | R-value of windows (F-ft$^2$-h/Btu) [43] | *N/A* | 2.29 | *N/A* |
| $\eta$ | Efficiency of furnace/boiler [42] | *N/A* | 0.78 | *N/A* |
| $P_{insert}$ | Price of inserts ($/ft$^2$) [40] | *N/A* | $10 | *N/A* |
| $E_{oil}$ | Energy content of #2 fuel oil (MMBtu/gallon) [42] | *N/A* | 0.13869 | *N/A* |
| $A_{insert}$ | Area of inserts (ft$^2$) | *N/A* | 155 | *N/A* |

*Table 17 – Predictive model parameters for Customer B*

| Symbol | Description | Low | Default | High |
|---|---|---|---|---|
| $P_{oil}$ | Price of #2 fuel oil ($/gal) [46] | $1.79 | $3.10 | $4.09 |
| $d$ | Heating degree days ($^oF$ day/yr) [47] | 5,812 | 6,758 | 7,148 |
| $R_{insert}$ | R-value of inserts (F-ft$^2$-h/Btu) [23] [44] [45] | 0.92 | 2.3 | 3 |
| $R_{win}$ | R-value of windows (F-ft$^2$-h/Btu) [43] | *N/A* | 0.91 | *N/A* |
| $\eta$ | Efficiency of furnace/boiler [42] | *N/A* | 0.78 | *N/A* |
| $P_{insert}$ | Price of inserts ($/ft$^2$) [40] | *N/A* | $432 | *N/A* |
| $E_{oil}$ | Energy content of #2 fuel oil (MMBtu/gallon) [42] | *N/A* | 0.13869 | *N/A* |
| $A_{insert}$ | Area of inserts (ft$^2$) | *N/A* | 192 | *N/A* |

The actual energy savings is calculated using the equations in section 3.3.2 for both customers individually. Actual pricing data for the price of oil is used only for the winter of 2016 to 2017 when the customer had their inserts, in order to determine actual achieved savings to date and compare it to what they were told before the winter (Table 18 and 19). Heating degree days are also kept constant to the 2016-2017 heating season, as we know this is the exact number of heating degree days in the winter the customers had inserts (6,257). The range of values for actual consumption information will come from the difference in temperature dependent gallons used both before and after inserts were installed using the default, case 2, and case 3 measurements outlines in section 3.3.2. We expect the range of both customers' actual energy savings to overlap with the range provided in their the predicted model; however, errors may be caused due to the remaining uncertainty (when heating oil actually used), unreported changes in energy consumption (leaving the front door open, altering the thermostat at any time, even cooking and showering may raise home temperature causing the heater to come on less often, etc.), and the assumption that supplementary heating remains constant. The calculation also does not account for infiltrative heat loss which may contribute 16% of heating consumption [57].

Finally, a direct rebound effect will be estimated by comparing the default results for gallons of heating oil saved in the model to actual gallons saved for both customers using Equation 12.

$$DR = \frac{\frac{Q_{savings}}{E_{Oil}} - \Delta G_{2015-2016}}{\frac{Q_{savings}}{E_{Oil}}} \qquad (12)$$

*DR = direct rebound effect;* $\frac{Q_{savings}}{E_{Oil}}$*=predicted gallons of heating oil saved;* $\Delta G_{2015-2016}$= actual change in gallons consumed during the winter of 2015 to 2016 as a result of inserts

*Table 18 – Actual consumption data for Customer A*

| Symbol | Description | Default | Case 2 | Case 3 |
|---|---|---|---|---|
| $TDG_{base}$ | Gallons of heating oil used per heating degree day before inserts are installed | 0.087 | 0.071 | 0.103 |
| $TDG_{inserts}$ | Gallons of heating oil used per heating degree day after inserts are installed | 0.077 | 0.077 | 0.077 |
| $P_{oil}$ | Price of #2 fuel oil Winter 2016-2017 | $2.08 | $2.05 | $2.15 |
| $d$ | Heating degree days Winter 2016-2017 ($^{o}$F day/yr) [47] | *N/A* | 6257 | *N/A* |
| $N$ | Number of inserts | *N/A* | 10 | *N/A* |
| $E_{oil}$ | Energy content of #2 fuel oil (MMBtu/gallon) [42] | *N/A* | 0.13869 | *N/A* |

*Table 19 – Actual consumption data for Customer B*

| Symbol | Description | Default | Case 2 | Case 3 |
|---|---|---|---|---|
| $TDG_{base}$ | Gallons of heating oil used per heating degree day before inserts are installed | 0.086 | 0.086 | 0.086 |
| $TDG_{inserts}$ | Gallons of heating oil used per heating degree day after inserts are installed | 0.067 | 0.058 | 0.076 |
| $P_{oil}$ | Price of #2 fuel oil Winter 2016-2017 | $2.15 | $2.16 | $2.15 |
| $d$ | Heating degree days Winter 2016-2017 ($^{o}$F day/yr) [47] | N/A | 6257 | N/A |
| $N$ | Number of inserts | N/A | 15 | N/A |
| $E_{oil}$ | Energy content of #2 fuel oil (MMBtu/gallon) [42] | N/A | 0.13869 | N/A |

## 3.4. Results and Discussion

### 3.4.1. Predicted Energy Savings Model

Results from the "typical customer" are seen in Table 16 (individual customers will be presented in Section 3.4.3). The typical customer saves 35 gallons of home heating oil per year, 4.0 MMBtu per year, $105 in savings per year, and has a simple payback period of 3.9 years when oil is $3.10 per gallon. However, if this customer received the special rate of $10 for 10 inserts, the monetary payback period is estimated to be less than one month. Each insert saves 3.5 gallons of heating oil or 0.4 MMBtu.

*Table 20 – Base case results for a "typical customer"*

| | |
|---|---|
| Heat loss[1] through windows (MMBtu/yr) | 9.0 |
| Heat loss through windows + inserts (MMBtu/yr) | 5.0 |
| Energy savings from reduced heat loss (MMBtu/yr) | 4.0 |
| Energy savings (gallons of oil per yr) | 35 |
| Monetary Energy savings ($/yr) | 105 |
| Energy savings per insert (MMBtu/*insert-yr*) | 0.40 |
| Energy savings per insert (gal oil/*insert-yr*) | 3.5 |
| Payback period (years) | 3.9 |

[1]*Does not include heat loss from infiltration*

*Full price for 150 square feet of inserts is estimated to be $412*

The default results for the typical customer are the same as the 50th percentile results from the Monte Carlo analysis (Figure 7, Monte Carlo simulations for additional parameters can be found in Appendix D). Customers in the 95th percentile of the Monte Carlo results would save 85 gallons of heating oil per year, 11.8 MMBtu per year, \$260 per year and have a simple payback period of 1.5 years. Customers in the 5$^{th}$ percentile would save 17 gallons of heating oil per year, 2.4 MMBtu per year, \$50 per year, and have a simple payback period of 8.6 years.

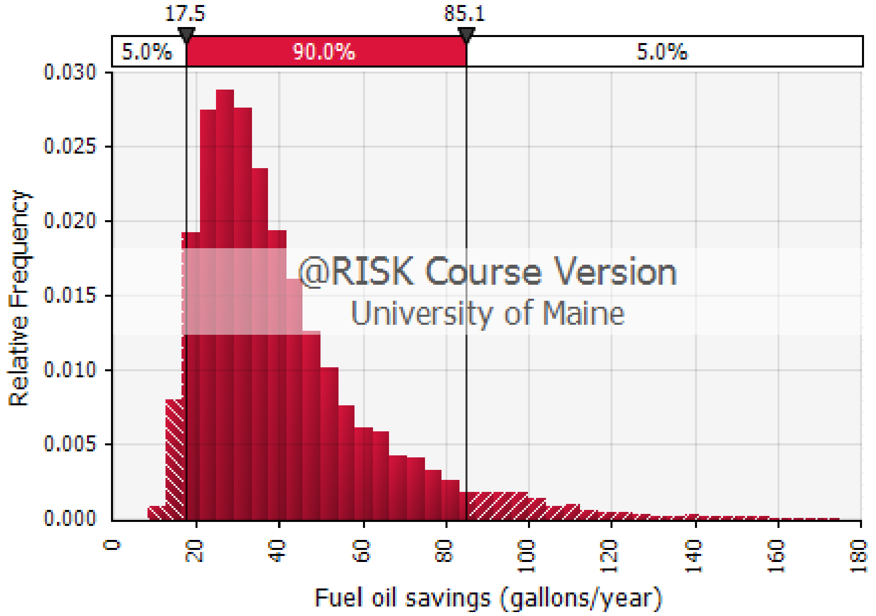


*Figure 7 – Monte Carlo results for gallons of oil saved per household (predictive model)*

Even in the 5$^{th}$ percentile, a special rate customer would have a monetary payback period of less than two months because of the low upfront cost of the inserts (\$1/insert). Commercially available Indow Window inserts are available for \$20-36 per square foot. Using the same model but changing the price per square foot to a minimum of \$20, maximum of \$36, and default value of \$28, the model predicts customers in the 5$^{th}$, 50$^{th}$, and 95$^{th}$ percentiles could achieve a simple payback period of 16.6, 41.9, and 91.0 years, respectively, with Indow Windows (see Appendix D for graphs).

A tornado graph (Figure 8, additional tornado graphs can be found in Appendix D) demonstrates the level of sensitivity each parameter has on the predicted energy savings; the larger the bar the greater the effect on the model. The model is most sensitive to the R-value of the windows, area of the windows, and R-value of the inserts compared to the number of heating degree days and furnace efficiency. Fortunately, the R-value of the existing windows and area of their windows are able to be determined for an individual customer. However, the R-value of the insert will remain uncertain until it can be tested in a lab similar to the way the Indow Window was [33]. This precise measurement was beyond the funding for this project and therefore not completed.

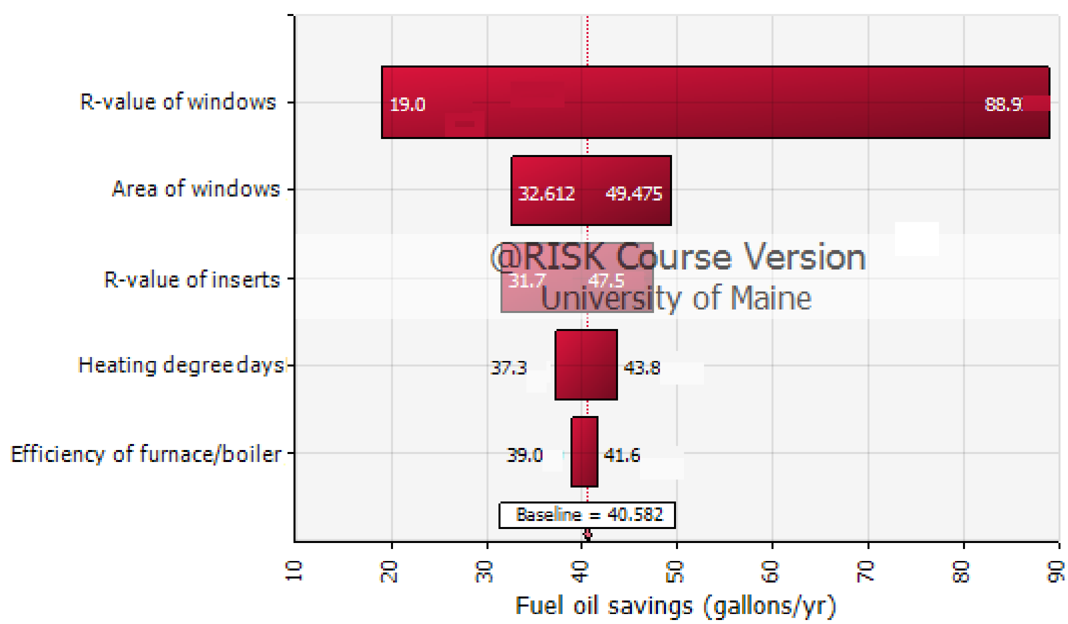


*Figure 8 – Tornado graph demonstrating model sensitivity to each parameter*

The opportunity cost is determined by the number of inserts a customer orders and whether or not they actually participate in the requested volunteer shifts. However, using the median household income in Maine, a general opportunity cost can be valued at $24 per hour, which translates to an average opportunity cost per insert ordered of $14 (($24/hr x 4 hrs)/7 inserts). For our "typical" customer who purchased 10 inserts, inclusion of opportunity cost increases the payback period by 1.3 years, resulting in a total payback period of 5.2 years for a full price customer and 1.4 years for a special rate customer. However, for a special rate customer, this result is likely unrealistic because they likely earn lower than the median household income. Low-income customers may also be retired and not earning any hourly income. There were also students that were asked to participate for class that this calculation would not apply to. Finally, the opportunity cost calculation does not take into account any benefits of volunteering, which would lower the opportunity cost (good feelings, interactions with community members, etc.).

The "typical customer" would save 35 gallons of oil per year, 357 kilograms of $CO_2$, 14 grams of $CH_4$, and 3 grams of $N_2O$ per home, per year; or 35.7 kilograms of $CO_2$, 1.4 grams of $CH_4$, and 0.3 grams of $N_2O$ per insert, per year (based on gallons of oil saved per insert presented in Table 20). These emissions savings amount to a social benefit of $9.51 per household, per year or $0.95 per insert, per year. Including the value for annual emissions savings in addition to the opportunity cost, decreases the total payback period for the "typical customer" to 4.8 years for a full price customer and 1.3 years for a special rate customer. WindowDressers has built 20,844 inserts to date since 2010 (Figure 1), all of which are theoretically still in use. The 6,113 inserts built in 2016-2017 alone saved an estimated 218,000 kilograms of $CO_2$, 8,600 grams of $CH_4$, and 1,800 grams of $N_2O$. The heating oil saved by these 6,113 inserts contributed to a social benefit of approximately $5,800 (2016 USD) and a 0.004% reduction in the 555 million gallons of distillate fuel used in the state of Maine every year [58]. Dating back to 2010, WindowDressers inserts have saved an estimated total of over 744,000 kilograms of $CO_2$, 29,000 grams of $CH_4$, and 6,200 grams of $N_2O$ (Figure 9) for a total social savings of nearly $20,000. The amount of oil predicted to be saved by these 20,844 inserts (nearly 73,000 gallons) is approximately 0.013% of the 555 million gallons of distillate fuel used in the state of Maine every year. While this is still a very small percentage, it should be noted that it is a number that is growing exponentially (Figure 1) each year.

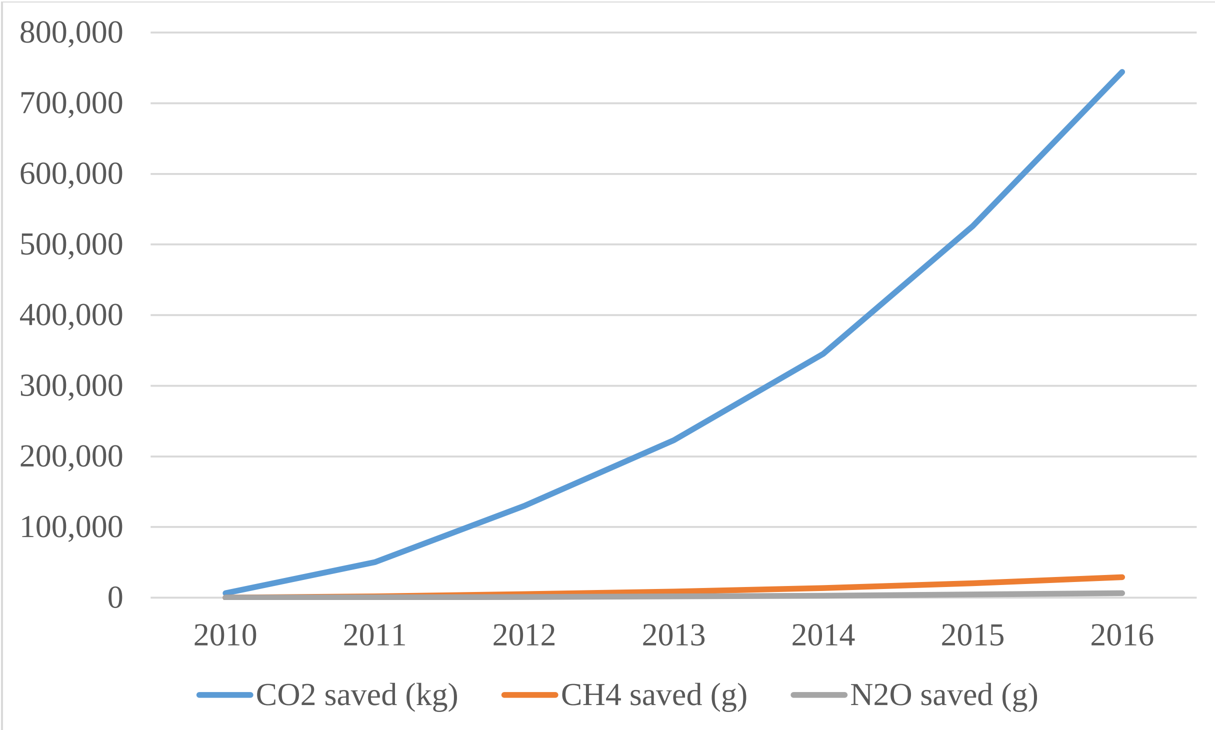


*Figure 9 – Cumulative emissions savings by WindowDressers inserts in total since 2010*

### 3.4.2. Actual Energy Savings

The 50th percentile of the actual energy savings analysis shows that these three customers saved 17% (individual changes are seen in Figure 10) of their total heating oil consumption during this last winter from having inserts compared to the average of previous winters without having inserts (Table 21). 17% results in 128 gallons of heating oil and $326 saved per household, and 10.5 gallons and $27 saved per insert. Given the level of uncertainty associated with the analysis, this result is consistent with Indow Window research that found estimated savings of 19% [33] and 21.1% per household [38]. 128 gallons of heating oil per household is substantially higher than 35 gallons per household found in the predictive model. It should be stressed that the 3 customers used in the actual heating consumption do not necessarily represent the "typical households" from the predictive model. The only comparison that can be accurately determined will be done in section 3.4.3. where the predictive estimates for specific households will be compared to the actual savings.

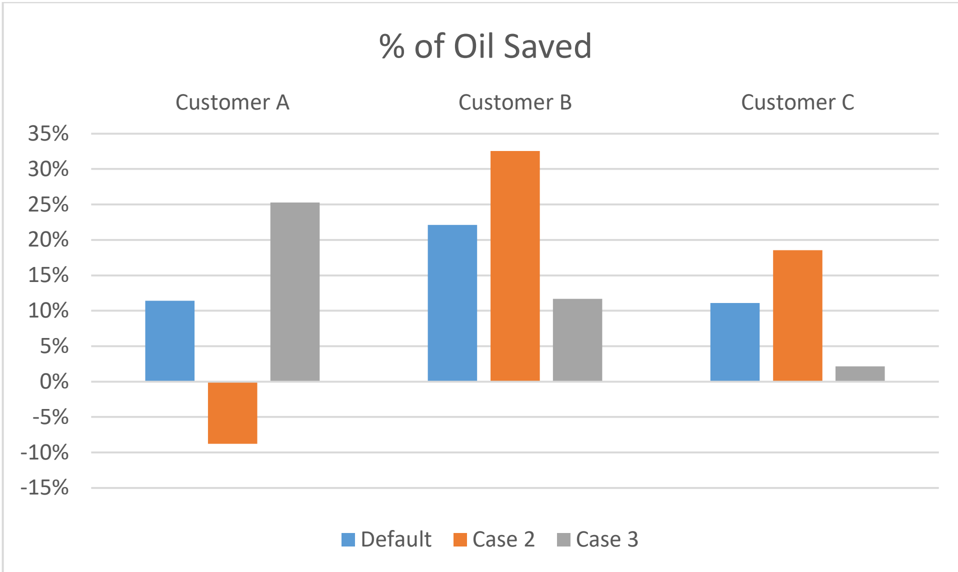


*Figure 10 – Comparison between default, case 2, and case 3 values for all three customers (actual consumption)*

*Table 21 – Default case for the "typical customers" actual savings*

| | |
|---|---|
| % of heating oil saved | 17% |
| Amount of heating oil saved (gallons/year) | 128 |
| Heating oil cost savings[1] (2016$/gallon) | $326 |
| Heating oil savings per insert (gallons/insert) | 13.8 |
| Heating oil cost savings per insert (2016$/gallon) | $27 |
| Energy consumption saved (MMBtu/year) | 17.8 |
| Energy consumption saved per insert (MMBtu per insert) | 1.45 |

[1]*When oil is priced at $2.53 per gallon*

The 95th percentile of the Monte Carlo simulation suggests a 45% energy savings; 414 gallons of annual heating oil per household being saved (Figure 11); $1,075 in annual heating cost per household being saved; 34.2 gallons of annual heating oil being saved per insert; and $30.92 being saved in annual heating costs per insert (Monte Carlo distribution for all parameters is found in Appendix E). The 5th percentile shows an actual increase in energy consumption of 25%; 150 more gallons of annual heating oil per household; $373 more in annual heating cost per household; 12.3 more gallons of annual heating oil consumed per insert; and $88.95 more in annual heating costs per insert.

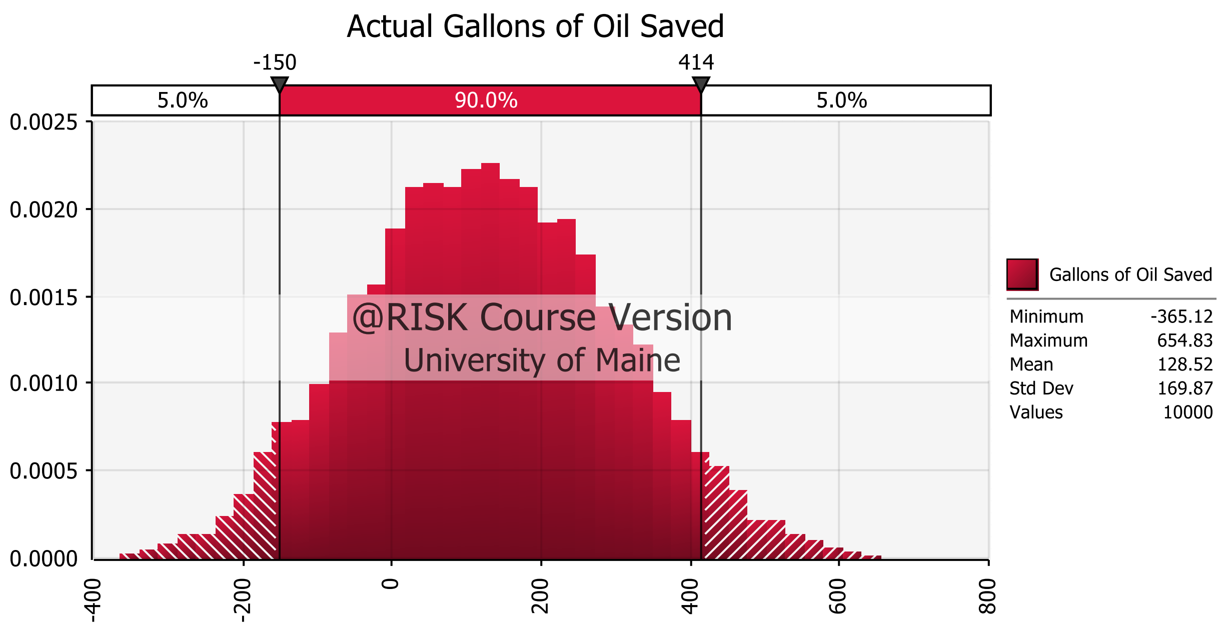


*Figure 11 – Monte Carlo distribution for the actual change in gallons consumed after inserts were installed*

This large range in possible savings is attributed to our low sample size and uncertainty stated in Section 3.3.2. The tornado graph in Figure 12 demonstrates the large sensitivity effect the gallons of heating oil consumed before and after inserts were installed has on the model. If a study can be conducted on a larger sample size in the future, we will see greater certainty in the model (additional tornado graphs found in Appendix E).

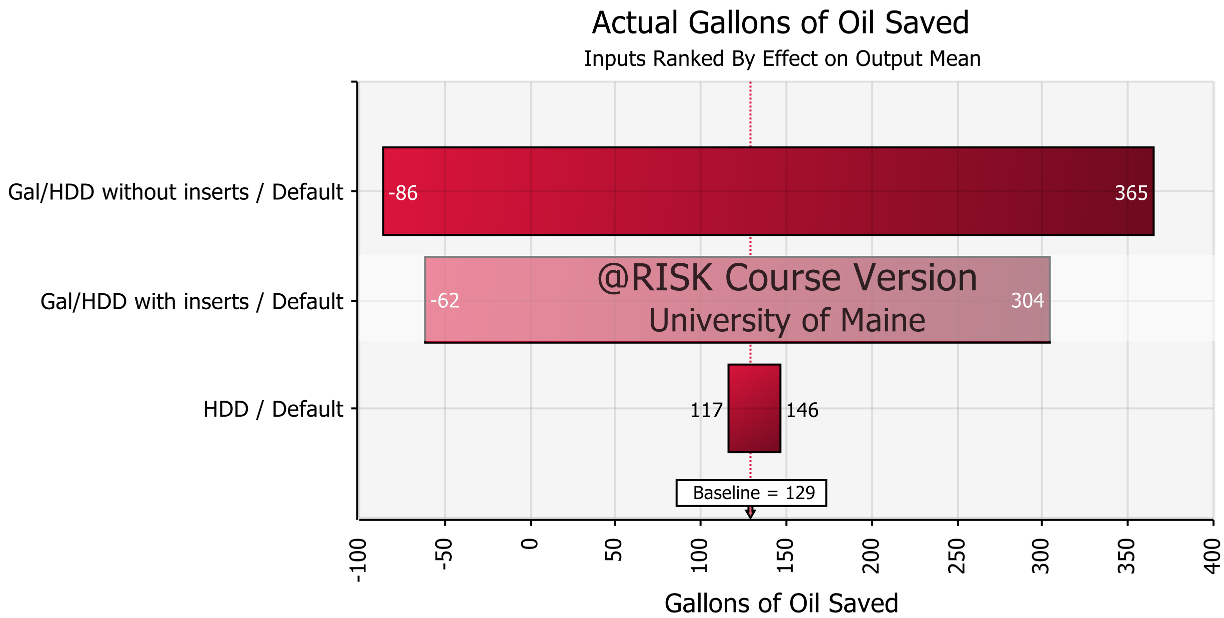


*Figure 12 – Tornado graph demonstrating the model sensitivity for change in gallons for each parameter*

The 50th percentile of the Monte Carlo simulation showed that the "typical" home saved 128 gallons of heating oil, 1,300 kilograms of $CO_2$, 52.5 grams of $CH_4$, and 10.2 grams of $N_2O$. Each insert individually saved about 111 kg of $CO_2$, 4.49 grams of $CH_4$, and 0.87 grams of $N_2O$. The social valuation of these abated emissions is $34.58 per household or $2.96 per insert, per year.

### 3.4.3. Comparing Predicted and Actual Savings

Customers A and B each had their house analyzed using our predictive model before they bought their window inserts. No predictive model was created for Customer C and will therefore not be included in this section. The analysis for Customer A estimated that they should save between 25 and 61 gallons of heating oil per year, 2.71 and 6.61 MMBtu per year, between $45 and $250 per year, and have a payback period between 0.04 years and 0.223 years (Table 22). Analysis of actual consumption data showed that Customer A saved between -38.7 and 162 gallons, -5.37 to 22.5 MMBtu, -$79 to $348, and had a payback period of between -0.126 years and 0.029 years (Table 23). The analysis on Customer B estimated that they would save between 136 and 256 gallons of heating oil per year, 14.8 to 27.7 MMBtu per year, $244 to $1050 per year, and have a payback period of 0.41 years to 1.77 years. Analysis of the actual consumption for Customer B found that they saved between 62.7 and 175 gallons per year, 8.71 to 24.2 MMBtu per year, $135 to $244 per year, and have a payback period of between 1.77 and 2.47 years. This information is shown graphically in Figure 13.

*Table 22 – Predicted energy savings for Customers A and B*

| Case | | Customer A | Customer B |
|---|---|---|---|
| Default | Heating oil saved (gallons) | 51.0 | 226 |
| Default | MMBtu saved | 5.52 | 24.5 |
| Default | Annual monetary savings | $158 | $701 |
| Default | Simple payback period (years) | 0.063 | 0.616 |
| Low | Heating oil saved (gallons) | 25.0 | 136 |
| Low | MMBtu saved | 2.71 | 14.8 |
| Low | Annual monetary savings | $45 | $244 |
| Low | Simple payback period (years) | 0.223 | 1.77 |
| High | Heating oil saved (gallons) | 61.0 | 256 |
| High | MMBtu saved | 6.61 | 27.7 |
| High | Annual monetary savings | $250 | $1050 |
| High | Simple payback period (years) | 0.040 | 0.41 |

*Table 23 – Actual energy savings achieved by Customers A and B*

| Case | | Customer A | Customer B |
|---|---|---|---|
| Default | Heating oil saved (gallons) | 61.8 | 118 |
| Default | MMBtu saved | 8.57 | 16.5 |
| Default | Annual monetary savings | $128 | $255 |
| Default | Simple payback period (years) | 0.028 | 3.64 |
| Case 2 | Heating oil saved (gallons) | -38.7 | 175 |
| Case 2 | MMBtu saved | -5.37 | 24.2 |
| Case 2 | Annual monetary savings | ($79.23) | $375 |
| Case 2 | Simple payback period (years) | -0.126 | 2.47 |
| Case 3 | Heating oil saved (gallons) | 162 | 62.7 |
| Case 3 | MMBtu saved | 22.5 | 8.71 |
| Case 3 | Annual monetary savings | $348 | $135 |
| Case 3 | Simple payback period (years) | 0.029 | 6.88 |

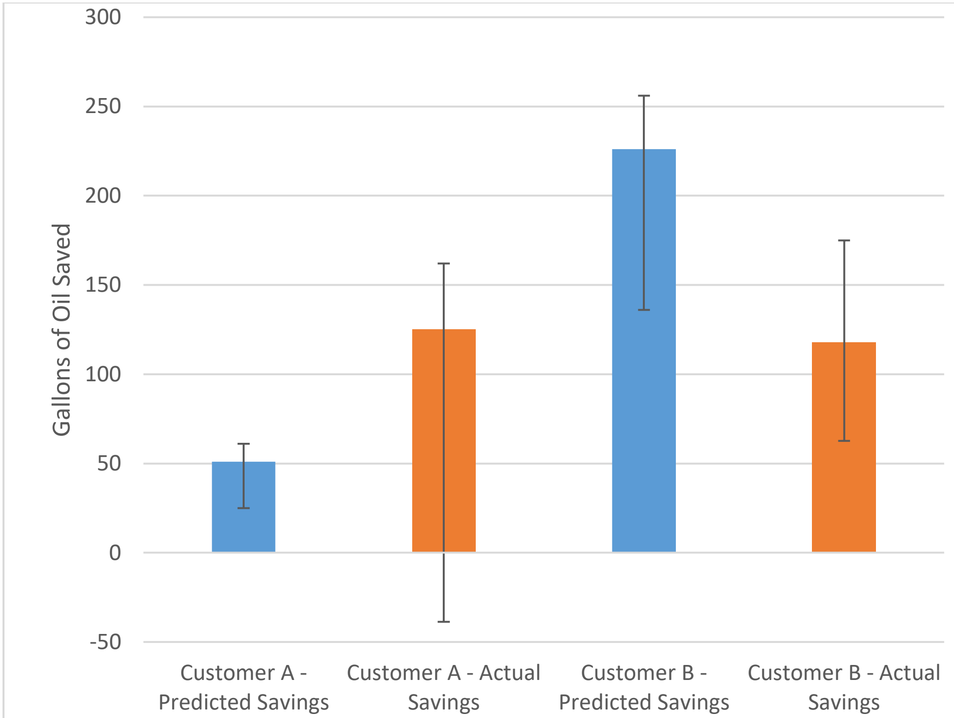


*Figure 13 – Comparison of predicted and actual annual energy savings for Customer A and B*

Actual energy savings for both Customer A and B does overlap with what the predictive model suggested savings should be. Depending on when Customer A actually consumed their heating oil, they either overachieved their modelled savings by up to 101 gallons, or greatly underachieved them to a point where they lost money on their investment. Actual energy consumption data for Customer B either aligned with the predicted low end savings, or underachieved their savings by up to 193 gallons of oil.

Comparing the default cases from the predictive model and actual savings shows a direct rebound effect of -21% for customer A and 48% for Customer B. The findings for Customer A would align with Portland State University findings where actual energy consumption demonstrated larger savings than the model predicted [33]. The findings for Customer B would align with most research that find as energy efficiency improves or the marginal cost of heating decreases, consumption increases and lowers achieved savings [41] [42] [43]. However, these estimates are weak due to uncertainty in when fuel oil is actually consumed, and a lack of knowledge in the secondary heating consumption. Neither Customer A or B participated in our survey which may have shed additional light on their changes in energy use as well. Therefore, a direct rebound effect as a result of insert adoption is neither proved nor disproved with certainty.

**3.5. Conclusions**

This chapter had three research objectives. The first was to model the money, energy, and emissions savings associated with window inserts. Portland State University estimated that the Indow Window would reduce household energy consumption by an average of 9.8% in their sample of 4 test homes [33] and researchers in Burlington, VT estimated two different 15 square foot inserts would save between 1.24 gallons and 18.1 gallons each year, depending on the tightness of the window [57]. Our predicted model does not measure the percent change in consumption because the total consumption for our typical home is not modelled, only the change in heat loss. However, the 50th percentile of our Monte Carlo distribution estimates that the same size WindowDressers insert would save approximately 3.5 gallons of oil per year, which does align with the Burlington study. Unity College builds the same inserts and estimates that each square foot of insert would save roughly one gallon of heating oil, or 15 gallons for our typical insert. The 95th percentile of our predictive model estimates that up to 8.5 gallons of heating oil can be saved per insert. Unity College did not specify their methods to draw their conclusion, but it is much larger than our estimation.

The 50th percentile of the simple payback period for a typical WindowDressers customer was modelled to be 3.9 years for full price customers and less than one month for low-income customers. A simple opportunity cost of $24 per hour was placed on the inserts, which increased our predicted total payback period by 1.3 years, leaving a typical home with a total payback period of 5.2 years and a low-income home with a payback period of 1.4 years. Accounting for emissions, the total payback period would decrease to 4.8 years for the typical homes and 1.3 years for a low-income home. The 50th percentile of our predicted model determined that a commercially available Indow Window would have a payback period of 49.1 years, with the 5th and 95th percentile predicting 16.6 years and 91 years respectively. PNNL claimed that Indow Windows in a recently retrofitted house had a payback period of 80.6 years, however the payback period would have dropped to 9.9 years if the home had not received so many energy efficiency improvements prior to installing window inserts. Our model estimates a payback period for Indow Window inserts would be longer than 9.9 years, but 80.6 years does fall within our estimates. Predicted emissions savings for a typical home is 357 kilograms of $CO_2$, 14 grams of $CH_4$, and 3 grams of $N_2O$ per home, per year; or 35.7 kilograms of $CO_2$, 1.4 grams of $CH_4$, and 0.3 grams of $N_2O$ per insert, per year. This is valued to be about $9.46 per household, per year or $0.95 per insert, per year (when $CO_2$ is priced at $24.05 per ton). However, the 6,113 inserts they have built before the winter of 2016-2017 are predicted to have saved over 21,000 gallons of heating oil in their first year of use, or 0.004% of the total distillate fuel oil consumed annually in the state of Maine. The 20,844 inserts built since 2010 have saved nearly 73,000 gallons in total, for a predicted abatement of over 744,000 kilograms of $CO_2$, 29,000 grams of $CH_4$, 6,200 grams of $N_2O$, and an estimated total social benefit of nearly $20,000.

The second objective was to analyze actual energy, money, and emissions savings. Two previous studies into the Indow Window found that the inserts decreased energy home consumption by 19.1% [33] and 21.1% [38]. The 50th percentile of our three customer sensitivity analysis showed a household savings of 17%, very close to the research on Indow Windows. The actual savings also suggest 128 gallons of heating oil being saved per household;

$326 being saved per household; 10.5 gallons being saved per insert; and $27 being saved per insert. This would translate to 1,300 kilograms of $CO_2$, 52.5 grams of $CH_4$, and 10.2 grams of $N_2O$ per household, per year. Each insert individually saved about 111 kg of $CO_2$, 4.49 grams of $CH_4$, and 0.87 grams of $N_2O$. The social valuation of these abated emissions is $34.58 per household or $2.96 per insert, per year. The actual savings was found to be much higher than the predictive savings. It should again be stressed that these three customers do not necessarily represent the "typical customer" used in the predictive model.

The third objective was to compare predicted estimates and actual consumption data that can be used to compare our model to the actual savings. This was completed using the estimated model presented to two customers on the day they purchased their inserts, and actual consumption data from after their first winter with inserts. The predictive model estimated that Customer A should save between 25 and 61 gallons of heating oil per year, and an analysis of their historical heating oil consumption data showed they actually saved between -38.7 and 162 gallons. Customer B was estimated to save between 136 and 256 gallons of heating oil per year and actually saved between 62.7 and 175 gallons per year. The actual consumption data for both customers overlapped with at least part of their predicted savings. Previous research shows the potential for a rebound effect. Researchers in Austria measured the change in consumption for 14 households after they each improved the energy efficiency of their home and found a direct rebound effect of 30% of the expected savings that were not achieved. Other research has used price elasticities of demand to estimate the direct rebound effect from a change in price, and found the effect to be anywhere from 12% to 49% [41] [42] [43]. Research conducted in this thesis did not conclusively determine whether or not a direct rebound effect is a result of window insert adoption. Customer A was estimated to have a negative rebound effect of 21%, suggesting a conclusion closer to Portland State which also predicted energy savings that turned out to be lower than actual savings. Customer B was estimated to have a positive rebound effect of 48% suggesting a conclusion of a direct rebound effect being present.

Limitations to this chapter include a small sample size of usable consumption data. 51 customers indicated that they agreed to share their usage information with us in one of our surveys, however we only ultimately received 24 signed waivers in total. From those 24 consenting customers, we were able to obtain the historical consumption data from the utility from 13 of them. We were not able to gather information for the other 11 consenting customers due to the heating provider either not accepting our waiver (Appendix C), or accepting the waiver but never providing the information. One heating supplier was not contacted because it was a truck stop that sold cords of wood. From the 13 customers we received information for, most were not used because of an insufficient history or a major change was made to their home that would affect energy consumption in same year they purchased their inserts. There were three customers that had enough historical information and did not make another major change to their home in the year before installing inserts, however all three still reported using a supplemental heating source. An assumption had to be made that their supplementary heat remained constant in the years before and after window insert installation. These three customers all also used #2 heating oil as their primary heating source, which is difficult to monitor when it is actually used (however it is the most common heating fuel source in Maine).

There are a lot of ways to reduce the uncertainties in this research that should be considered for future researchers. If a future study can gather a sufficient sample of homes that only have one heating source, it would remove the assumption of secondary heating sources remaining constant. If single heating source homes are not gathered however, future work could also monitor the amount of secondary heating consumption to remove that assumption. Further uncertainty would be removed if customers who use a monthly metered heating source (electricity, natural gas, etc.) could be analyzed. Metered sources would allow the researcher to know exactly when the source was consumed, as opposed to educated guesses for unmetered fuel oil. However, while fuel oil is not monitored by providers, researchers could install a meter of their own at the consent of a customer to achieve the same result. A longer heating consumption history before a customer installed their insert would allow for a better baseline of how much heat that customer typically uses. Analyzing customers several years after they installed inserts would also give a better representation of how their consumption changed. Finally, a sample size of larger than three customers would allow for a more realistic "typical" household that could be compared directly with our predictive savings estimation.

This research can be expanded upon across disciplines. Economists can further develop statistical changes, specifically the rebound effect that may be associated with insert adoption. Engineers can test the R-value of several different types of inserts or materials to determine if a better insert can be built with a faster payback period. The infiltrative heat loss that is not accounted for in our model can also be included. Sociologists, anthropologists, and psychologists can interview customers who are having their homes analyzed to determine how well the customer thinks their inserts are reducing consumption compared to the actual changes. Finally, government agencies that are concerned with heating consumption can use this research as a possible alternative to low-income heating subsidies. Window inserts have not been fully explored across any discipline, and this study gives reason to suggest why they should be.

# CHAPTER 4

# CONCLUSION

This thesis provides information into a community energy efficiency program that is growing in the state of Maine. WindowDressers, the Island Institute, Midcoast Green Collaborative, and Unity College are all continuing to help keep the residents of Maine warm during the winter. Very little research has been conducted on window inserts, however they are easy to build, cheap to produce, and are a cheaper alternative to replacing drafty windows. They are worth taking notice as they are part of a larger national movement toward community energy. This thesis had five research objectives:

1. Identify social motivations and perceptions of participating in the window insert builds.
2. Identify whether behaviors change after participating in a window insert build.
3. Predict how much money, energy, and emissions that window inserts would save.
4. Determine how much money, energy, and emissions that window inserts actually saved.
5. Compare how the predictive savings compared to the actual savings.

These objectives were answered using survey data gathered from 337 respondents over 2 years, a predictive model estimating heat loss through a window, and actual heating oil consumption from three WindowDressers customers.

Survey data were used to find that customers are motivated by energy savings, improving comfort, saving money, reducing dependency on fossil fuel, benefitting the environment, and the sense of community associated with the project to purchase inserts for the majority of respondents. This supports the influence of a rational motivation to save money and energy that aligns with traditional economics. There is also evidence to support an anthropological theory of social embeddedness that helped foster participation. Low-income customers were more financially and comfort motivated than higher-income customers and were able to pay a lower rate for their inserts, which will allow their financial investment to pay off much sooner as well. The motivations for volunteering in a window insert build were the same as the motivation for purchasing them. Helping others conserve energy, improving the comfort of others, benefitting the environment, and the sense of community associated with the project all act as a motivation for the majority of respondents to volunteer. The perception of their experience that these volunteers had is correlated with the amount of time they spent participating in them. Participants who volunteered more than 8 hours reported a higher satisfaction in their volunteer experience compared to those who volunteered less. The perception of the window insert builds as a whole shows a 96% satisfaction amongst all participants, which is encouraging for all organizations who complete these builds or are interesting in adopting a project like this one.

Survey data was also used to identify changes in behavior as a result of participating in a window insert build. Survey responses indicate that participants are likely to participate or recommend someone else participate in a future window dressers builds. This might lead to a positive spillover of participants being more inclined to engage in energy reducing behaviors after participation in a community energy efficiency project. However, people who volunteered are more likely to participate in the future compared to someone who did not volunteer. The alternative negative spillover is whether a direct rebound effect could be found by customers increasing the temperature in their homes as a result of window insert installation. While some customers did report raising their thermostat, even more reported lowering it. However, the majority of participants did not report changing their thermostat at all. This suggests that a self-reported rebound effect is not found from window insert adoption. This study is the first to examine rebound effect from a weatherization improvement using survey data. Actual consumption data was also used in this study to try to determine whether a rebound effect existed, however the results were inconclusive.

A predictive model was created to determine how much money, energy, and emissions would be saved from installing inserts on a "typical" home. This model suggested that the financial, energy saving, and environmental motivations that led customers to purchase their inserts could be attained. The model predicted that the "typical" home would reduce their heating consumption by between 17 and 85 gallons of heating oil per year, with the 50$^{th}$ percentile of our sensitivity analysis showing a 35-gallon savings per year. 35 gallons of heating oil saved is estimated to save the customer \$105 per year, as well as 357 kilograms of $CO_2$, 14 grams of $CH_4$, and 3 grams of $N_2O$ per year. A simple payback period on the investment is estimated to be 3.9 years for higher-income customer and less than a month for low-income customers. A total payback period on the investment that included volunteer time and a social valuation of greenhouse gases is estimated to be 4.8 years for higher-income customers and 1.3 for low-income customers. The entire WindowDressers program (20,844 inserts) since 2010 is estimated to have saved a total of over 744,000 kilograms of $CO_2$, 29,000 grams of $CH_4$, and 6,200 grams of $N_2O$ (Figure 9) for a total social savings of nearly \$20,000. The amount of oil predicted to be saved by these 20,844 inserts (nearly 73,000 gallons) is approximately 0.013% of the 555 million gallons of distillate fuel used in the state of Maine every year. While this is still a very small percentage, it should be noted that it is a number that is growing exponentially (Figure 1) each year.

Actual heating oil consumption from three WindowDressers customers was used to determine how much money, energy, and emissions window inserts save relative to the predictive model. A Monte Carlo analysis shows that these customers saved between -150 and

414 gallons per year, with 128 gallons/year saved at the $50^{th}$ percentile. 128 gallons/year is estimated to have saved $326 per year and reduce 1,300 kilograms of $CO_2$, 52.5 grams of $CH_4$, and 10.2 grams of $N_2O$ in greenhouse gases per year. It should again be reiterated that the sensitivity analysis conducted on these three customers do not necessarily represent a "typical" Maine household and is not directly comparable to our predictive model results.

In order to directly compare the predicted energy savings model to the actual savings, a model was created using the home attributes of two of the three customers. The predicted savings were compared with the actual energy savings of the customer and the estimates did overlap. One customer was estimated save between 25 and 61 gallons of heating oil per year and actually saved between -38.7 and 162 gallons per year (depending primarily on when the fuel oil was actually consumed). Another customer was estimated to save between 136 and 256 gallons of heating oil per year and actually saved between 62.7 and 175 gallons per year. This is promising to the validity of our predictive model, however more research is needed to truly confirm the model.

Future research should expand upon these results across disciplines. This research demonstrates the importance of community energy movements. Engineers, sociologists, anthropologists, psychologists, and other economists can all build upon the groundwork laid out in this thesis. The main focus should be on reducing the uncertainties that exist in both the predictive model as well as the actual energy savings analysis. The predictive model will be stronger if the R-value of the insert can be measured and infiltrative heat loss can be accounted for. The actual savings analysis would benefit from a more exact measurement of when fuel oil, or another heating source is used each winter. Future research should also focus on expanding the survey data. Non-participants should be surveyed to determine what is different between people participating in community window insert builds to those who are not. More low-income survey participants should also be sought out as they are the participants community built inserts are most likely to help. Finally, any government agencies and other organization trying to increase residential energy efficiency or provide heating assistance to low-income household should take note of this research. Community energy efficiency can be a viable alternative to the traditional "top down" approaches. Window inserts are cheap and underexplored technology that can help promote energy sustainability, one community at a time.

## WORKS CITED


[1] "Governor's Energy Office: Current Heating Oil Prices: Home Heating Calculator." [Online]. Available: http://www.maine.gov/energy/fuel_prices/heating-calculator.php. [Accessed: 14-Dec-2016].

[2] "Indow | Indow Cost | Get a Free Estimate," *Indow*. .

[3] J. Cook *et al.*, "Consensus on consensus: a synthesis of consensus estimates on human-caused global warming," *Environ. Res. Lett.*, vol. 11, no. 4, p. 048002, 2016.

[4] L. Ross, M. Jarrett, and D. York, "Reaching More Residents: Opportunities for Increasing Participation in Multifamily Energy Efficiency Programs." American Council for an Energy-Efficient Economy, May-2016.

[5] "Governor's Energy Office: Archived Heating Oil Prices." [Online]. Available: http://www.maine.gov/energy/fuel_prices/archives.shtml. [Accessed: 14-Dec-2016].

[6] "WindowDressers | Insulating Window Inserts." [Online]. Available: http://windowdressers.org/. [Accessed: 06-Dec-2015].

[7] S. J. W. Klein and S. Coffey, "Building a sustainable energy future, one community at a time," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 867–880, Jul. 2016.

[8] "Unity Barn Raisers." [Online]. Available: http://www.unitybarnraisers.org/news.html. [Accessed: 13-May-2016].

[9] "Midcoast Green Colaborative," *Midcoast Green Colaborative*. .

[10] "Energy Efficiency," *Island Institute*, 13-Jan-2015. [Online]. Available: http://www.islandinstitute.org/program/energy/energy-efficiency. [Accessed: 14-May-2016].

[11] B. Winner, "Island Institute window insert builds," 01-Jun-2016.

[12] "Indow | About Us |," *Indow*. .

[13] G. Browning, A. Halcli, and F. Webster, *Understanding Contemporary Society*. SAGE, 1999.

[14] M. Chibnik, *Anthropology, Economics, and Choice*. University of Texas Press, 2011.

[15] M. Gladwell, *Blink :the power of thinking without thinking*. New York: Little, Brown and Co., 2005.

[16] S. Foy, C. Schleifer, and E. Tiryakian, “The Rise of Rational Choice Theory as a Scientific/Intellectual Movement in Sociology | SpringerLink,” *Am. Sociol.*, 2017.

[17] Polanyi, Karl, *The Great Transformation: The Political and Economic Origins of Our Time*. Beacon Press, 1944.

[18] Granovetter, Mark, “Economic Action and ocial Structure: The Problem of Embeddedness,” *Am. J. Sociol.*, vol. 91, no. 3, pp. 481–510, 1985.

[19] M. A. Hager, J. Galaskiewicz, and J. A. Larson, “Structural embeddedness and the liability of newness among nonprofit organizations,” *Public Manag. Rev.*, Feb. 2007.

[20] T. D. Gerarden, “AN ASSESSMENT OF THE ENERGY-EFFICIENCY GAP AND ITS IMPLICATIONS FOR CLIMATE-CHANGE POLICY,” *Natl. Bur. Econ. Res.*, Jan. 2015.

[21] A. Kollmuss and J. Agyeman, “Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior?,” *Environ. Educ. Res.*, vol. 8, no. 3, pp. 239–260, Aug. 2002.

[22] “Overview of Residential Energy Feedback and Behavior-based Energy Efficiency,” 2011.

[23] M. Redclift and T. Benton, *Social Theory and the Global Environment*. United Kingdom: Routledge, 1994.

[24] C. Noblet and S. McCoy, “Does One Good Turn Deserve Another? Evidence of Domain-Specific Licensing in Energy Behavior,” *Environ. Behav.*, vol. 1, no. 25, 2017.

[25] R. De Young, “New Ways to Promote Proenvironmental Behavior: Expanding and Evaluating Motives for Environmentally Responsible Behavior,” *J. Soc. Issues*, vol. 56, no. 3, pp. 509–526, Jan. 2000.

[26] R. W. Holland, B. Verplanken, and A. Van Knippenberg, “On the nature of attitude–behavior relations: the strong guide, the weak follow,” *Eur. J. Soc. Psychol.*, vol. 32, no. 6, pp. 869–876, Nov. 2002.

[27] K. Gillingham, D. Rapson, and G. Wagner, “The Rebound Effect and Energy Efficiency Policy,” *Rev. Environ. Econ. Policy*, vol. 10, no. 1, pp. 68–88, Jan. 2016.

[28] S. Sorrell and J. Dimitropoulos, “The rebound effect: Microeconomic definitions, limitations and extensions,” *Ecol. Econ.*, vol. 65, no. 3, pp. 636–649, Apr. 2008.

[29] L. A. Greening, D. L. Greene, and C. Difiglio, “Energy efficiency and consumption — the rebound effect — a survey,” *Energy Policy*, vol. 28, no. 6–7, pp. 389–401, Jun. 2000.

[30] F. Yu and Z. Liu, “Direct Energy Rebound Effect of Family Cars: An Analysis Based on a Survey in Chang-Zhu-Tan City Group,” *Energy Procedia*, vol. 104, pp. 197–202, Dec. 2016.

[31] Q. Su, “A quantile regression analysis of the rebound effect: Evidence from the 2009 National Household Transportation Survey in the United States,” *Energy Policy*, vol. 45, pp. 368–377, Jun. 2012.

[32] J. Schleich, B. Mills, and E. Dütschke, “A brighter future? Quantifying the rebound effect in energy efficient lighting,” *Energy Policy*, vol. 72, pp. 35–42, Sep. 2014.

[33] David J. Sailor, “Oregon Best Commercialization Grant Program Final Report: Development, Testing, and Pilot Scale Evaluation of a new Retrofit Window Insulation Product - The Indow Window,” Portland State University, Mar. 2013.

[34] “Independent T-Test - An introduction to when to use this test and what are the variables required | Laerd Statistics.” [Online]. Available: https://statistics.laerd.com/statistical-guides/independent-t-test-statistical-guide.php. [Accessed: 08-Aug-2017].

[35] “Mission – WindowDressers.” .[online]. Available: https://windowdressers.org/our-mission/.

[36] J. Thøgersen and C. Noblet, “Does green consumerism increase the acceptance of wind power?,” *Energy Policy*, vol. 51, pp. 854–862, Dec. 2012.

[37] K. Konrad and J. Alvarez, “Restoring Our Appreciation of Historic Wood Windows: Making a Case for Restoration Versus Replacement.” New York State Office of Parks, Recreation and Historic Preservation, Mar-2009.

[38] J. Knox and S. Widder, “Characterization of Energy Savings and Thermal Comfort Improvements Derived from Using Interior Storm Windows.” Sep-2013.

[39] V. Glaser, “Total Immersion,” *MARY ANN LIEBERT INC*, vol. 3, no. 5, p. 4, Oct. 2010.

[40] R. Haas and P. Biermayr, “The rebound effect for space heating Empirical evidence from Austria,” *Energy Policy*, vol. 28, no. 6–7, pp. 403–410, Jun. 2000.

[41] R. Nesbakken, “Energy Consumption for Space Heating: A Discrete–Continuous Approach,” *Scand. J. Econ.*, vol. 103, no. 1, pp. 165–184, Mar. 2001.

[42] C. Guertin, S. Kumbhakar, and A. Duraiappah, "Determining Demand for Energy Services: Investigating incomedriven behaviours," *Int. Inst. Sustain. Dev.*, 2003.

[43] R. Madlener and M. Hauertmann, "Rebound Effects in German Residential Heating: Do Ownership and Income Matter?," *Inst. Future Energy Consum. Needs Behav.*, Feb. 2011.

[44] "Calculating Envelope Energy Loss." U.S. Department of Energy, Dec-2012.

[45] Eileen Wilkinson, "2016 Pricing Clarification," 17-Mar-2016.

[46] "Governor's Energy Office: Archived Heating Oil Prices (2004-2016)." [Online]. Available: http://www.maine.gov/energy/fuel_prices/archives.shtml. [Accessed: 20-May-2016].

[47] "Weather Data Depot: free downloads of heating & cooling degree days." [Online]. Available: http://www.weatherdatadepot.com/. [Accessed: 20-May-2016].

[48] "Building interior window insulation panels." [Online]. Available: http://www.arttec.net/Thermal-Windows/. [Accessed: 19-May-2016].

[49] "Our Product: Window Insulating Inserts – WindowDressers." [Online]. Available: https://windowdressers.org/window-insulating-inserts/.

[50] "ColoradoENERGY.org - R-Value Table." [Online]. Available: http://www.coloradoenergy.org/procorner/stuff/r-values.htm. [Accessed: 20-May-2016].

[51] "Governor's Energy Office: Current Heating Oil Prices: Home Heating Calculator (heatcalculatorMEv3_1.xls)." [Online]. Available: http://www.maine.gov/energy/fuel_prices/heating-calculator.php. [Accessed: 19-May-2016].

[52] "Weather Data Depot: free downloads of heating & cooling degree days." [Online]. Available: http://www.weatherdatadepot.com/?gclid=CJjIoOiW6MgCFRCCaQodmIEMBg. [Accessed: 06-Dec-2015].

[53] "Home Energy Magazine :: Creating Windows of Energy-Saving Opportunity." [Online]. Available: http://www.homeenergy.org/show/article/nav/windows/page/3/id/1330. [Accessed: 15-Dec-2015].

[54] "2011-2015 American Community Survey 5-Year Estimates," *U.S. Census Bureau*. [Online]. Available:

https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF. [Accessed: 15-Jun-2017].

[55] "Emission Factors for Greenhouse Gas Inventories." EPA, Nov-2015.

[56] United States, Environmental Protection Agency, Office of Transportation and Air Quality, and Assessment and Standards Division, *Regulatory impact analysis: final rulemaking for 2017-2025 light-duty vehicle greenhouse gas emission standards and corporate average fuel economy standards*. Washington, D.C.: Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, 2012.

[57] Brad C. James, "Testing the energy performance of historic windows in a cold climate," Master of Science in Civil and Environmental Engineering, University of Vermont, Burlington, VT, 1997.

[58] "Maine State Energy Profile," *U.S. Energy Information Administration*, 15-Jun-2017. [Online]. Available: https://www.eia.gov/state/print.php?sid=ME. [Accessed: 08-Aug-2017].

## APPENDIX A

## SURVEYS

There were three surveys used in this thesis (discussed in chapter 2). All three can be found in the supplemental materials. Note that the numbering is out of order in the survey. This is due to the way Qualtrics generates their numbers. The questions were asked in the order they are shown, not in the numerical order of the question numbers. A screenshot of what the questions in the survey look like is placed here:

Display This Question:

If Have you installed any of your inserts yet? Yes Is Selected

Q265 Please indicate your level of satisfaction with the following traits about your inserts.

| | 1 (Very Dissatisfied) | 2 (Dissatisfied) | 3 (Neutral) | 4 (Satisfied) | 5 (Very Satisfied) |
|---|---|---|---|---|---|
| Less drafty | ❍ | ❍ | ❍ | ❍ | ❍ |
| Warmer rooms | ❍ | ❍ | ❍ | ❍ | ❍ |
| Clarity of inserts | ❍ | ❍ | ❍ | ❍ | ❍ |
| The way the inserts look | ❍ | ❍ | ❍ | ❍ | ❍ |
| Quality of inserts | ❍ | ❍ | ❍ | ❍ | ❍ |
| Durability of inserts | ❍ | ❍ | ❍ | ❍ | ❍ |
| Other | ❍ | ❍ | ❍ | ❍ | ❍ |

*Figure 14 – Sample survey question*

## APPENDIX B

## LEVENE'S TEST FOR EQUALITY OF VARIANCES

This appendix includes all of the Levene's test for equality of variances information for the t-tests conducted in Chapter 2.

*Table 24 – Levene's Test for equality of variances comparing low-income responses to all other responses for why they purchased inserts*

| Motivation for Purchase | F-statistic | Significance |
|---|---|---|
| To conserve energy | 3.669 | 0.057 |
| To improve comfort | 2.935 | 0.001** |
| To save money | 13.946 | 0.000** |
| To reduce dependency on fossil fuels | 0.634 | 0.427 |
| To benefit the environment | 0.085 | 0.085 |
| Because they valued the sense of community associated with the project | 2.935 | 0.088 |

*** indicates statistical significance at (α=0.05)*

*Table 25 – Levene's Test for equality of variances comparing low-income responses to all other responses for why they volunteered for WindowDressers*

| Motivation for Volunteering | F-statistic | Significance |
|---|---|---|
| To help others conserve energy | 5.692 | 0.020** |
| To improve the comfort of others | 5.339 | 0.024** |
| To reduce dependency on fossil fuels | 8.594 | 0.004** |
| To benefit the environment | 20.961 | 0.000 |
| Because they valued the sense of community associated with the project | 0.335 | 0.565 |

*** indicates statistical significance at (α=0.05)*

*Table 26 – Levene's Test for equality of variances comparing volunteer satisfaction for volunteers participating for more than 8 hours to volunteers to volunteers participating 8 hours or less*

| Metric | F-statistic | Significance |
|---|---|---|
| Overall volunteer experience (rated 1-5) | 0.314 | 0.576 |

*Table 27 – Levene's Test for equality of variances comparing likeliness of future participation between those who volunteered and those who did not*

| Future Participation | F-statistic | Significance |
|---|---|---|
| **Recommend a friend purchase inserts in a future build** | **0.099** | **0.753** |
| **Recommend a friend to volunteer in a future build** | **30.299** | **0.000**** |
| **Volunteer in a future build** | **6.647** | **0.010**** |
| **Initiate a future build** | **8.926** | **0.003**** |

*** indicates statistical significance at (α=0.05)*

# APPENDIX C

## UTILITY RELEASE FORM

This release form was presented to and signed by WindowDressers customers who agreed to let us contact their heating provider to receive their last 5 years (or however long they have been a customer if shorter) of energy consumption. It is similar to the form used by realtors to access the same information when valuing a home on the market.

**Authorization to Release Information**

To Whom It May Concern:

1. Name:_______________________________________________________

   Name:_______________________________________________________

2. Property Address:_______________________________________________

3. Heating fuel Provider(s):__________________________________________

   Account Number(s):______________________________________________

4. Electricity Provider(s):____________________________________________

   Account Number(s):______________________________________________

5. I/We are participating in a research study concerning energy efficiency practices for the above-described real estate. Participants involved in the research process (professors, graduate students, coordinators, etc.) need to obtain energy cost and consumption information to complete the study.

6. I/We authorize you to provide to any such participants any and all information and documentation that they request. To establish a credible baseline for each home/building, researchers will request 5 years of energy data prior to insert installation.

7. Participants may address the authorization to any party having information necessary to complete the study.

8. A copy or facsimile of this authorization may be accepted as an original.

_________________________________ _________________________________

Signature Date Signature Date

1865 THE UNIVERSITY OF MAINE

**APPENDIX D**

**MONTE CARLO SIMULATION FOR PREDICTED**

**ENERGY CONSUMPTION**

This appendix includes the rest of the Monte Carlo distribution and tornado graphs for the predicted energy consumption analysis conducted in chapter 3.

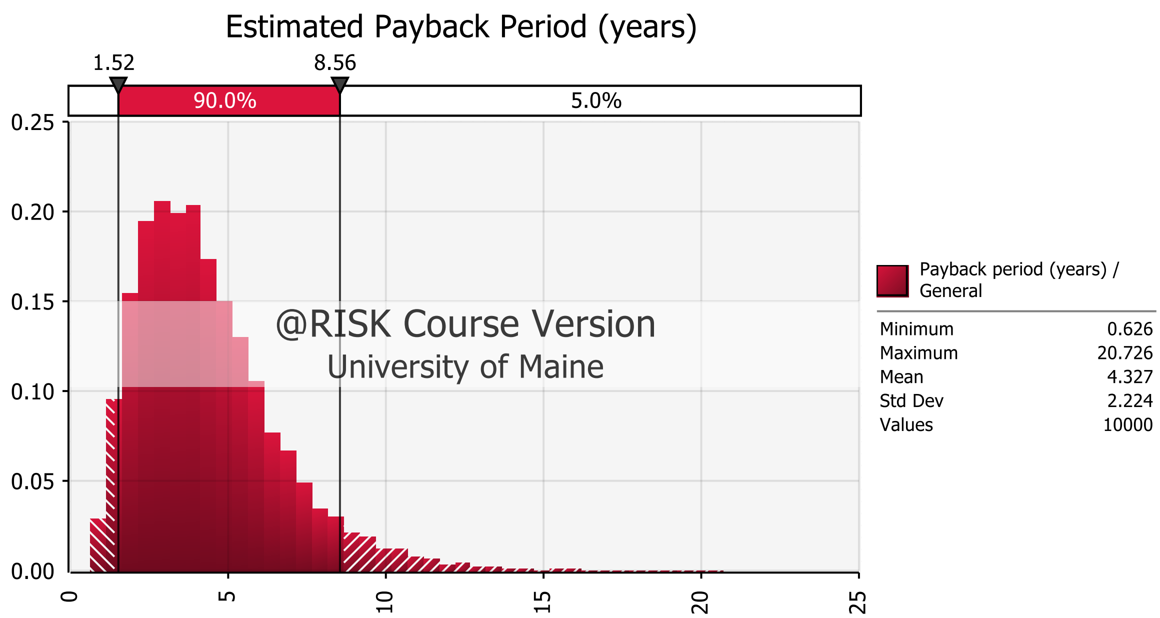


*Figure 15 – Monte Carlo distribution for the predicted simple payback period after inserts were installed*

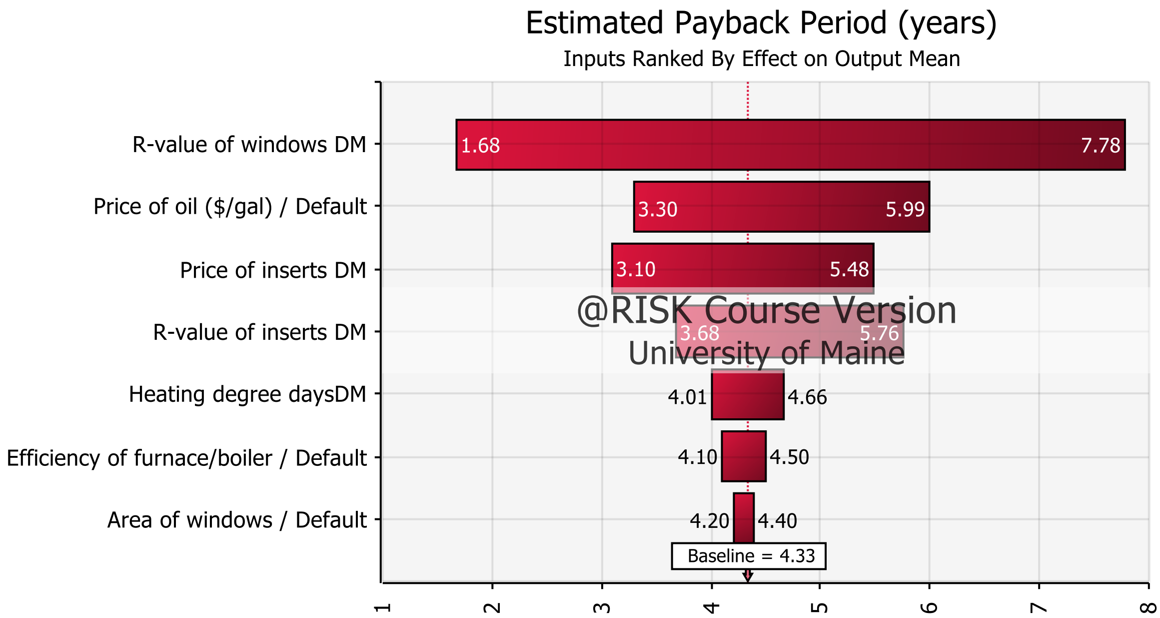


*Figure 16 – Tornado graph demonstrating the model sensitivity for the simple payback period*

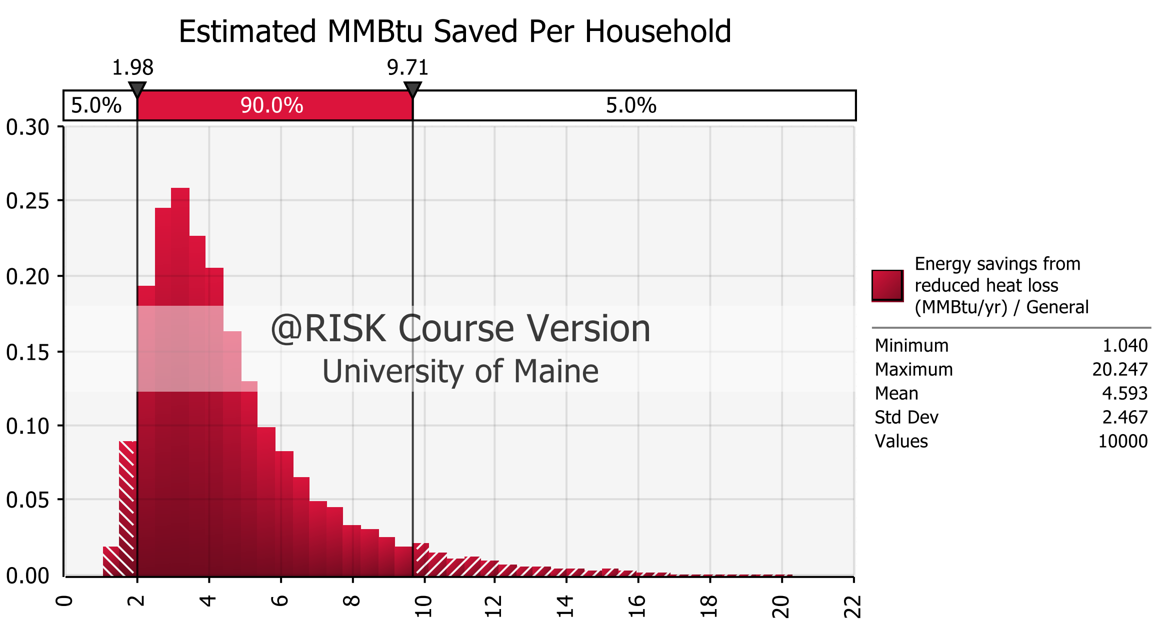


*Figure 17 – Monte Carlo distribution for the predicted MMBtu saved per household after inserts were installed*

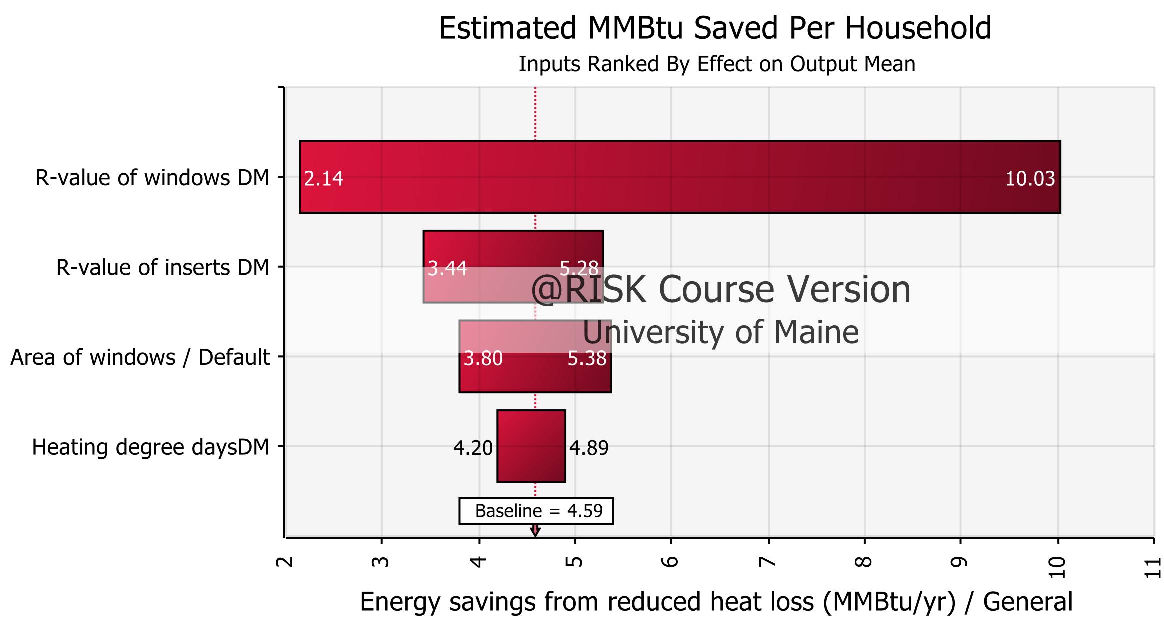


*Figure 18 – Tornado graph demonstrating the model sensitivity for MMBtu saved per household*

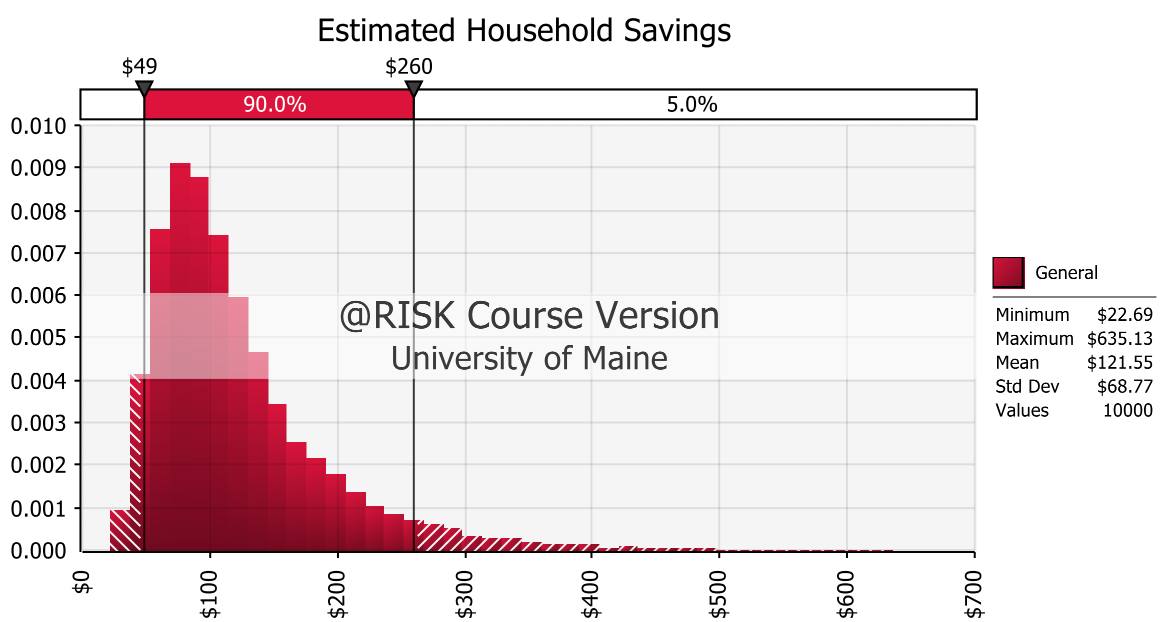


*Figure 19 – Monte Carlo distribution for the predicted simple payback period after inserts were installed*

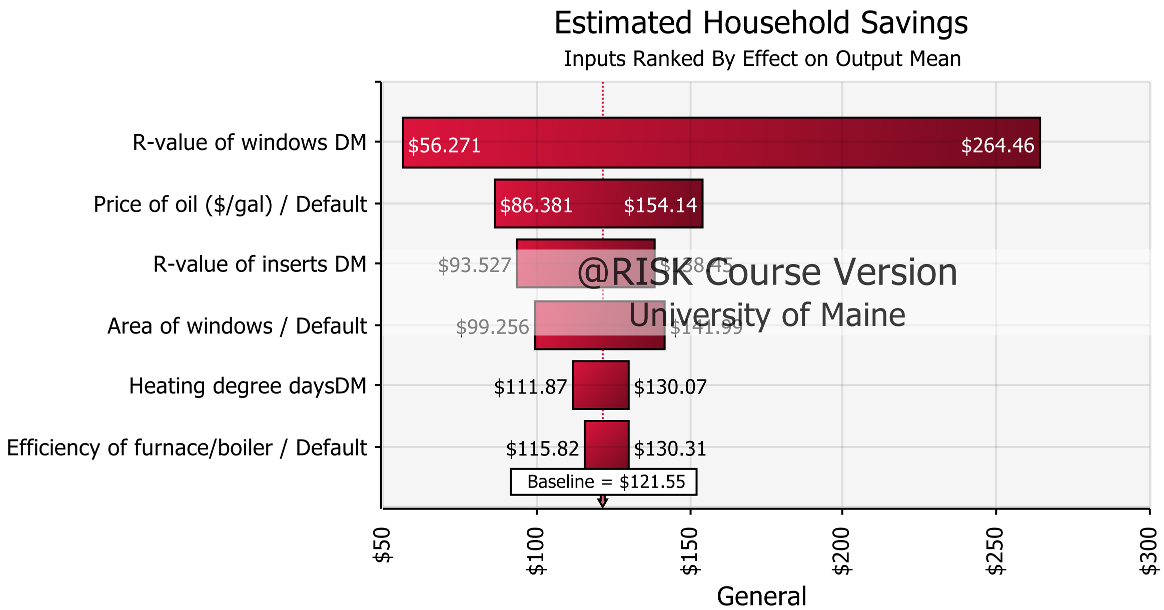


*Figure 20 – Tornado graph demonstrating the model sensitivity for the estimated household savings*

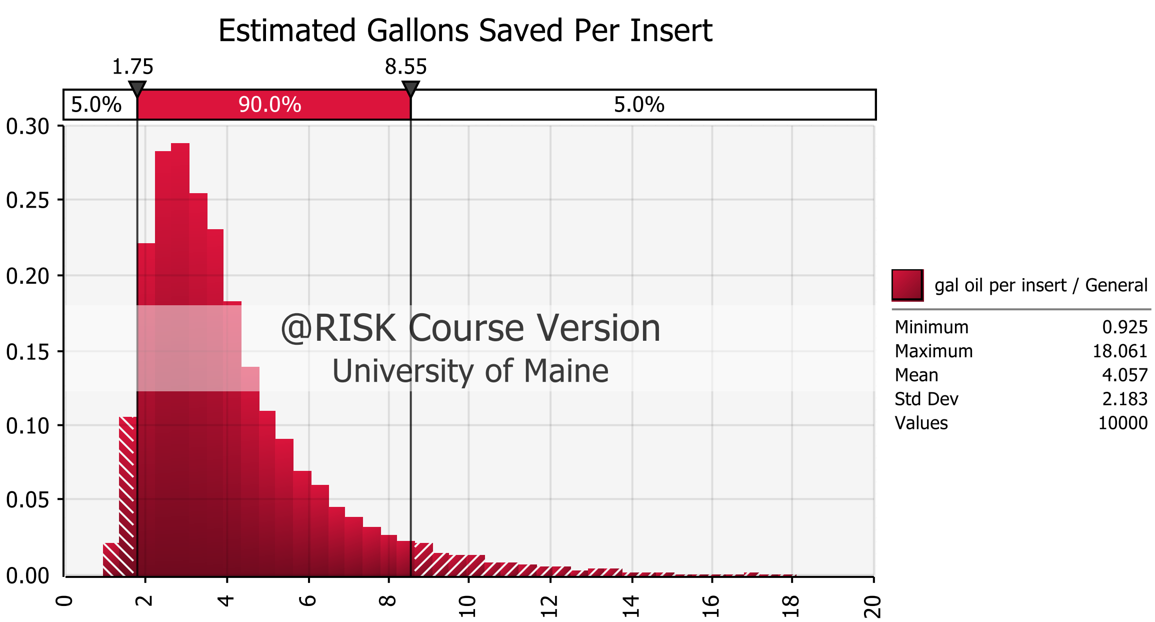


*Figure 21 – Monte Carlo distribution for the predicted gallons saved per insert after inserts were installed*

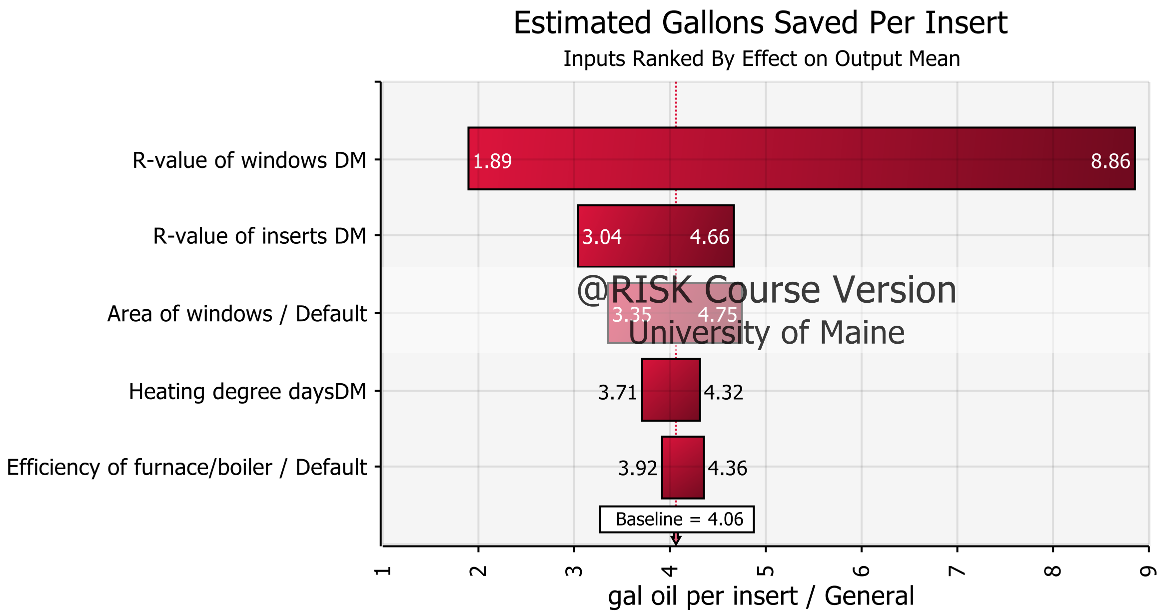


*Figure 22 – Tornado graph demonstrating the model sensitivity for estimated gallons saved per insert*

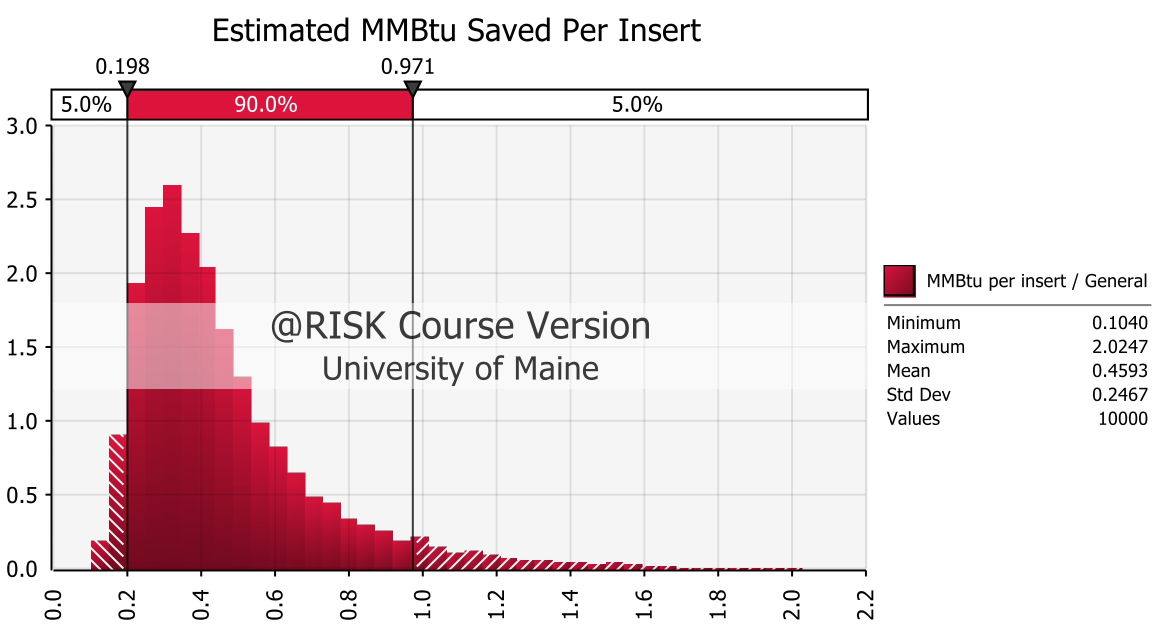


*Figure 23 – Monte Carlo distribution for the predicted MMBtu saved per insert after inserts were installed*

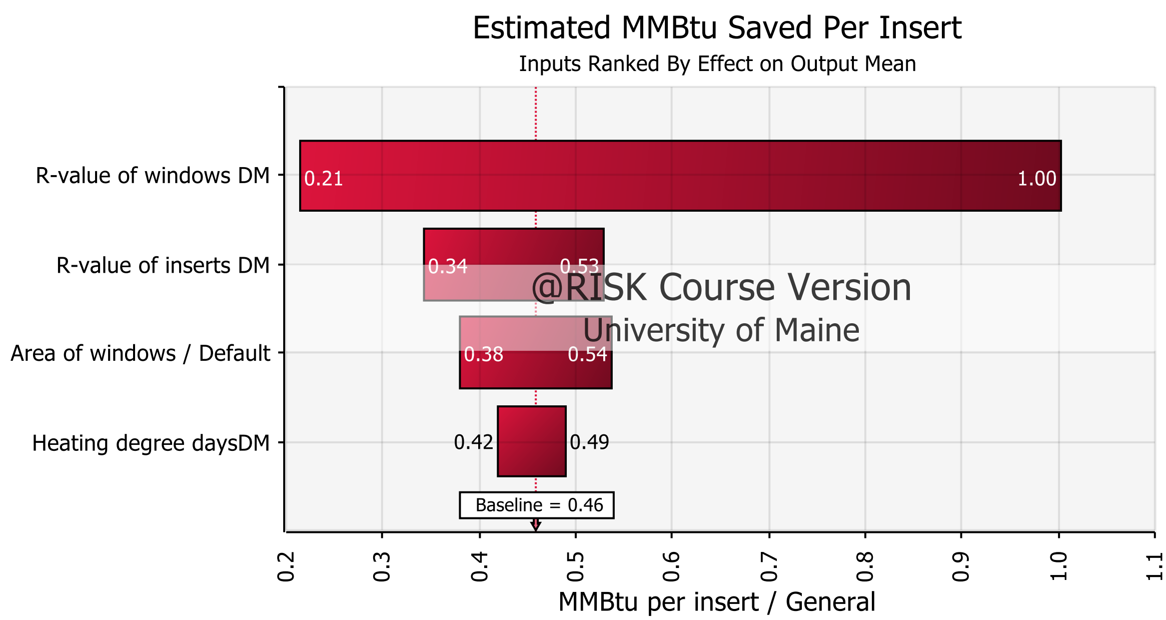


*Figure 24 – Tornado graph demonstrating the model sensitivity for the estimated MMBtu saved per insert*

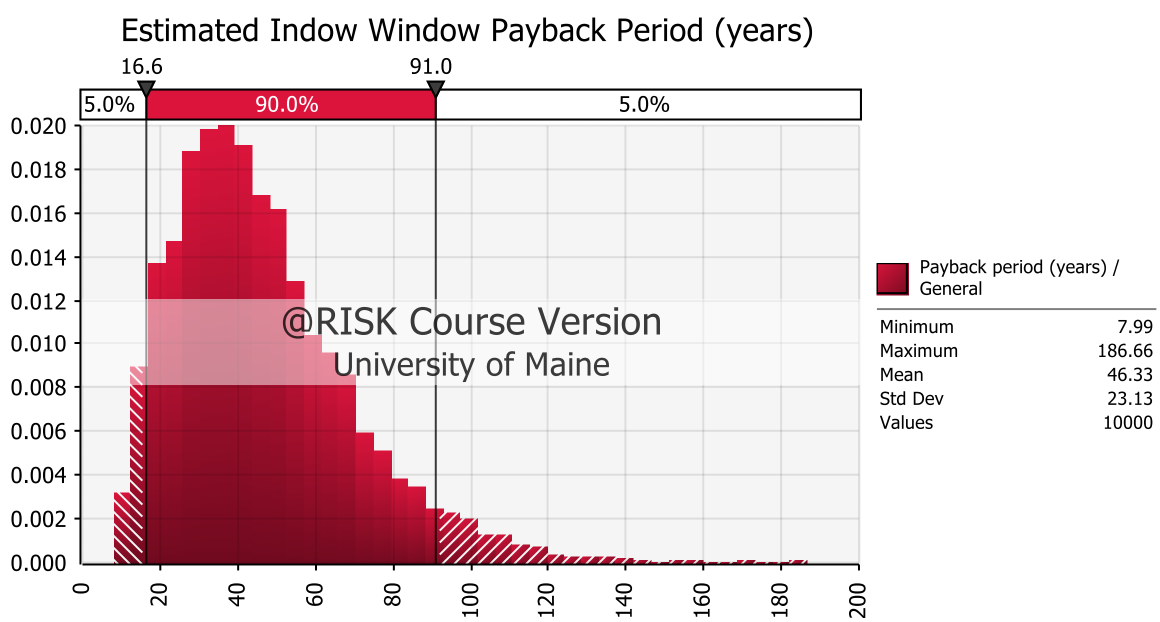


*Figure 25 – Monte Carlo distribution for the predicted simple payback period of Indow Window inserts*

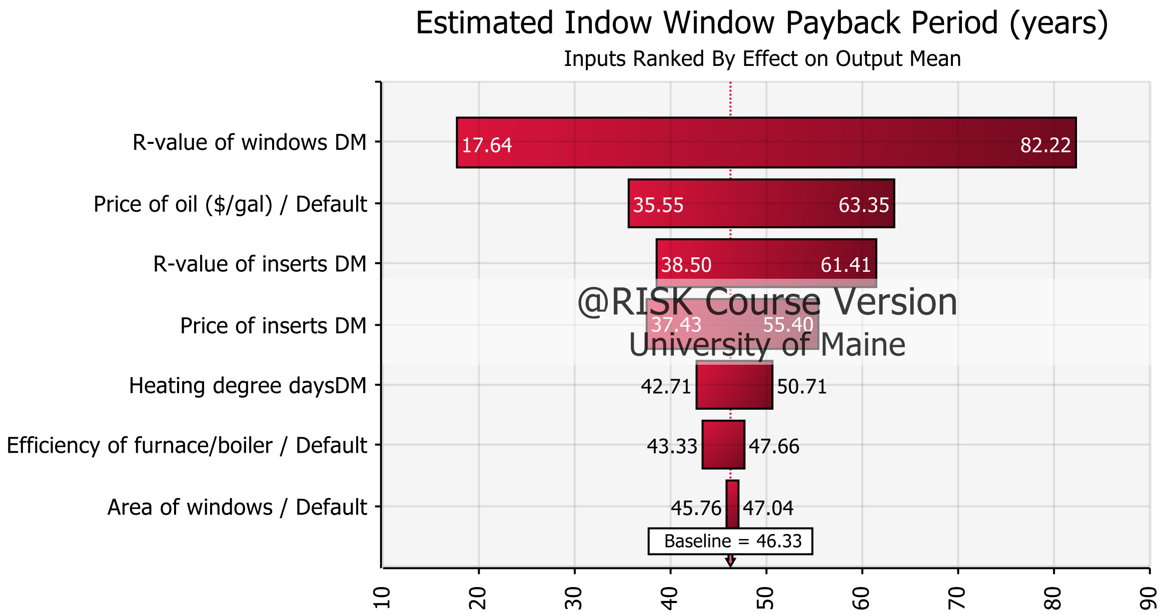


*Figure 26 – Tornado graph demonstrating the model sensitivity for the simple payback period of Indow Window inserts*

**APPENDIX E**

**MONTE CARLO SIMULATION FOR ACTUAL**

**ENERGY CONSUMPTION**

This appendix includes the rest of the Monte Carlo distribution and tornado graphs for the actual energy consumption analysis conducted in chapter 3.

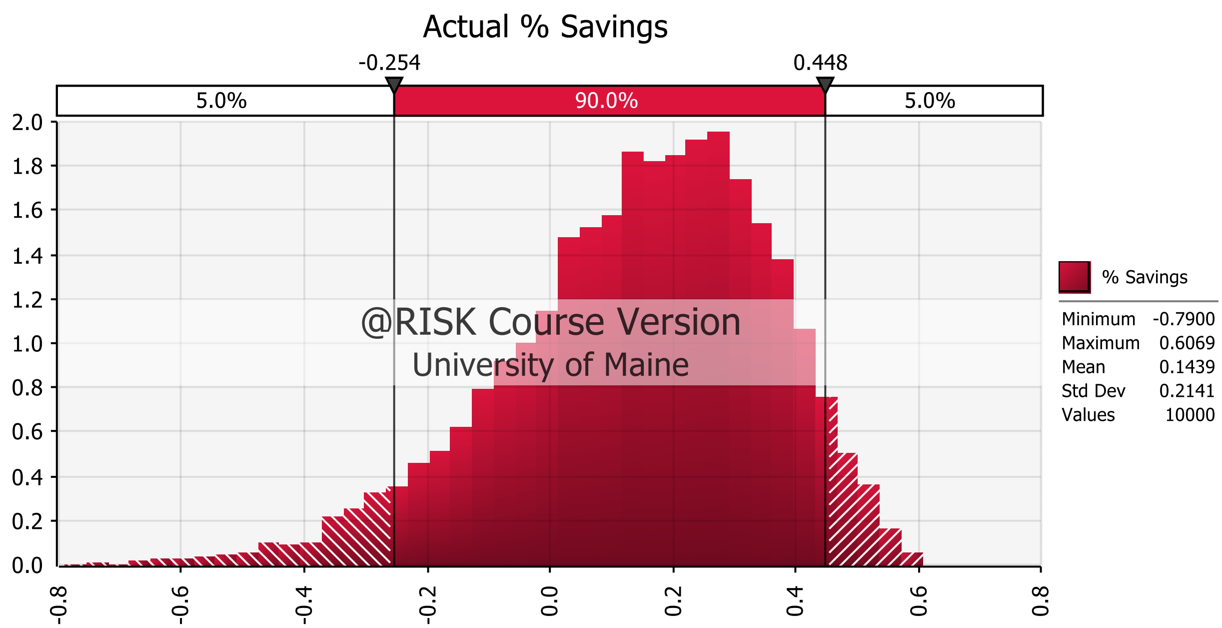


*Figure 27 – Monte Carlo distribution for the actual percentage of energy saved after inserts were installed*

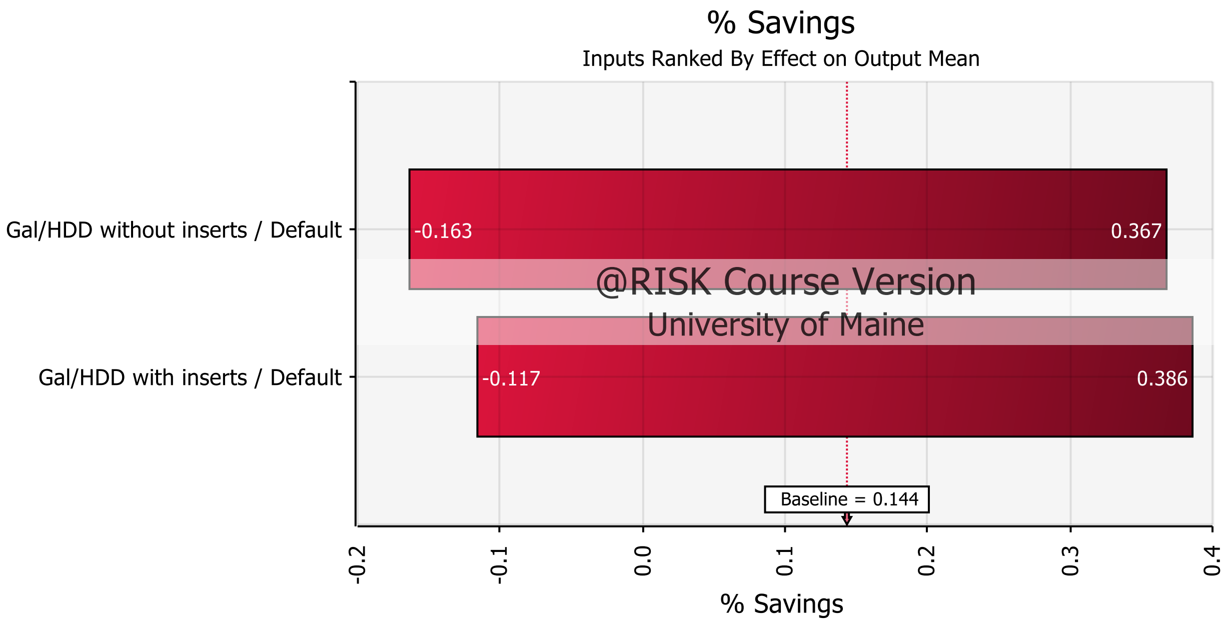


*Figure 28 – Tornado graph demonstrating the model sensitivity for percentage of energy savings for each parameter*

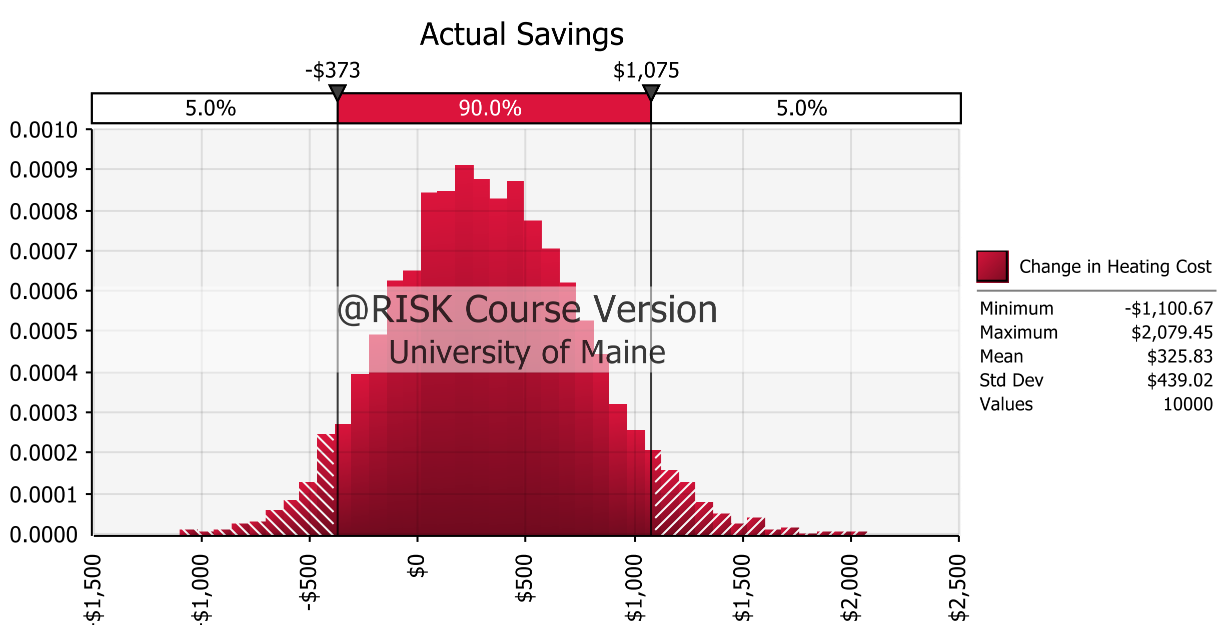


*Figure 29 – Monte Carlo distribution for the actual household savings after inserts were installed*

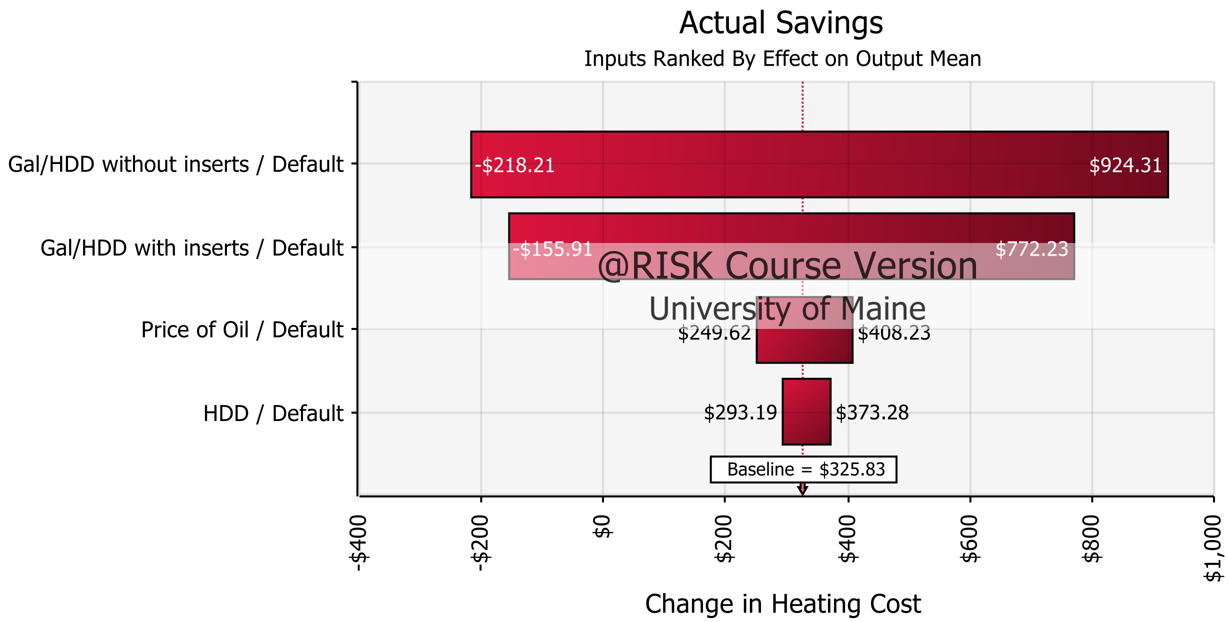


*Figure 30 – Tornado graph demonstrating the model sensitivity for household savings for each parameter*

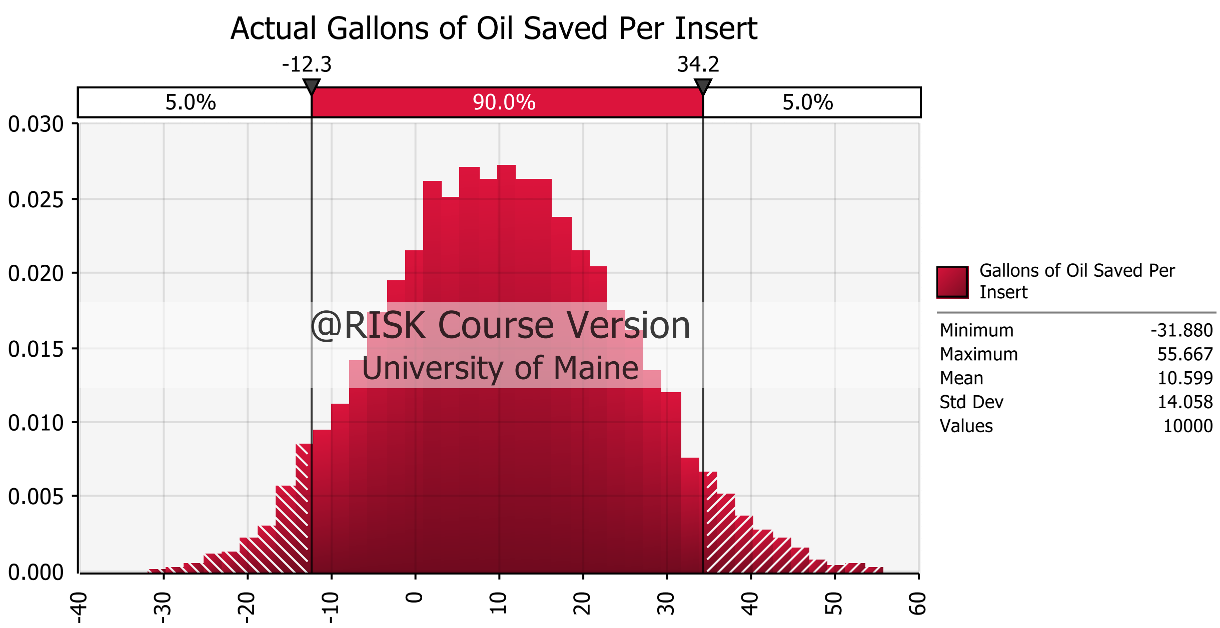


*Figure 31 – Monte Carlo distribution for the actual change in gallons consumed per insert after inserts were installed*

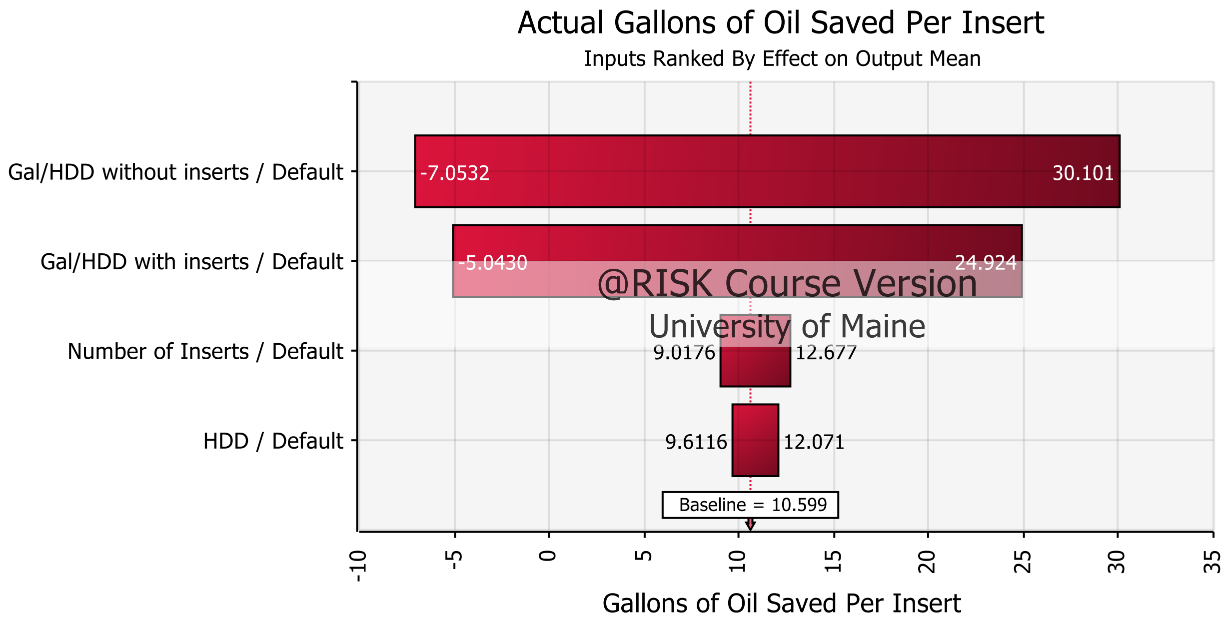


*Figure 32 – Tornado graph demonstrating the model sensitivity for change in gallons of oil per insert for each parameter*

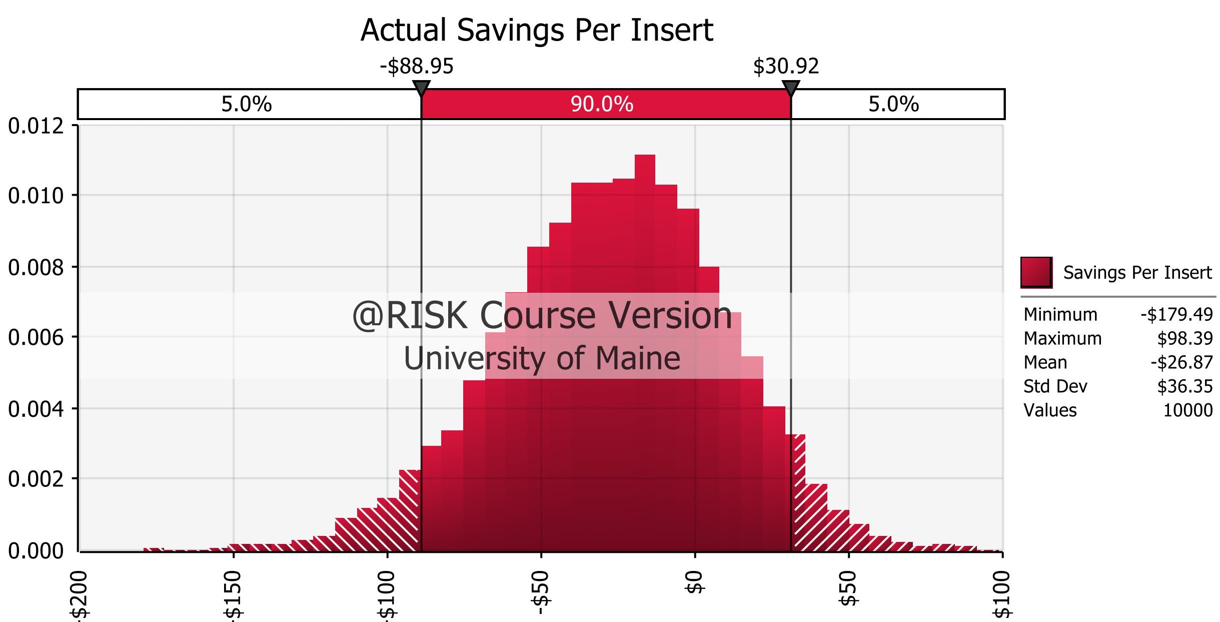


*Figure 33 – Monte Carlo distribution for the actual savings per insert after inserts were installed*

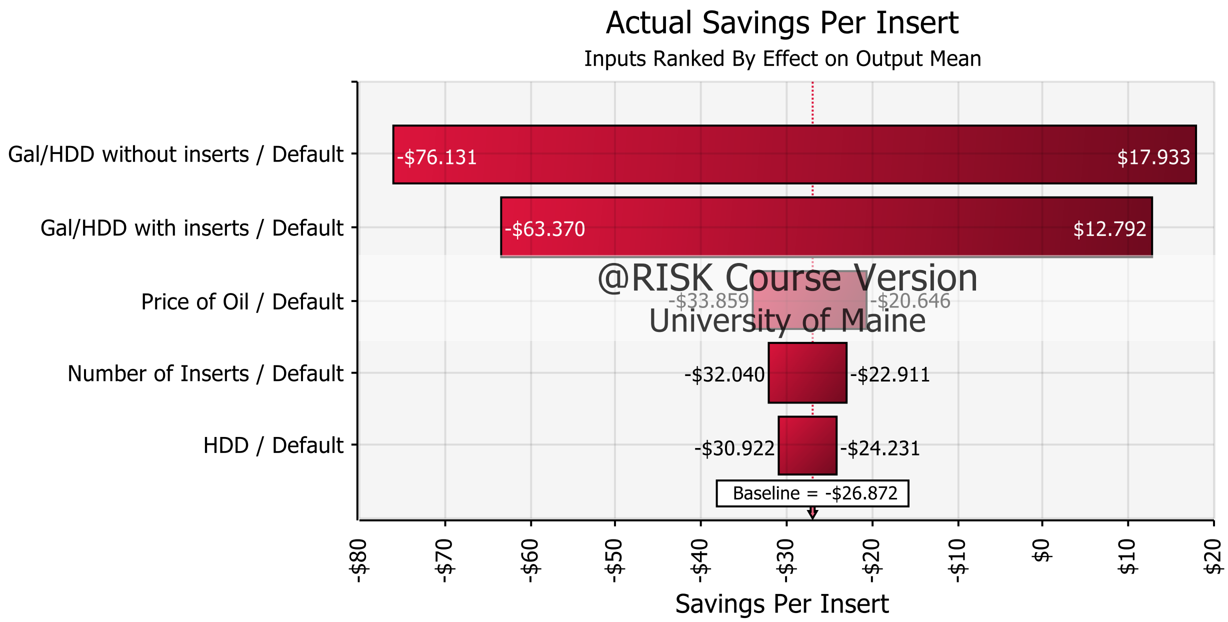


*Figure 34 – Tornado graph demonstrating the model sensitivity for savings per insert for each parameter*

## BIOGRAPHY OF THE AUTHOR

Daniel Mistro was born in Winfield, Illinois and graduated from Glenbard North High School in 2011. He attended Illinois State University in Normal, Illinois, where he graduated with a B.S. in Applied Economics in 2015. Daniel is a candidate for the Master of Science degree in Resource Economics and Policy from the University of Maine in August 2017.