THE RELATIVE VALUE OF WEATHERIZATION: COMPARING ENERGY SAVINGS, MONETIZED HEALTH IMPACTS FROM CHANGES IN INDOOR AIR QUALITY, AND HOME IMPROVEMENT COSTS

A Thesis
by
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Abstract

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Historically, the benefit of weatherizing homes has focused on decreasing energy costs to homeowners, with little quantitative evaluation of other effects—in particular, indoor air quality (IAQ) and subsequent health effects. The purpose of this study was to examine the relative impact of weatherization on energy savings and potential health implications from changes in IAQ. Using data from a cohort (n=49) of homes undergoing weatherization across the three distinct climate zones in North Carolina, this study performed an analysis that included building characteristics, weatherization improvements, and costs, along with indoor air quality data.

Analysis to convert indoor air quality measurements into IAQ effects on overall health in the form of a disability adjusted life year (DALY), as well as the impact on asthma symptoms, allowed for a comparison between projected energy cost savings and cost/benefit of weatherization. Results show that including the economic impact of the DALY along with energy cost savings indicates significant financial benefit from weatherization across the study population, but occupant behaviors (smoking) and building characteristics (manufactured vs. site built homes, forced air heating, and presence of combustion appliances) need to be considered to maximize the benefits from weatherization. Further work is needed to show long-term

impacts of weatherization on home occupants and to determine which methods provide the maximum benefit for health and energy.

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CHAPTER 1: INTRODUCTION

Statement of the Problem

Historically, calculating the benefits of weatherizing homes has focused on decreasing energy costs to homeowners, with little consideration on other effects, in particular, indoor air quality (IAQ) and subsequent health effects. With over 750,000 homes undergoing weatherization between 2009-2012 in the United States (United States Department of Energy [USDOE], 2016a) and more than 7 million homes since the program's inception in 1976 (USDOE, 2016a), the implications of weatherization's influence on IAQ are potentially far-reaching. In addition to needing a better understanding of the IAQ repercussions of weatherization, work that has been addressed in only a few studies (Doll, Davidson, & Painting, 2016; Pigg, Cautley, Francisco, Hawkins, & Brennan, 2014), it is important to gain a sense of the potential economic consequences of health effects from weatherization. Monetizing both the energy and health impacts of weatherizing homes will provide an increased understanding of the overall value of weatherization.

Purpose of the Study

This purpose of this study was to examine the relative impact of weatherization on energy savings and potential health implications resulting from changes in IAQ. A previous study (Pigg et al., 2014) that focused on weatherization and indoor air quality collected data from a large number of homes to compare IAQ before and after weatherization, but provided little analysis into the health impacts of IAQ changes and only collected data on a limited number of contaminants (temperature, relative humidity, CO, HCHO, and radon). This study performed an analysis that included building characteristics and weatherization improvements, along with an expanded set of indoor air quality data.

Research Questions

1. What is the relative value of weatherization when monetized health impacts resulting from changes in IAQ are compared with energy savings and cost of weatherization?
2. Do homes with similar cost/benefit results have shared characteristics?

Limitations of the Study

Making use of an existing dataset, this study was limited by three major factors from the original study: the scope, the population size, and the study location. The scope of the original study focused on changes in IAQ in homes that were eligible for weatherization assistance programs. This limited the homes studied to low-income housing, and provided a standard for weatherization that may not be representative of privately-funded energy retrofits. In addition, no energy bills were available to assess energy and cost savings. Therefore, for this research, different aspects of energy savings were determined through representations and estimates using weatherization information, building characteristics, air leakage, and ventilation rates. The original study enrolled 92 homes resulting in matched pre- and post-weatherization data sets from 69 homes, 10 homes with incomplete matched information, and 13 control homes that underwent no change. The study was conducted in North Carolina's mountain, Piedmont, and coastal regions, each of which has different climates and demographics. Although these limitations affect the generalizability of this study's findings, making use of this established dataset provided extensive field measurements that could be analyzed using a new methodological approach.

Significance of the Study

This study is the first to apply previous analysis methods for quantifying the effects of IAQ to a set of data collected in the field. In the studies where these methods were pioneered (Logue, Price, Sherman, & Singer, 2012; Fabian, Adamkiewicz, Stout, Sandel, & Levy, 2014) only data from computer modeling was used. Therefore, the findings from this study provide empirical support for the effects of weatherization on IAQ to those who have an interest in looking more broadly at the financial impacts that might be realized from weatherization efforts.

CHAPTER 2: REVIEW OF LITERATURE

Within the existing literature, there is a poorly understood connection between energy efficiency measures and their effect on indoor air quality, and subsequently on the health of occupants. In this review, building energy usage and the motivation for weatherization, especially within low-income populations, are explained, and an overview of the Weatherization Assistance Program is provided. This is followed by a description of the energy impacts of weatherization, potential indoor air quality effects, and what is known about the resulting effect on health of the occupants.

Buildings, Energy Use, and Climate Change

The combined energy used in commercial and residential buildings makes up approximately 41% of the entire United States (U.S.) energy consumption (United States Energy Information Administration [USEIA], 2015). This makes improving efficiency of the existing building stock a large target for reducing energy use and reaching climate change mitigation goals. While new buildings are increasing in both size and number of appliances, they are using less energy per square feet than older buildings. The United States Energy Information Administration (USEIA) shows in their 2009 Residential Energy Consumption Survey (RECS) that homes built from 2000-09 increased in size by 30% but, on average, only increased in energy consumption by 2%. These homes only accounted for 14% of all occupied housing units, leaving the remaining older housing stock with higher energy consumption per square foot (USEIA, 2013). This same trend holds true for commercial buildings as well. According to the USEIA's 2012 Commercial Buildings Energy Consumption Survey (CBECS) total energy consumption per square foot decreased by 13.75% from 2003 to 2012 (USEIA, 2016a).

Climate Change and Buildings

During 2015, residential and commercial buildings contributed 1,947 million metric tons of CO_2, approximately 37% of the United States' 5,259 million metric tons of CO_2 emissions (USEIA, 2016b). Increasing both existing and new buildings' energy efficiency to reduce CO_2 emissions is necessary to meet carbon reduction goals to mitigate climate change effects. The United Nations Environment Programme Sustainable Building and Climate Initiative states, "The building sector has the most potential for delivering significant and cost-effective GHG [greenhouse gas] emission reductions" (United Nations Environment Programme [UNEP], 2009, p. 4). With this in mind, innovative methods for reducing energy consumption should be a major goal.

Buildings not only contribute significantly to CO_2 emissions causing climate change but are also increasingly vulnerable to many climate change effects including hydrological changes, extreme weather events, temperature shifts, and sea level rise. The U.S. Department of Housing and Urban Development (HUD) has further broken down these effects into more specific primary impacts (2014), as shown in Table 1.

Climate-related changes that may impact buildings include extreme winter storms and heat waves that influence energy consumption, water-related consequences that contribute to increased mold in homes, and droughts and wildfires that increase airborne contaminants and negatively affect IAQ and occupant health (United States Department of Housing and Urban Development [HUD], 2012). These effects of climate change will lead to increased stress on building structures and systems and will result in a need to adapt in ways that will not increase energy consumption and CO_2 emissions.

Table 1. *Climate Change and Types of Impacts*

Climate Change Effects	**Primary Impacts**
Hydrological/Precipitation Changes	● Amount, Intensity, and Seasonality of Precipitation ● Stream Flows and Lake Levels ● Storm water Runoff
Extreme Weather Events	● Tropical Storms/Cyclones ● Floods ● Droughts ● Wildfires ● Landslides ● Tsunami ● Winter Storms
Temperature Shifts	● Heat Waves ● Water Temperature ● Snowpack ● Permafrost Melt
Sea Level Rise	● Costal Erosion ● Coastal Inundation ● Storm and Tidal Surge

Residential Energy Usage in the U.S.

In 2013 the U.S. residential energy market consumed approximately 21.1 quadrillion Btu's of combined energy in 114.3 million homes, leading to a combined output of 1,036 million metric tons of CO_2. The residential energy market accounts for approximately 53% of total building-related CO_2 output and 22 % of the 97.1 quadrillion Btus consumed by the US residential energy market (USEIA, 2015). Fortunately, these numbers have been consistently falling from a peak of 1,185 million metric tons in 2000 (USEIA, 2016b). Table 2 shows the amount of primary source energy used for various building functions.

The 8.33 quadrillion Btu of energy used for space conditioning accounts for approximately 39.5% of the entire residential energy market and is a primary focus for weatherization methods to reduce both energy costs and CO_2 emissions.

Table 2. *Residential Energy Consumption by End Use for 2013*

	Quadrillion Btu	Percent of Total
Space Conditioning	**8.33**	**39.5%**
Space heating	5.88	27.9%
Space cooling	2.05	9.7%
Furnace fans and boiler circulation pumps	0.4	1.9%
Water heating	**2.68**	**12.7%**
Appliances	**4.35**	**20.6%**
Refrigeration	1.12	5.3%
Cooking	0.56	2.7%
Clothes dryers	0.67	3.2%
Freezers	0.24	1.1%
Clothes washers	0.09	0.4%
Dishwashers	0.29	1.4%
Televisions and related equipment	1.01	4.8%
Computers and related equipment	0.37	1.8%
Lighting	**1.8**	**8.5%**
Miscellaneous	**3.95**	**18.7%**
Total	**21.1**	**100.0%**

The USEIA *Annual Energy Outlook 2015 with Projections to 2040* (*AEO2015*), indicates a less than 0.001% increase in residential consumption over the next 25 years. The *AEO2015* also projects a 0.8% increase in total number of households, as well as increases in end-user energy costs of 0.5%, 0.7%, 1.6%, and 0.6% growth per year (in 2013 dollars) for propane, distillate fuel, natural gas, and electricity, respectively (USEIA, 2015). These projections indicate that despite increases in overall energy efficiency there will still be an increase in residential energy costs across the United States.

Energy Usage in Low-Income Homes

It has long been known that low-income homes have a higher energy cost burden for homeowners than those of non-low-income homes. This leads to increased economic hardship and puts families at a higher risk for increased stress, thermal discomfort, and respiratory diseases (Drehobl & Ross, 2016). The energy burden, or the percentage of income spent on energy utility spending, is significantly higher for low-income households in the United States even with established programs such as the Weatherization Assistance Program (WAP) and the Low-Income Home Energy Assistance Program (LIHEAP). Even with the benefits of these programs, the median energy burden for low-income households is 7.2% of annual income, while non-low-income households have a much lower energy burden of 2.3% (Drehobl & Ross, 2016). Confirmed by the 2009 RECS data shown in Table 3, as income decreases both energy consumption and expenditure per square foot increase (USEIA, 2013).

TABLE 3. *Annual Household Income vs. Energy Consumption and Expenditures*

2009 Annual Household Income	Energy Consumption Per Square Foot (thousand Btu)	Energy Expenditures per Square Foot (Dollars)
Less than $20,000	54.3	$ 1.21
$20,000 to $39,999	49.0	$ 1.09
$40,000 to $59,000	44.6	$ 1.01
$60,000 to $79,999	44.1	$ 1.00
$80,000 to $99,999	42.5	$ 0.96
$100,000 to $119,999	39.8	$ 0.90
$120,000 or More	40.6	$ 0.94

All homes in the dataset used for this study qualified for the WAP, which focuses entirely on low-income homes and the specific challenges faced by these households.

Weatherization Overview

Weatherization assistance programs focus on reducing energy costs for low-income households by upgrading residential homes with cost-effective energy efficiency measures. The WAP, run by the U.S. Department of Energy (USDOE), is the largest residential energy efficiency program in the nation and has weatherized more than 7 million households since its inception in 1976. This program is unique because unlike many energy efficiency programs, the

WAP also addresses the overall health and safety of the clients (United States Department of Energy [USDOE], 2016a). By law the purpose of the WAP is to:

> Increase the energy efficiency of dwellings owned or occupied by low-income persons or to provide such person's renewable energy systems or technologies, reduce their total residential expenditures, and improve their health and safety, especially low-income persons who are particularly vulnerable such as the elderly, persons with disabilities, families with children, high residential energy users, and households with high energy burden. (Weatherization Assistance for Low Income Persons, 2006, para. 1)

All homes in the HUD grant data set underwent weatherization based on guidelines established by the WAP, and that were used in this study when referring to weatherization strategies. It is important to note that weatherization and energy retrofitting are not limited to services offered by the WAP; they are also performed by homeowners, contractors, energy auditors, and utilities for a wide variety of income brackets.

Funding Sources for Weatherization

The WAP receives funding through an annual appropriation from Congress. The WAP then allocates this money to the states through a base and formula allocation program. Each state gets an equal portion of a base allocation of $171,858,000 and the rest of the allocation is distributed based on a formula that factors in low-income population, climatic conditions, residential energy expenditure by low-income households in each state, and available funds from the appropriation. At the state level funds are then allocated to sub-grantees, of which there are over 900 nationwide. These sub-grantees are the local agencies that perform and oversee the work. For Program Year (PY) 2016, the total WAP allocation resulted in $213,814,000 distributed across the 50 states, District of Columbia, territories, and several Native American tribes. Since 1977, over 7.2 billion dollars has been allocated by the USDOE for weatherization funding (USDOE, 2016c). Typically, this funding is leveraged for additional funding at either the grantee or the sub-grantee level. During PY 2008 the approximately $236 million allocated from the USDOE was leveraged to obtain an additional $614 million for low-income weatherization. This supplemental funding comes from a variety of sources including LIHEAP, State Benefits and Program, Utilities, and Petroleum Violation Escrow (PVE) funds (Tonn et al., 2015a). During PY 2008 and PY 2010 this led to an average spending of $4,695 and $6,812 per unit, respectively (USDOE, 2015).

Guidelines for Weatherization

Guidelines for the WAP are set under Code of Federal Regulation Title 10 Part 440-Weatherization Assistance for Low-Income Persons. This sets guidelines for allocation of funds, selection of sub grantees, eligibility of clients and dwellings, oversight, training, technical assistance, standards for weatherization materials, and energy audit procedures. Under these guidelines, there are very specific regulations for energy audit procedures including when full energy audits will be performed, when the use of a priority list is acceptable, assigning priorities for weatherization measures, and how states can approve their energy audit procedures (Weatherization Assistance for Low-Income Persons, 2006). These guidelines are very specific about two key areas. First, the energy audit must prioritize weatherization materials based on cost effectiveness and second, the dwelling must be viewed as a whole system and all aspects of the unit must be examined.

Initiated in October 2014, the Quality Work Plan (QWP) defines quality requirements for the implementing of weatherization programs in five key areas:

1. Definition of Work Quality, Guidelines, and Standards
2. Communication of Guidelines and Standards

3. Inspection and Monitoring of Work Using Guidelines and Standards
4. Training to Implement and Maintain Guidelines and Standards
5. Exemptions

With these guidelines, the Grantees should be able to effectively provide guidance and oversight to sub-grantee organizations (USDOE, 2014).

Under this new guidance, the North Carolina Department of Environmental Quality (NCDEQ) developed the *North Carolina Weatherization Installation Standard Work Specifications* to clearly state all required work methods and standards under the North Carolina Weatherization Assistance Program (NCWAP, 2012). Within North Carolina, NCWAP has designated the use of two specific tools to ensure quality and consistent reporting of auditing, work done, and inspection of the weatherization work. The Residential Energy Assessment Tool (REAT) provides clear instructions for performing and recording all information in an initial energy audit, and the Final Inspection Report Certification provides instructions for performing and recording all information from an inspection of weatherization work (North Carolina Department of Environmental Quality [NCDEQ], 2016). Both forms are available for reference in Appendix A, with data relevant to this study indicated by highlighting.

Along with these WAP specific guidelines, organizations like the National Association for State Community Services Programs (NASCSP) and the National Community Action Foundation act as organizing forces to provide direction, tools, training, and best practices to individual organizations performing weatherization services. This is accomplished through the Weatherization Assistance Program Technical Assistance Center (WAPTAC), which not only provides information from building performance experts and the DOE, but also provides a place for community-building among weatherization organizations.

Demographics of Weatherized Households

The prescriptive guidelines set in place by the USDOE to determine who is eligible to receive free weatherization limit the demographics of households weatherized under the WAP. Under these guidelines, households receiving Supplemental Security Income or Aid to Families with Dependent Children are automatically eligible, but the primary factor for eligibility is whether the family is at or below 200% of the poverty level (USDOE, 2016b). During an evaluation of the WAP by Oak Ridge National Lab, a baseline occupant survey was administered to a representative group of clients serviced by the program in order to gain a better understanding of qualifying recipients. In this survey, interviews took place with a group of 1,468 clients who received WAP services during 2010-2011 (Carroll, Berger, Miller, & Driscoll, 2015). Survey results shown in Table 4 highlight the differences in demographics between WAP clients and the general population from the 2010 U.S. Census (U.S. Census Bureau, 2011). Cells in green exceed the Census statistics, while cells in red fall below Census data by more than +/- 1%.

Table 4. *WAP and General Population Demographics*

Demographics	WAP Clients		Census
	PY 2010	PY 2011	2010
Household Size			
1 household member	41%	38%	26.7%
2 household members	29%	28%	32.8%
3 household members	12%	12%	16.1%
4 household members	9%	10%	13.4%
5 or more household members	10%	12%	11%
Percent of Households with an Elderly Person			
60 years and older	55%	47%	NA
65 years and older	NA	NA	13%
75 years and older	21%	19%	NA
Percent of Households with a Child			
18 years and under	30%	36%	24%
5 years and under	11%	17%	6.5%
Head of Household's Education Level			
No School	6%	6%	10.2%
Some School	14%	14%	
High School Diploma or GED	40%	39%	27%
Some College	22%	22%	32%
Associate's Degree	8%	11%	
Bachelor's Degree	7%	7%	19.8%
Advanced Degree	2%	2%	11%
Head of Households' Race/Ethnicity			
White, Non-Hispanic	74%	73%	72.4%
Black, Non-Hispanic	16%	15%	12.6%
Hispanic	6%	8%	16.3%
Native American	2%	1%	.9%
Hawaiian & Pacific Islander	0%	<1%	<1%
Asian	1%	<1%	4.8%
Other/More than one	2%	2%	2.9%
Primary Wage Earner's Employment Status			
Employed Full-Time	24%	24%	56.5%
Employed Part-Time/Other	8%	11%	18%
Unemployed	5%	7%	25.5%
Homemaker	2%	2%	
Student	1%	2%	
Retired	36%	30%	
Unable to Work	24%	25%	

These data reveal that while the WAP client population is in general a diverse population there are significant differences between the client population and the general 2010 Census population. WAP clients are more likely to include:

- One-person households, and generally trend toward smaller households.
- Households with a child or elderly person (both are considered vulnerable populations).
- Significantly underemployed primary wage earners (33% retired, 24% unable to work, 10%-part time).
- Fewer Heads of Household with post-secondary education.
- Fewer Asians and Hispanics.

The above information is important in determining what is going to be most impactful to those undergoing weatherization through the WAP, and can help inform how energy cost savings and potential health implications will influence their lives.

Common Measures Used in Weatherization

Under the WAP, common measures that are implemented to increase efficiency and reduce energy consumption include air sealing; added insulation; energy efficient windows, HVAC components, and appliances; and household safety devices. Evaluation of weatherization measures by Oak Ridge National Laboratory during the PY 2010 (Tonn, Rose, & Hawkins, 2015b) documented how often weatherization measures were performed in homes. Table 5 shows the percentage of homes receiving each measure for Single Family and Mobile Homes.

From this analysis we can see that predominant weatherization methods performed relate to envelope improvements through air sealing, insulation, windows, and doors. These methods are followed by more expensive or complex measures such as improvement of duct sealing, appliances, water heaters, and finally HVAC equipment. It is worth noting that a greater percentage of mobile homes received floor insulation and duct sealing than did other types of homes.

Table 5. *Percent of Homes Receiving Weatherization Measures PY 2010*

Weatherization measure	Single Family	Mobile Home
Air Sealing		
Any Bypass Sealing or Caulking	89%	90%
Bypass Sealing w/ Blower Door	87%	87%
Insulations – Attics		
% Installed (All Types)	65%	23%
Insulations – Walls		
% Installed (All Types)	24%	3%
Insulation – Other		
% Floor Insulation	18%	43%
%Rim/Band Joist Insulation	18%	1%
Energy Efficiency – Windows		
Any Window Measure	18%	26%
Energy Efficiency – Heating Equipment		
New Heating System	30%	32%
Energy Efficiency – Heating Ducts		
Duct Sealing	36%	53%
Duct Insulation	11%	14%
Energy Efficiency –Water Heating Equipment		
New Water Heater	14%	14%
Energy Efficiency – Ventilation		
Whole House, Kitchen, Bath Fan	21%	20%
Energy Efficiency – Air Conditioning		
New Air Conditioner	7%	10%
Other Measures		
Refrigerator	19%	23%
Smoke Alarm	50%	57%
CO Monitor	63%	58%
Setback Thermostat	16%	16%

Although the main goal of weatherization it to improve energy efficiency, several health and safety methods are included to help ensure household well-being. These measures most frequently include the addition of CO monitors and smoke alarms, which have minimal impact on energy or IAQ, but can also include dryer venting, attic ventilation, and ground vapor barriers (Bensch, Keene, Cowan, & Koski, 2014). During PY 2010, over 50% of all homes received both a fire alarm and a CO monitor (Tonn et al., 2015b).

Energy Impacts of Weatherization

The main purpose of weatherization is to save energy, so it is important that energy savings and effectiveness of methods used are properly measured. Understanding how large populations of weatherized homes have performed based on building characteristics, climate, and weatherization methods can lead to better predictions and modeling for future projects.

Typical Energy Savings from Weatherization

As part of the larger evaluation of the WAP, an impact evaluation of energy effects for single-family site-built homes, mobile homes, and multi-family homes was performed during the PY 2008 and PY 2010. The energy impact evaluation utilized pre- and post- weatherization energy bill data to get an accurate measure of savings achieved by weatherization. Energy bills from a comparison group that underwent no treatment were used as a control for other factors that could also affect energy consumption, such as weather changes. This evaluation classified energy savings by main source of energy for heating, number of weatherization methods performed, types and combinations of methods performed, cost of methods, and climate zones where homes were located. Detailed tables of energy savings for each of these categories are available in Appendix B. Overall savings for building type (Mobile Home vs. Site Built) and main energy source are summarized in Table 6 (Blasnik, Dalhoff, Carroll, & Ucar, 2014a; Blasnik, Balhoff, Pigg, Mendyk, Carroll, & Ucar, 2014b; Blasnik, Dalhoff, Carroll, Ucar, & Bausch, 2015a; Blasnik, Dalhoff, Carroll, Ucar, Bausch, & Johnson, 2015b). The data reveal significant savings for both mobile homes and single-family homes, with approximately 40% and 10% more savings realized in the single-family homes for gas and electric heat, respectively. Note that these values reflect total energy savings and are not normalized for volume.

Table 6. *PY 2008/PY 2010 Energy Savings for Mobile and Site Built Homes*

Group	Gas Heated Homes Net Savings (therms/year)	Electric Heated Homes Net Savings (kWh/year)
Mobile Homes	97 (±13)/ 89 (±11)	1,547 (± 510)/ 1,692 (±330)
Site Built Homes	181 (±13)/ 147 (±9)	1,804 (±458)/ 1,841 (±270)

Another representation of the data from these reports comparing total annual energy costs and savings for PY 2008 and PY 2010 is shown in Table 7. Although the annual savings values may appear small, they reduce overall energy costs to by 8-12%.

Table 7. *PY 2008/PY 2010 Annual Energy Costs and Savings*

Group	Annual Energy Costs (2008 & 2010 dollars respectively)	Annual Savings (First Year)	% Savings
Mobile Homes	$2,042/$1,926	$167/$190	8.2%/9.8%
Site Built Homes	$2,279/$1,863	$283/$223	12.4%/12%

Table 8 shows that the cost of energy comprised 17-18% and 12-13% of household income in 2008 and 2010, respectively. Reduction in the energy burden after weatherization was 1.3-2%. Take note that these calculated energy burdens do not show any energy bill assistance through LIHEAP or other similar programs, and would likely be significantly lower.

Table 8. *PY 2008/PY 2010 Reduction in Household Energy Burden*

Group	Median Income	Initial Energy Burden	Energy Burden After Savings	% Reduction
Mobile Homes	$11,472/$14,712	17.8%/13.1%	16.3%/11.8%	1.5%/1.3%
Site Built Homes	$13,223/$15,607	17%/11.9%	15%/10.5%	2%/1.4%

Weatherization Average Cost and Cost Effectiveness

Under the WAP National Evaluations for PY 2008 and PY 2010, one of the biggest questions being addressed was how effective the program was at systematically reducing household energy consumption in a way that made best use of the allocated money. In PY 2008 and PY 2010 an average of $4,695 and $6,812, respectively, was spent on homes, with only 62% and 52%, respectively, spent on energy-related measures (USDOE, 2015).

Each type of home had different levels of energy savings and cost-effectiveness. From the PY 2008 and PY 2010 Evaluations data shown in Table 9 we can see how the different building types have different levels of cost effectiveness and potential return on investment (Blasnik et al., 2014a; Blasnik et al., 2014b; Blasnik et al., 2015a; Blasnik et al., 2015b). A Savings/Investment Ratio (SIR) value greater than 1.0 indicates that the energy savings were higher than the cost of the energy-related weatherization measures.

Table 9. *PY 2008/ PY 2010 Energy Cost Savings and Cost-effectiveness in 2008 and 2010 Dollars*

Group	**Energy Cost Savings (Present Value of Lifetime Savings)**	**Energy Measure Costs**	**Net Benefits**	**Savings/ Investment Ratio**	**SIR 90% c.i.**
Mobile Homes	$2,419/$2,290	$2,721/$3,538	-$302/ -$989	0.89/0.72	0.73-1.11/ 0.61-0.87
Site Built Homes	$4,196/$3,803	$2,846/$3,777	$1,350/ $25	1.47/1.01	1.19-1.89/ 0.75-1.36

The evaluation shows significantly higher SIR in Site Built Homes compared to Mobile Homes due to the higher energy savings in Site Built Homes. These SIR calculations do not consider other non-energy benefits, which are discussed in the next section.

Indoor Air Quality Considerations

Even though saving energy has many benefits, it is important to understand the effects of weatherization on IAQ in order to protect the health of building occupants.

Building Changes and IAQ Contaminants

Making changes in the building envelope and systems during weatherization will not only affect energy consumption but may also impact IAQ. If done properly, weatherization and retrofits can have a positive impact on IAQ by causing reductions in common contaminants (Frey, Destaillats, Cohn, Ahrentzen, & Fraser, 2015). However, improper tightening of the envelope to reduce air leakage can have unintended consequences such as increased humidity within the building, leading to an increase in mold (Schenck, Ahmed, Bracker, & DeBernardo, 2010) and increased indoor contaminant concentrations. Different contaminants are affected by different changes in the indoor conditions that can come about from weatherization. Properly understanding how changes made during weatherization can affect IAQ is vital to continuing to increase energy efficiency while at the same time preventing negative health impacts.

Formaldehyde (HCHO) is a colorless gas commonly found in building materials, consumer products, and tobacco smoke. Indoor concentrations have been shown to have a slightly negative linear relationship with air change rate, and a slightly positive linear relationship with temperature and relative humidity (Salthammer, Fuhrmann, Kaufhold, Meyer, & Schwarz, 1995). Formaldehyde concentrations decrease over time at different rates, depending on the materials, but elevated temperature increases emission rates (Zhang, Lou, Wang, Qian, & Zhao, 2007). To reduce the risk of increased formaldehyde in the air, proper weatherization should avoid trapping moisture, provide adequate air changes, and prevent large temperature increases in warm climates.

Particulate matter (PM) is emitted from a variety of outdoor and indoor sources, including energy production, internal combustion engines, smoking, cooking, candles, and vacuuming. PM has been linked to adverse health effects including increases in lung cancer, heart disease, and asthma exacerbation (Fisk, Faulkner, Palonen, & Seppanen, 2002). PM size ranges from less than 0.1 μm in diameter to larger than 10 μm and is generally monitored by measuring $PM_{2.5}$, meaning particles 2.5 μm or smaller, and PM_{10}, particles 10 μm or smaller. Smaller particles remain suspended in the air for longer periods of time and lead to more negative health effects by entering farther into the lungs due to their small size. Air sealing will reduce the infiltration of outdoor particles into the home but can also lead to trapping of particles generated from indoor sources. Depending on the envelope tightness after weatherization, additional ventilation may be needed to help reduce the PM load. High capture efficiency vacuum filters, such as HEPA, can also help prevent PM accumulation and recirculation of particulates (Seppänen & Fisk, 2004).

Volatile Organic Compounds (VOCs) have a low boiling point and are emitted by almost all buildings products, except non-organic materials such as fiberglass, metal, and glass. Many of the products associated with air sealing (e.g. caulk, spray foam, and mastic) have large concentrations of VOCs within their formulas. Although they play a role in IAQ and have been linked to several different health disorders, there is not a straightforward health association due to the many different chemicals included under the VOC nomenclature. In-home measurements have shown that VOC levels can continue to increase for up to 60 days after major renovations, depending on the type and number of products used. Emissions from new materials can be reduced to baseline levels within 14 days by installing increased ventilation (Herbarth & Matysik, 2010). Understanding VOC sources and their residual effects can help reduce the impact of VOCs on IAQ after weatherization is completed.

Nitrogen Dioxide (NO_2) is a byproduct of combustion. There is solid evidence of negative health effects, such as lung and mucosal membrane inflammation, from occupant exposure (Seppänen & Fisk, 2004). Indoor sources include gas cooking and heating appliances, and special care must be taken to properly vent combustion gases through range hoods and flues. Improper sizing or installation of exhaust ventilation may cause under-pressurization of the home, which could cause back drafting of flue gases into occupied spaces (Seppänen & Fisk, 2004). Therefore, if exhaust fans are added during weatherization it is important to understand the dynamics of building ventilation.

Indoor Air Quality Guidelines

The only officially regulated indoor contaminant in the United States is radon (United States Environmental Protection Agency [USEPA], 1992). Multiple agencies and organizations provide air quality guidelines for other common contaminants. This leads to a patchwork of indoor and ambient air quality guidelines that are difficult to interpret and to enforce. Table 10 shows common indoor air quality contaminants and conditions, along with concentrations considered acceptable for occupant comfort and health.

Table 10. *Guidelines for Acceptable Indoor Air Quality*

Variable	Acceptable Level	Conditions	Reference
Carbon Dioxide	1000 ppm	Indicator for human bio effluents, 5000ppm can pose a health risk	(ASHRAE, 2010a)
Carbon Monoxide	9 ppm	Maximum indoor concentration, or 2ppm above outdoor ambient	(USGBC, 2013)
Temperature	67-82° F	Acceptable indoor temperature range	(ASHRAE, 2010b)
Relative Humidity	65%	Maximum indoor humidity reduces likelihood of conditions that can lead to mold growth.	(ASHRAE, 2010b)
$PM_{2.5}$	15 µg/m^3	Maximum indoor concentration	(USGBC, 2013)
	35 µg/m^3	Ambient 24-hour average, 98th percentile, averaged over 3 years	(NAAQS, 2000)
PM_{10}	50 µg/m^3	Maximum indoor concentration	(USGBC, 2013)
	150 µg/m^3	Ambient 24-hour average, not to be exceeded more than once per year	(NAAQS, 2000)
Radon	4 pCi/L	Indoor action level, 2 pCi/L may warrant investigation	(USEPA, 1992)
Formaldehyde	27 ppb	Maximum indoor concentration, sometimes used with average data	(USGBC, 2013)
Nitrogen Dioxide	21 ppb	Annual indoor average (0.04 mg/m^3)	(WHO, 2010)

Weatherization and Indoor Air Quality

Low-income homes that undergo weatherization are typically more likely to contain environmental hazards including mold, combustion by-products, second-hand smoke, and inadequate ventilation—all of which may lead to an increased risk for poor health (Adamkiewicz et al., 2014). Extra precautions must be taken to prevent and eliminate hazards in these homes undergoing weatherization.

Under the nationwide WAP evaluation, a study within a subset of all homes weatherized investigated whether weatherization was causing changes in IAQ that could have health consequences (Pigg et al., 2014). This study analyzed indoor carbon monoxide, radon, formaldehyde, temperature, and relative humidity before and after weatherization in 514 single-family homes. Results from this study showed that:

- CO levels rarely exceeded 5 ppm regularly in weatherized homes.
- Radon levels were slightly increased, with an average increase of 0.4 ± .02 p Ci/L and with the greatest increases in homes with already higher radon levels.
- Formaldehyde increased a net 1.6 ± 1.1 ppb nationwide and correlated with indoor humidity levels.
- There was a small increase in relative humidity, with a 1.1 ± 0.6% increase in wintertime relative humidity.

This snapshot of IAQ in pre- and post-weatherized homes showed that overall the WAP program is causing little to no harm but has a small likelihood of worsening IAQ (Pigg et al., 2014).

An additional study performed in 54 homes throughout North Carolina under the Healthy Homes program of HUD showed similar results (Doll et al., 2016). Collected data for nine contaminants (CO_2, CO, NO_2, Temperature, Relative Humidity, Formaldehyde, $PM_{2.5}$, PM_{10}, and Radon) pre- and post-weatherization revealed:

- CO_2 was lower or had no significant change in most homes.
- CO showed no change in all homes except two, which had an average increase of 2.2 ppm.
- All homes experienced minimal change in NO_2 except three homes with faulty combustion appliances.
- Of all the homes, 20 experienced higher temperatures during the winter heating season, showing the possibility of increased thermal comfort.
- Relative humidity remained split, with 20 homes showing a decrease post weatherization and 22 homes showing an increase, but the overall average showed no difference.
- Formaldehyde increased in 13 of the homes, of which eight were in higher-humidity cooling season homes. This follows the well-studied correlation between increasing formaldehyde levels as relative humidity increases.
- Particulate matter results were mixed, with reductions in $PM_{2.5}$ and PM_{10} throughout all non-smoking homes but increases in $PM_{2.5}$ in homes with smokers and PM_{10} in homes with pets.
- Radon concentrations were all below acceptable levels.

While the results of this study are similar to those of the larger WAP National Evaluation showing that weatherization has minimal to no harm to home occupants, the study also concluded that homes are not meeting indoor contaminant guidelines, as shown in Figures 1 and 2, and that more work should be done to improve IAQ within homes (Doll et al., 2016). Within the population homes there was poor compliance with Formaldehyde (HCHO) and even worse compliance with PM. With known health effects from these contaminants, they are prime targets for improving IAQ and health among these homes.

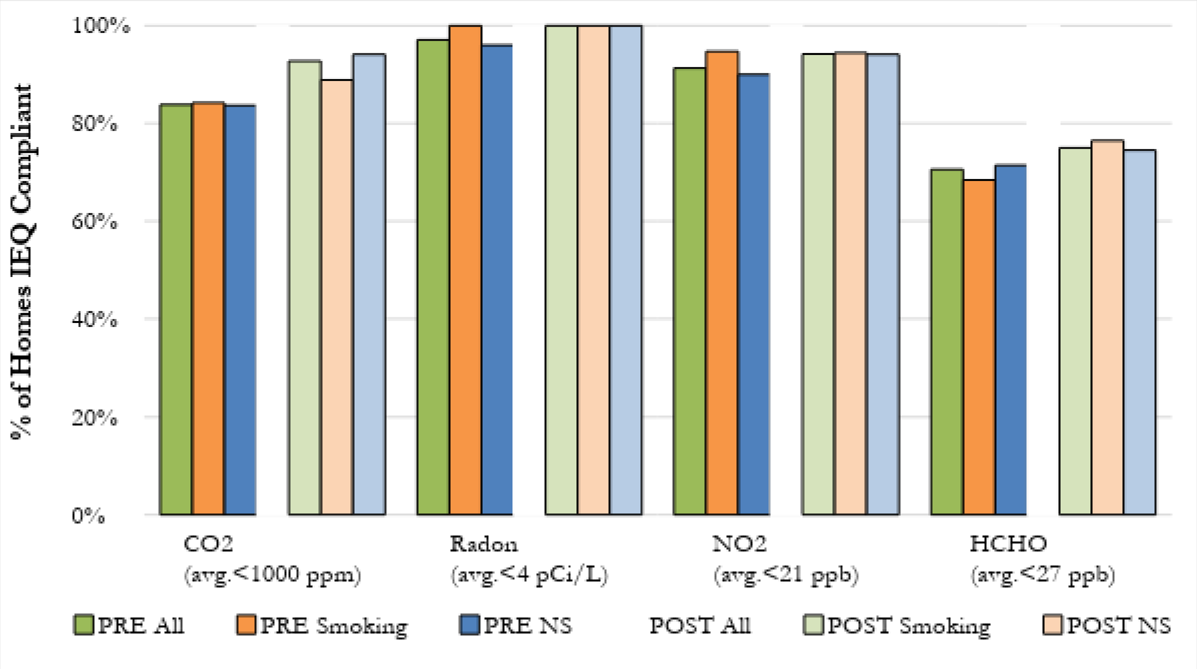


Figure 1. IAQ compliance - average value criteria (CO2, Radon, NO2, Formaldehyde) (Doll et al., 2016).

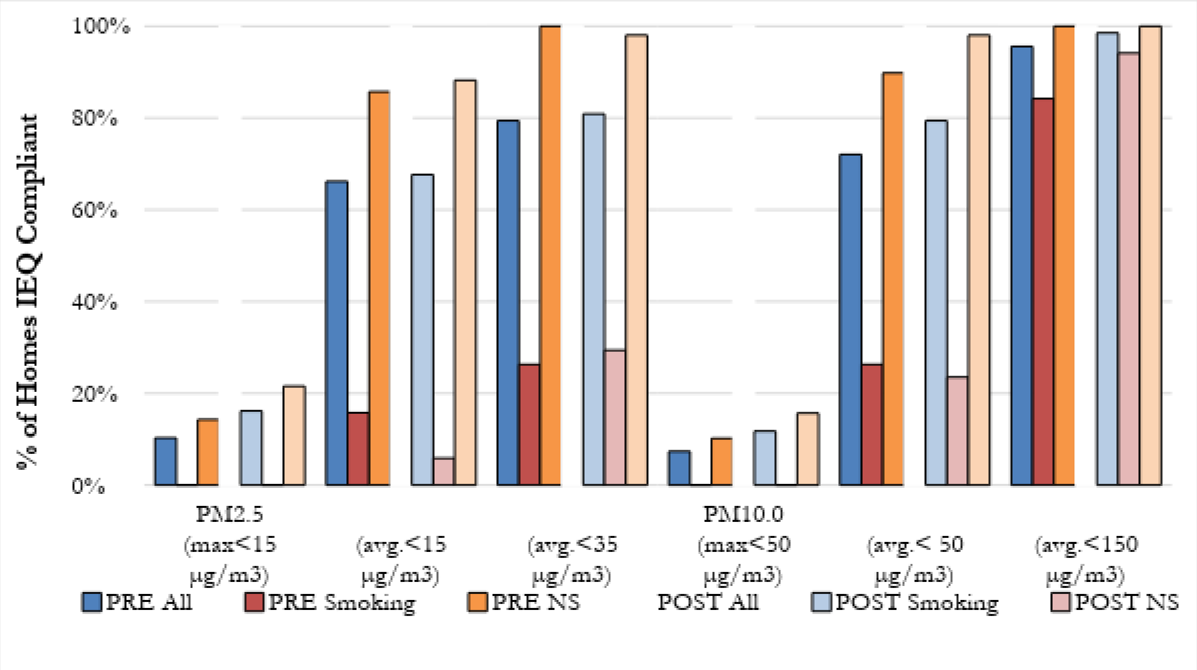


Figure 2. IAQ compliance - different average & maximum value criteria ($PM_{2.5}$, PM_{10}) (Doll et al., 2016).

Health Impacts of Weatherization

Although the effects of individual interventions on health have not been well studied, numerous studies have shown a link between weatherization and health (Shrubsole, Macmillan, Davies, & May, 2014; Breysse, Dixon, Jacobs, Lopez, & Weber, 2015). A number of other studies have shown how different indoor contaminants such as lead exposure, thermal stress, and noise pollution affect health, including psychological stress (O'Connor et al., 2008; Schenck et al., 2010; Tonn & Rose, 2014).

Effects of Indoor Air Quality on Inhabitants' Health

As discussed previously, each of the individual contaminants have specific health ramifications. Research on health effects of airborne contaminants has been shifting from ambient air to indoor air to account for the majority of time spent inside buildings. As explained by Zummo and Karol (1996), Table 11 shows this shifting emphasis.

Table 11. *Shifting Emphasis in Air Pollution Research*

From →	To
Ambient air and occupation exposures →	Indoor air
Cancer effects →	Non-cancer effects
High levels of single pollutants →	Multiple lower level pollutants
Healthy and non-clinically exposed individuals →	Protection of the general public from disease and attempt to protect sensitive individuals

Weatherization has been effective at reducing the infiltration of outdoor produced air contaminants and may lead to an increase in overall indoor contaminants unless proper ventilation is in place (Shrubsole et al., 2014). A variety of studies have shown self-reported increases in general well-being and decreases in exposure to environmental tobacco smoke following green renovations of public housing (Breysse et al., 2015; Szanton et al., 2011), but there are fewer studies showing direct connections to general health benefits.

Indoor Air Quality, Lung Function, and Asthma

Asthma is one of the most common pediatric illnesses and the most frequent cause of hospitalization during childhood (Merrill & Elixhauser, 2005). Asthma sufferers are often negatively impacted by both indoor and outdoor air pollution. Several studies have considered the impacts of lung function, specifically FEV1%, as it relates to air pollution levels (Connor et al., 2008; Akinbami, Lynch, Parker, & Woodruff, 2010). Several specific air pollutants have shown a negative impact on lung function, as shown in Table 12 (Connor et al., 2008).

Table 12. *Change in FEV1% Compared to Pollutant Change*

Pollutant	10th to 90th Percentile Change	Change in FEV1%
O_3	26.7 ppb	-.55
$PM_{2.5}$	13.2 $\mu g/m^3$	-1.47
NO_2	20.4 ppb	-1.36
SO_2	12.4 ppb	-1.60
CO	872.1 ppb	-.56

FEV1% is the Forced Expiratory Volume for 1 second expressed as a percentage of the total predicted FEV1 for the patient. This value, obtained through a spirometry test, is useful in identifying reduced lung function and predicting future symptoms from the reduced function (Walter, 1989). Several studies have used FEV1% as a tool to measure asthma severity and to predict asthma symptoms (Fuhlbrigge et al., 2006; Pearlman et al., 1992; Pearlman et al., 1999)

The relationship between asthma symptoms and FEV1% is a good predictor of asthma symptom days and asthma-related events, as shown in Figures 3 and 4 (Fuhlbrigge et al., 2006).

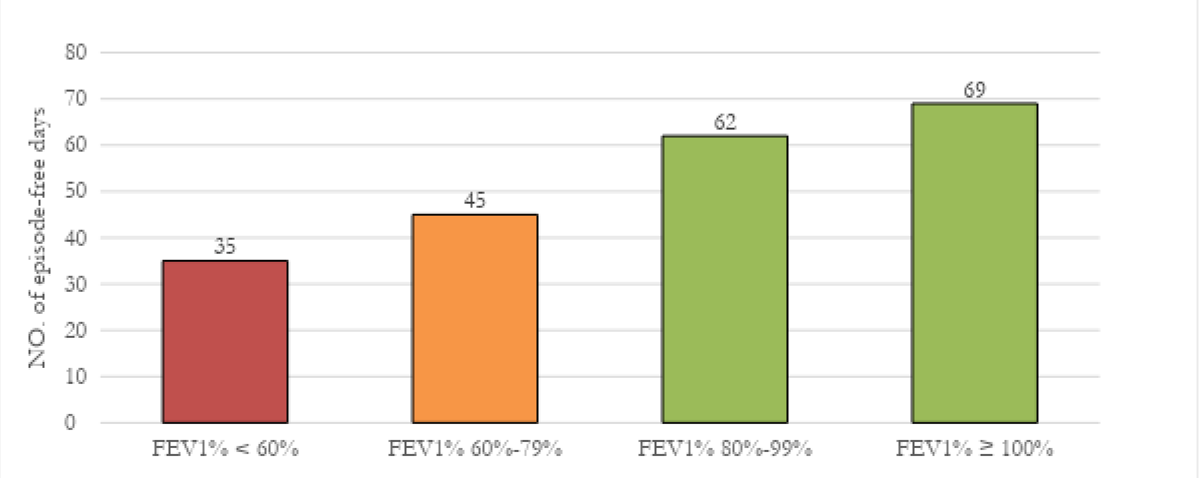


Figure 3. Association between FEV1% and asthma symptoms: number of EFS during a 4-month period (Fuhlbrigge et al., 2006, Figure 1).

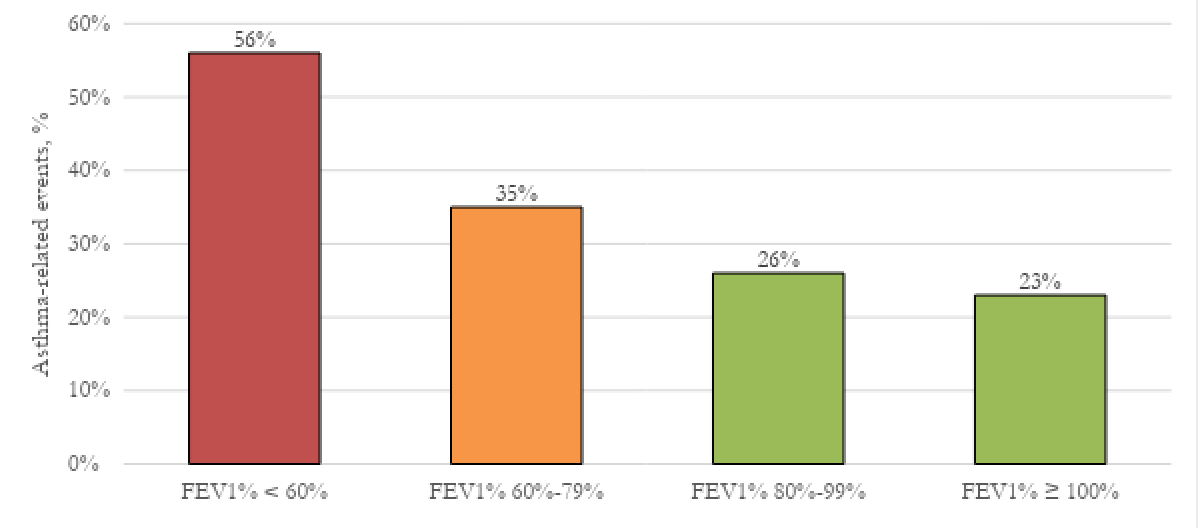


Figure 4. Association between FEV1% and serious asthma exacerbation. Proportion of children within each FEV1% who reported a serious asthma exacerbation during a 4-month period (Fuhlbrigge et al., 2006, Figure 3).

Both of these figures show a decrease of asthma symptom days and an increase of asthma related events as FEV1% decreases. If weatherization reduces these common air pollutants and increases FEV1% it could be considered an effective intervention for asthma sufferers.

Weatherization and Asthma

The multi-component and multi-trigger aspect of asthma means that preventing attacks can be difficult, but recent studies have shown that home-based environmental interventions are effective at providing a reduction in symptoms and an increase in productivity (Crocker et al., 2011). Since IAQ changes may occur during weatherization, this may be another effective intervention for low-income families suffering from asthma.

Recent studies have produced conflicting results on the effects of weatherization and asthma, both focusing on the specific costs associated with medical treatment for asthma (Hawkins, Tonn, Rose, Clendenning, & Abraham, 2016; Rose, Hawkins, Tonn, Paton, & Shah, 2015; Fabian et al., 2014). One of the studies focused on Medicaid claims for asthma treatments before and after weatherization and another sent out occupant surveys before and after weatherization (Hawkins et al., 2016; Rose et al., 2015). Both of these studies showed weatherization had a positive impact on asthma as demonstrated by a decrease in symptoms and events. The third study focused on modeling building interventions and their effect on IAQ and asthma events (Fabian et al., 2014). This study showed positive results for improving source exhaust ventilation and reducing heating from an oven, but negative results for weatherizing overall.

As part of the PY2010 WAP National Evaluation, a small cohort study looked at the impacts of weatherization on children with asthma in northwestern Washington State (Rose et al., 2015). Under this study, three different groups were compared for their effect: (1) Weatherization Only Homes (Wx Only), these homes only underwent weatherization performed by a WAP Community Action Agency; (2) Healthy Home Only (HH Only), these homes underwent interventions based on the HUD Healthy Home Program; and (3) Weatherization Plus Health (Wx + HH), these homes underwent both weatherization and Healthy Home interventions. This study discovered that 83% of the homes observed a decrease in Medicaid claims per month and 64% observed a decrease in the cost per claim post-intervention across all the intervention categories. While all observed significant differences, Wx + HH and Wx Only Homes showed the greatest reduction, with 90% and 83.3% decrease in average number of claims per month post intervention, respectively, and a 50% and 66.7% decrease in the average cost of claims per month post intervention, respectively. This shows that weatherization has the potential to increase home quality and decrease asthma triggers while also reducing Medicaid costs for asthmatic children. The small size of this study as well as the specialization of the Wx + HH provided by the CAA make it difficult to generalize this study to the larger population, but the results still show promise for weatherization to lead to improved IAQ and enhanced health.

Along with the WAP National Weatherization Evaluation, a specialized study was performed for the Massachusetts Program Administrators to compare other non-energy impacts (NEI) of weatherization within the state of Massachusetts. The largest NEI discovered during this evaluation was reduced asthma and associated lower medical costs after weatherization. An occupant survey sent pre-and post-weatherization reported an 11.5% reduction in asthma related emergency department (ED) visits and a 3.1% reduction in asthma-related hospitalization. This led to an estimated reduction of 9.9 asthma-related adult hospitalizations, 4.2 asthma-related child hospitalizations, and 54.6 ED visits annually per 1,000 units weatherized (Hawkins et al., 2016).

An important modeling study evaluated different building interventions and the effects on pediatric asthma along with associated costs in multi-family public housing (Fabian, et al. 2014). Within this study, interventions considered were fixing exhaust fans, replacing gas stoves, preventing the use of ovens for heat, no smoking, HEPA filters, integrated pest management, and weatherizing. This modeling study defined weatherizing as solely the addition of air sealing and insulation to the unit rather than the holistic approach normally performed by the WAP. This public housing building model indicated that weatherization led to an increase in dampness, NO_2, and $PM_{2.5}$ and significant increases in asthma symptom days and serious asthma events. Based on this model, weatherizing caused a negative impact on asthma costs of an additional $322/year. While this model puts weatherization in a negative light, it should be noted that common measures such as fixing fans, improving filtration, and preventing the use of stoves for heat through improved thermal performance, measures that are typically included in the WAP, were shown separately to have significant positive impacts on asthma savings (Fabian et al., 2014).

Additional Health Impacts

As previously mentioned, weatherization can have substantial impacts on additional health aspects including reduced lead exposure, reduced thermal stress, noise reduction, and increased psychological health.

Lead exposure is a significant health problem, especially among children in low income homes. Occupants typically encounter lead through flakes of lead paint or lead-contaminated soil (Schenck et al., 2010). Lead poisoning can cause many diverse health problems including reproductive complications, kidney damage, nerve damage, stomach pain, and many other problems, depending on blood concentrations. Lead is particularly dangerous because of how long it can stay in the blood and because of the delayed symptoms that present long after exposure. The USDOE has issued a minimum standard to prevent lead exposure to occupants and workers during weatherization. This program has successfully prevented occupant exposure by prompting the removal or encasing of lead-based products throughout the home during the weatherization process (USDOE, 2012).

Older adults are particularly susceptible to temperature extremes. Maintaining reasonable indoor environmental quality is especially important for vulnerable populations such as children and the elderly that are a disproportionally large percentage of low-income occupants. On average, 274 Americans are victim to heat-related diseases each year. In addition, increased heat also causes non-fatal consequences such as heat stroke, heat edema, and stress. Coping with raised temperatures is something that the older population is physiologically disadvantaged for with a decreased ability for thermoregulation (Ahrentzen, Erickson, & Fonseca, 2015). Weatherization can significantly reduce indoor temperatures during summer months and increase temperatures during winter months, greatly reducing thermal stress on vulnerable populations (Tonn & Rose, 2014).

Outdoor noise can lead to disruptions in communication, sleep, and relaxation while causing significant psychological stress. Sleep disruption and increased stress leads to unhealthy activities, including decreases in daytime alertness and well-being and an increase in unhealthy coping habits. A recent survey of weatherization households showed a significant decrease in noise, as shown in Table 13 (Tonn & Rose, 2014).

Table 13. *Weatherization and Noise Reduction*

How much noise do you hear indoors when the windows are closed?	**Pre-weatherization**	**Post-weatherization**
Number of Respondents	664	801
A great deal	28%	12%
Some	42%	39%
Hardly any	26%	39%
None at all	4%	10%
Total	100%	100%

Although this study showed a self-reported decrease in noise pollution, no weatherization study found to date has measured decreases in noise penetration.

Quantifying Health Impacts

Several different methods are available for quantifying health impacts as they relate to environmental measures, medications, and governmental policy changes. These include but are not limited to avoided deaths, Quality Adjusted Life Years (QALY), and Disability Adjusted Life Years (DALY). All of these measures have validity when determining the effectiveness of a measure and its net impact on specific diseases.

Although it is one of the simplest ways to explain quantifying health impacts, avoided deaths is much more complicated to calculate. Finding distinct relationships between morbidity and environmental or health conditions can be difficult and requires strong epidemiological and physiological evidence to be valid. An example of this is deaths avoided from preventing climate change through the correlation between heart disease and heat (Campbell-Lendrum & Woodruff, 2007).

A QALY is a widely used measure of health improvement used to guide resource distribution related to healthcare. QALYs allow for priorities to be set for different programs with the final goal of maximizing reduction of morbidity and mortality. This is different from avoided deaths because it also considers years spent sick (Weinstein, Torrance, & McGuire, 2009). QALYs can also be used in determining cost-effectiveness of medical treatments or policy changes with an economic value starting at $50,000 per QALY; however, this number is highly contested and has been valued anywhere from $50,000 to $300,000 (Braithwaite, Meltzer, King, Leslie, & Roberts, 2008; Hirth, Chernew, Miller, Fendrick, & Weisser, 2000; Neumann, Cohen, & Weinstein, 2014). QALY cost effectiveness is based upon how much a person would be willing to spend in order to gain another year of quality life. The $50,000 per QALY threshold came about in the mid-1990s, but increasingly the idea of a higher QALY value based upon a function of per capita annual income results in values from $120,000 - $180,000 (Braithwaite, et al., 2008), or as a basis of willingness to pay valued from $100,000 - $300,000 depending upon socioeconomic status and diseases prevented (Hirth, et al., 2000).

The DALY is years lost to morbidity and mortality from disease burden. Using similar epidemiological and physiological information required for avoided deaths and QALYs, DALYs are calculated using disease incident rates. DALYs are useful for indoor air quality research because significant research has been done on physiological effects from air pollution and emissions. Like the QALY, the economic value of a DALY is highly contested and is not consistent among different researchers. Similar to the QALY, a base value of $50,000 was originally accepted, but while the value of a QALY is based upon the willingness to pay for treatment the economic value of a DALY is based on the value of life lost to disease. These widely varying values can fall into a range of $50,000 to over $200,000. Proposed methodologies for valuing the DALY have been based upon cost of treatment to prevent disability, valuing DALYs at $50,000 - $100,000 (Eggleston, Shah, Smith, Berndt, & Newhouse, 2011); lost wages and economic effect of lost wages, valuing DALYs around $80,000 to $120,000 dollars (Brown, 2008; Lvovsky, Huges, Maddison, Ostro, & Pearce, 2000); and as depreciation of the Value of the Statistical Life Year (VSL), with the value of a DALY around $218,000 (Anderson, 2017). Regardless of the amount, all relate back to the lost economic impact from a year of lost life.

CHAPTER 3: METHODOLOGY

Overview

This research involves a secondary analysis of quantitative data collected by Dr. Susan Doll from December 2012 to April 2015 under a U.S. Department of Housing and Urban Development (HUD) Healthy Home Technical Studies grant. This chapter will describe the (1) original data set, and the subset of data selected for this study; (2) methods for conducting cost/savings estimates for energy, health, and weatherization measures; and (3) data analysis approach and methods.

Data Set

Data Collection Methods

The original data were collected during the 2012- 2015 HUD study in 92 homes, including 54 matched pre- and post-weatherization pairs, 13 control homes, 14 homes receiving alternate ventilation, and 11 homes with incomplete data sets. The 54 matched pairs included both manufactured and site built homes selected to undergo weatherization via community action agency partners with ongoing weatherization assistance programs. During recruitment, each home was given an identifying number that was used throughout the testing and weatherization process to protect the identities of those in the study. Nine IAQ parameters were monitored inside the home including temperature, relative humidity, carbon monoxide, carbon dioxide, nitrogen dioxide, formaldehyde, particulate matter size counts and mass concentration, radon, and Total Volatile Organic Compounds (TVOC). Measurements outside the home included temperature, relative humidity, wind speed and direction, maximum wind speed, rainfall, and barometric pressure. Figure 5 shows the indoor equipment set up, including protective cage and storage bin, individual sampling devices, and outdoor weather station.

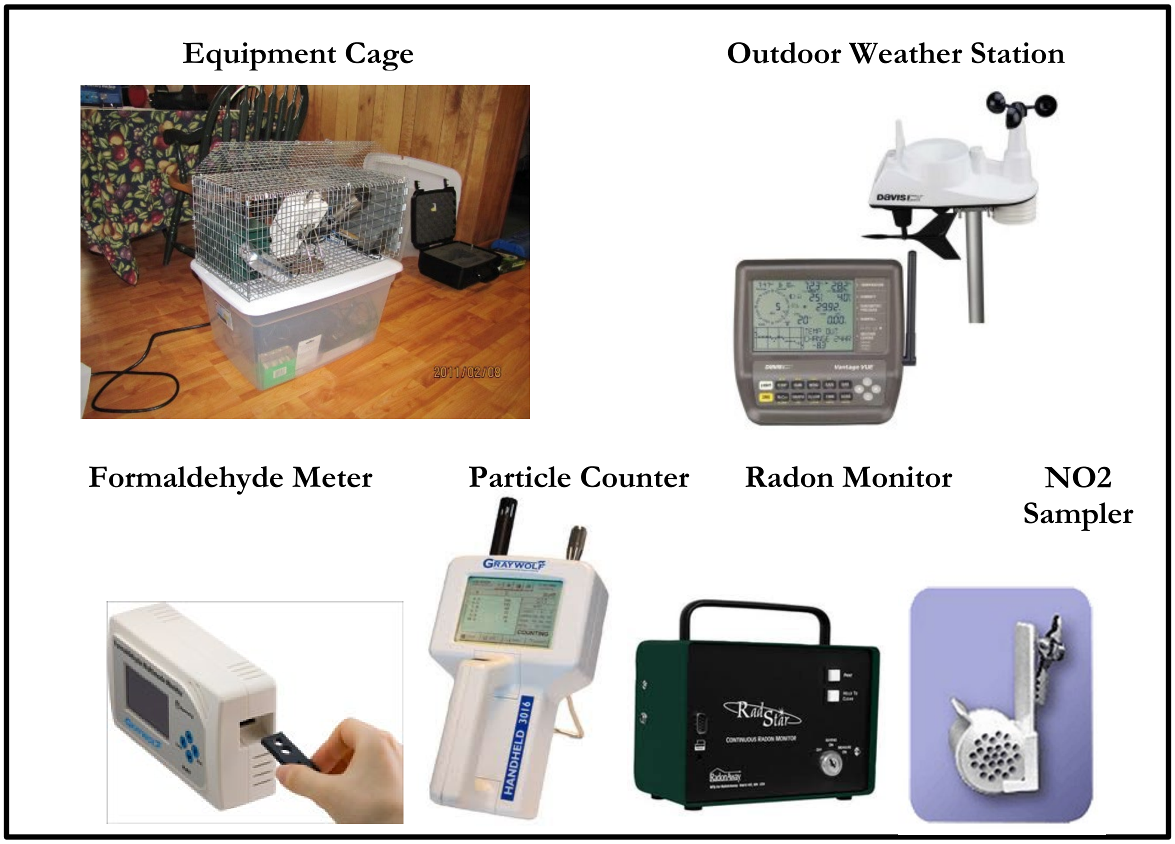


Figure 5. HUD study monitoring equipment.

The homes tested were located in three regions of North Carolina (Wilmington, Raleigh, and Boone) that represent three different climate zones (3A, 4A, and 5A, respectively). This allowed comparisons with approximately 40% of the contiguous United States and increased the relevance of the small sample size. Figure 6 outlines the study timeline for obtaining informed consent from homeowners, pre-weatherization IAQ monitoring, performance of weatherization services, and post-weatherization. Data from the third follow-up data collection period were not used in this study.

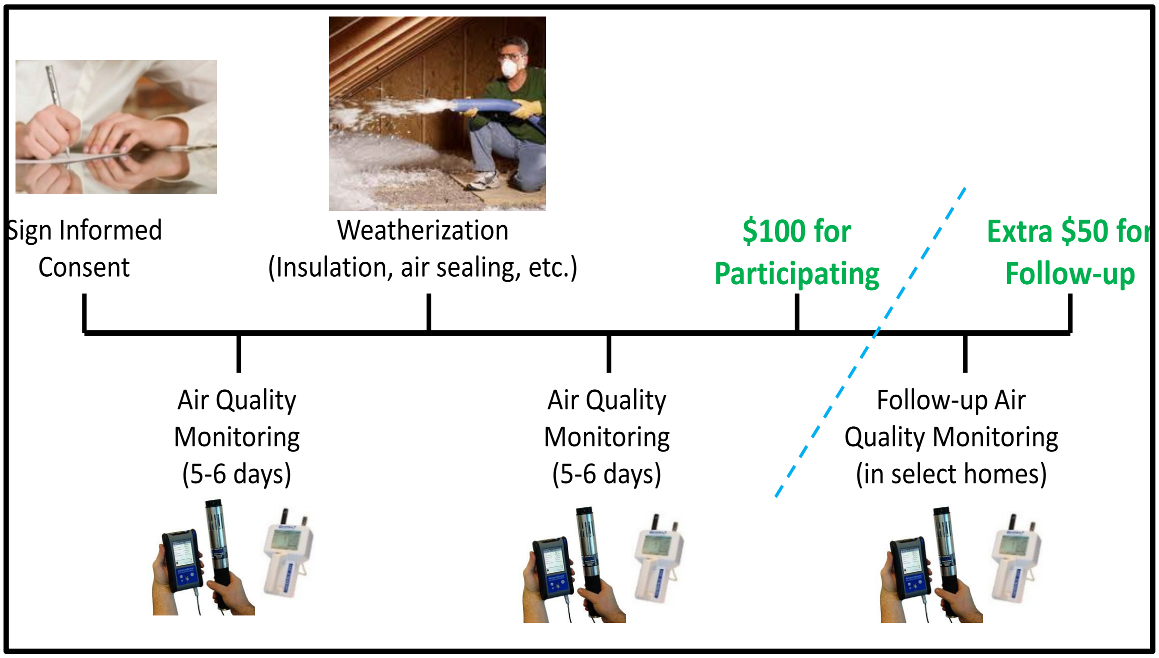


Figure 6. HUD study data collection timeline.

Occupant and building characteristics for the 54 pre- and post-weatherization matched-pair homes used in this study, and the number of homes from each sampling season (HS=heating season, CS=cooling season) at each location (MTN=Boone, CST=Wilmington, PDT=Raleigh), are shown in Table 14.

Table 14. *Household Features by Location and Sampling Season, Paired PRE-and POST (N=54)*

		MTN		CST		PDT			MTN	CST	PDT
Characteristic		**HS1**	**HS2**	**HS1**	**CS1**	**HS2**	**CS2**	**N**	**17**	**22**	**15**
Smoking	**Y**	4	1	4	3	2	-	14	5	7	2
	N	6	6	7	8	6	7	40	12	15	13
Pets	**Y**	6	5	3	6	2	2	24	11	9	4
	N	4	2	8	5	6	5	30	6	13	11
Type of Home	**S**	5	1	3	5	6	7	27	6	8	13
	M	5	6	8	6	2	-	27	11	14	2
Combustion	**Y**	8	5	2	-	3	1	19	13	2	4
	N	2	2	9	11	5	6	35	4	20	11
Electric Heat	**Y**	4	3	10	11	5	5	38	7	21	10
	N	6	4	1	-	3	2	16	10	1	5
Sampling Season	**HS**	10	7	11	-	8	-	36			
	CS	-	-	-	11	-	7	18			

Data Selected for Use

Analysis for this study used a subset of the original variables. Variables selected were occupants, home characteristics, weatherization measures and improvements, IAQ measurements, and home performance data. Data retrieved from the WAP REAT and Final Inspection documents are highlighted in the forms included in Appendices A and B, respectively. Additional household characteristics were recorded as shown on the Field Logs included in Appendix C.

Occupants and their lifestyles greatly impact indoor air quality and energy usage. The variables shown below were pulled from the Field Log Form and were used in the health and energy analysis.

Occupants

- Smoker vs. Non-Smoker
- Pets
- Number of Occupants
- Occupant Density
- Percent of Time Cleaning Mean
- Percent of Time Cooking Mean

Coming directly from the REAT and Final Inspection forms, the Housing Characteristic variables shown below comprise the primary data used for determining energy usage. All of these home variables can impact the energy used and indoor air quality within the home and were used for exploring the effectiveness of weatherization by regions and type of home.

Home Characteristics

- Location (Mountain, Piedmont, Costal)
- Heating Equipment (Unit Type and Fuel Type)
- Sampling Season (Heating Season vs. Cooling Season)
- Combustion Appliances
- Forced Air
- Type of Home (Site Built or Manufactured Home)
- Area of conditioned space
- Number of Stories
- Number of Bedrooms
- Wind Exposure Level
- Crawlspace

Calculations for the study homes' potential energy savings used weatherization details obtained from the partner community action agencies (CAAs). Pertinent information included building characteristics necessary to calculate energy savings: square footage, volume, existing insulation conditions, air tightness testing, mechanical equipment, and changes made during weatherization. This information was gathered from the North Carolina Weatherization Assistance Program Residential Energy Assessment Tool (REAT) and Final Analysis forms. While these forms are required for weatherization funding they are not always completed thoroughly, which can cause information gaps.

Pulled directly from the weatherization work orders, Weatherization Measures and Improvements were used in conjunction with the ORNL WAP National Evaluation (Blasnik et al., 2015a; Blasnik et al., 2015b) to get a representative value for energy savings at each home. Lacking energy bills, these variables were necessary to determine the number of major weatherization measures implemented. Health and Safety improvements were used to compare different subsets within the population and to look for causes in improved IAQ. When performing statistical analysis CO, Fire Alarms, and Ventilation were not included. CO and Fire Alarms have no effect on the IAQ of the home, and homes receiving ventilation cannot provide a valid comparison to homes without ventilation.

Weatherization Measures and Improvements

- Air Sealing
- Attic Insulation
- Wall Insulation
- Floor Insulation
- Duct Sealing
- Heating System Replacement
- Ventilation
- CO and Fire Alarms
- Range Hood Installation
- Crawl Space Vapor Barrier Repair
- Dry Vent Installation

As previously discussed, the three contaminants listed below have the largest effect on health, especially for those suffering from asthma. These were used for calculating the cost of the health effects from changes in IAQ.

IAQ Data

- $PM_{2.5}$ - Pre-and Post-Averages
- Formaldehyde (HCHO) - Pre-and Post-Averages
- NO_2 - Pre-and Post-Averages

In the absence of energy bills, Home Performance variables are key to get accurate estimates of energy savings as well as to allow for sorting of homes and looking for correlations based on Blower Door Measurements and Ventilation Rates.

Home Performance

- Indoor Temp & RH Pre-and Post
- Outdoor Temp & RH Pre-and Post
- Blower Door Measurements (CFM50 and ACH50) Pre-and Post
- Equivalent Continuous Ventilation Rates (CFM)
- Barometric Pressure
- Wind Speed (Max and Average)

In the absence of energy bills, these characteristics were key in getting accurate estimates of energy savings as well as allowing for sorting of homes and looking for correlations based on Blower Door Measurements and Ventilation Rates.

Exclusion Criteria

After reviewing the original data set, several homes were excluded from the analysis. Although excluding homes reduced the sample size, five homes were removed from the 54 matched-pair homes, resulting in a sample size of 49 homes based on data quality and relevance to existing housing stock.

The homes in the HUD study included a large variety of home sizes, with square footages ranging from a minimum of 391 square feet (sf) to a maximum of 1879 sq ft, and a mean of 1131 sq ft. Very small homes experience greater IAQ fluctuations for a given source strength causing non-representative changes in IAQ and potential energy savings. For these reasons, homes under 500 square feet total or less than 300 square feet per person were excluded from the data set. This criterion excluded two homes from the data set.

Within the original study population, several homes had incomplete IAQ data sets for a variety of reasons. Three homes that did not have the IAQ data required for the analyses conducted in this study were removed from the study population.

Health Cost Estimate Calculations

Multiple methods and sources were used to determine costs/savings for (1) health, (2) energy, and (3) weatherization measures. Methods for monetizing health costs associated with changes in IAQ used two different methods described in the literature. The first focused on the DALY, a measurement of years of productive life lost to morbidity and mortality (Logue et al., 2012). The second focused on how changes in IAQ affect asthma sufferers and the related medical treatment costs.

DALY Assessment

The DALY focuses on years of life lost and years of life unhealthy or disabled due to a specific disease. Considerable previous work (Huijbregts, Rombout, Rabas, & van de Meent, 2005; Lvosky, Huges, Maddison, Ostro, & Pierce, 2000; Murray & Lopez, 1996; World Health Organization [WHO], 2009) has determined the validity of this method focused around the equation:

$$DALYs = \frac{\partial DALYS}{\partial Disease\ Incidence} * Disease\ Incidence \qquad [1]$$

DALYs lost equals DALYs per Disease Incidence times the disease incidence rate. There are two different methods for calculating the disease incidence rate. The Intake-Incidence-DALY (IND) method uses epidemiology-based functions to determine disease incidence rates and the Intake-DALY (ID) method, based off the work of Huijbregts et al. (2005), calculates the heath impact associated with the intake of pollutants.

IND method.

The IND method calculates the DALYs lost from exposure to $PM_{2.5}$ and NO_2 using this concentration-response function:

$$\Delta Incidence = -[y_o * \left(\exp\left(-\beta \Delta C_{exposure}\right) - 1\right] * population \qquad [2]$$

y_o = baseline prevalence of illness per year
β = the coefficient of the concentration change
$\Delta C_{exposure}$ = change in chronic exposure concentration
Population = # of people exposed

The literature provides information for baseline prevalence and the β coefficient. Increased $PM_{2.5}$ and NO_2 exposure can lead to multiple health outcomes. It is important to chronicle each of these in accounting for DALYs lost. Table 15 shows the necessary epidemiological information necessary for the calculations.

Table 15. *$PM_{2.5}$ and NO_2 C-R Function Outcomes and Disability and DALYs Lost per Incidence*

Pollutant	Outcome	β	Y_o	DALYs per incidence
PM 2.5	Total Mortality (Pope et al. 2002)	0.058 (0.002-0.010)	0.0074	1.4 (Pope 2007; Pope, Burnett, & Thun, 2002; Pope, Ezzati, & Dockery, 2009)
	Chronic Bronchitis (Abbey et al., 1995)	0.091 (0.078-0.105	0.004	1.2 (Lvovsky et al., 2000; Melse, Essink-Bot, Kramers, & Hoeymans, 2010)
	Non-fatal stroke (Brook et al., 2010)	0.025 (0.002-0.048)	0.002	11.7 (Hong et al. 2010)
NO_2	Hospital Admission (Burnett et al., 1999) Respiratory issues	0.004 (0.000-0.008)	9.5E-3	4E-4 (Lvovsky et al., 2000)
	Congestive Heart Failure	0.003 (0.001-0.004)	3.4E-3	
	Ischemic Heart Disease	0.003 (0.002-0.004	8.0E-3	
	Respiratory Illness (Hasselblad, Eddy, & Kotchmar, 1992)	0.028 (0.002-0.053	N/A	4E-4 (Lvovsky et al., 2000)

ID method.

The ID method goes directly from intake of an indoor pollutant to total DALYs lost due to a specific pollutant. Equation 3 shows the DALYs lost to both carcinogenic and non-carcinogenic effects from breathing a set concentration. This was used in calculating the DALYs lost from formaldehyde.

$$DALYS_i = C_i * V * [\frac{\partial DALY_{cancer}}{\partial intake} * ADAF + \frac{\partial DALY_{non-cancer}}{\partial intake}] \qquad [3]$$

C_i = indoor concentration
V = Volume of air breathed in the residence
ADAF = age-depend adjustment factor for cancer

Huijbregts et al. calculated the $\frac{\partial DALY_{cancer}}{\partial intake}$ of formaldehyde to equal 7.6 kg (2005). Calculating volume of air breathed can be accomplished using equation 4 and the information available in Table 16.

$$V = Fraction\ of\ day\ at\ home * Daily\ Air\ intake * \#\ of\ Days \qquad [4]$$

Table 16. *Residential Occupancy Characteristics by Age Groups*

Characteristic	<2	2-16	≥ 16	Population Average	Source
Fraction of Population	3%	19%	78%		U.S. Census, 2010
Fraction of Day at Home	75%	75%	69%	70%	Klepeis et al. 2001
Air Intake (m^3/day)	7	13	15	14.4	USEPA, 2009

The Age Dependent Adjustment Factor (ADAF) for cancer is used to calculate the cumulative effects of cancer on heath over an individual's lifetime. The age-related function allows increased effects during the developmental phase of children and young adults, with decreasing effects as the person ages. The EPA has calculated the following ADAFs, as shown in Table 17 (USEPA, 2005).

Table 17. *Age and Cancer ADAF*

Age	Cancer ADAF
<2	10
2-16	3
≥ 16	1
Population Average	1.6

Based on this information, a DALY value can be appropriately calculated for exposure to contaminants. This value is then multiplied by a monetary value assigned for the value of a year of life (VOLY). The standard approach for a cost benefit analysis of reductions in air pollution in the United States focuses on valuing measures by years of premature morbidity and by mortality prevented. These are then appreciated according to the value of statistical life (VSL), presently valued at $7.4 million by the EPA (Industrial Economics, Inc. [IEc], 2010). Anderson (2017) calculates the discount from a VSL to the VOLY of $218,723. A DALY of life lost or prevented is equivalent to the value of a year of healthy productive life, so this sum will be used when valuing DALYs. The $218,723 value is within the range of DALY values seen in the literature, and it complies with EPA recommendations for the value of a statistical life year.

Health Costs – Asthma

As discussed in Chapter 2, there are distinct relationships between air contaminants and FEV1% and between FEV1% and asthma symptoms. These relationships have been used in several different studies looking at effectiveness of asthma medications and interventions (Paltiel et al., 2001; Fuhlbrigge et al., 2006; Fabian et al., 2014). The pollutant change and effect on FEV1% from Connor, et al. (2008) and the relationship between FEV1% and asthma symptoms from Fuhlbrigge et al. (2006) were used to estimate the effect of weatherization on asthma for four months after intervention occurs.

Focusing on NO_2 and $PM_{2.5}$, the change in FEV1% per unit change in a contaminant is shown in Table 18. This rate was multiplied by the change in contaminants pre-and post-weatherization.

Table 18. *Change in FEV1% per Unit Change in* $PM_{2.5}$ *and* NO_2

Contaminant	**Δ FEV1% per unit increase**
$PM_{2.5}$ (μg/m^3)	-0.111
NO_2 (ppb)	-0.067

Once a change in FEV1% from the change in contaminant concentration was determined, a regression fit of the data available from Fuhlbrigge et al. (2006) provided a continuous function to calculate the change in symptoms due to the changed lung function.

Estimated midpoints for each FEV1% of 50%, 70%, 90%, and 110% were used to create the continuous functions for the number of asthma-free symptom days and percent of serious asthma-related events over a four-month period. The best fit follows expressions shown in equations 5 and 6:

$$\#_{A.S.F.\ Days} = .595FEV1\% + 5.15 \tag*{[5]}$$

$$\%_{serious\ event} = -.54FEV1\% + 78.2 \tag*{[6]}$$

With each of these equations we can calculate the number of asthma symptom days and probability of a serious asthma event for each of the homes over a four-month period.

Energy Costs

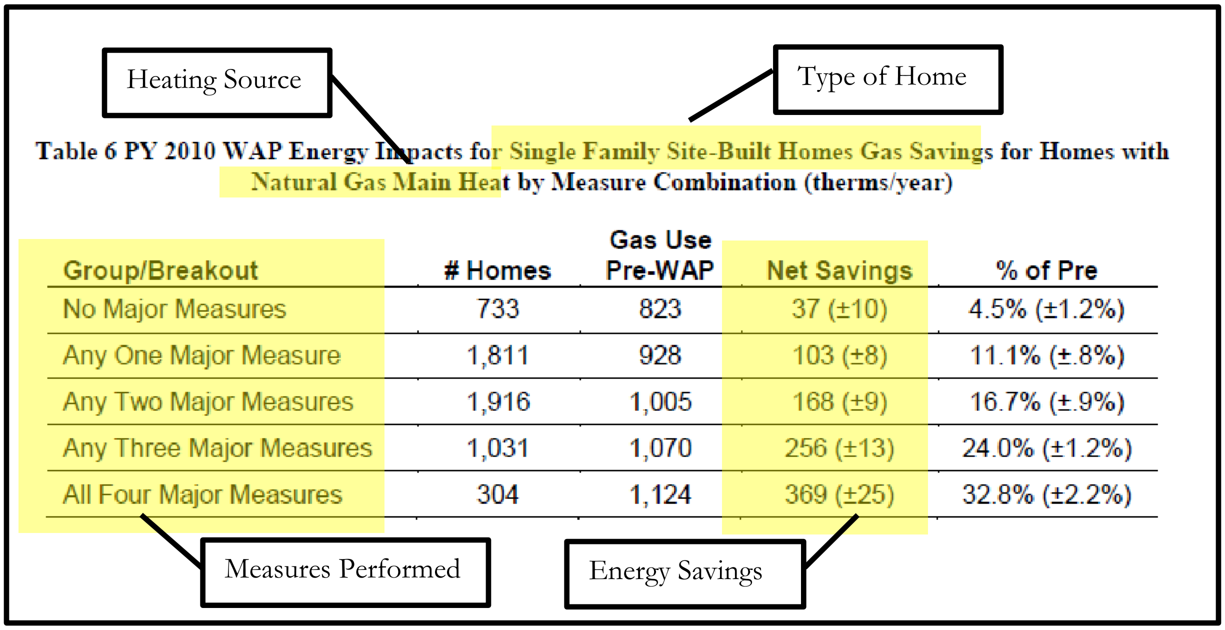
Without energy bills from the study homes, it was not possible to calculate exact energy usage and cost. However, two methods were used to provide relative estimates of energy savings. The first method made use of energy savings data from the PY 2010 WAP National Evaluation (Blasnik et al., 2015a; Blasnik et al., 2015b). By matching home characteristics and weatherization measures from this study and those in the National Weatherization Program, a representation of the potential energy savings was calculated. The second used blower door data and installed ventilation flow rates to determine potential convective energy savings to approximate losses from air sealing and ventilation. The link between indoor air quality and ventilation rates made this analysis especially important (Seppänen & Fisk, 2004; Sundell et al., 2011).

WAP National Evaluation: Representative Energy Savings

Under the PY 2010 WAP National Evaluation, Oak Ridge National Labs undertook a special impact assessment for energy savings and cost savings in all homes served by the WAP. Availability of the following key information allowed a complete analysis of energy and costs associated with services provided under the WAP (Blasnik et al., 2015a; Blasnik et al., 2015b):

- Installed weatherization measures and measure costs
- Energy usage information from energy bills
- Analysis of pre- and post-weatherization energy usage
- Cost effectiveness of energy measures

Figure 7 shows the typical information provided from the study with key information highlighted and labeled; additional tables with data used in this analysis are available in Appendix B.



Heating Source

Type of Home

Table 6 PY 2010 WAP Energy Impacts for Single Family Site-Built Homes Gas Savings for Homes with Natural Gas Main Heat by Measure Combination (therms/year)

Group/Breakout	# Homes	Gas Use Pre-WAP	Net Savings	% of Pre
No Major Measures	733	823	37 (±10)	4.5% (±1.2%)
Any One Major Measure	1,811	928	103 (±8)	11.1% (±.8%)
Any Two Major Measures	1,916	1,005	168 (±9)	16.7% (±.9%)
Any Three Major Measures	1,031	1,070	256 (±13)	24.0% (±1.2%)
All Four Major Measures	304	1,124	369 (±25)	32.8% (±2.2%)

Measures Performed

Energy Savings

Figure 7. Typical table from ORNL energy impacts assessment.

This distilled information provided a useful format that allowed for more direct comparison with the homes in this study, including:

- Type of Home (Site Built or Manufactured)
- Main Source of Heating (Natural Gas, Electricity, Delivered Fuels)
- Climate Zone (Cold, Moderate, Hot)
- Weatherization Measures Preformed

All of the required variables were available through the REAT Forms and Work Orders submitted for each of the homes. Work Orders were especially important in lining up the measures performed with weatherization definitions from the ORNL National Weatherization Evaluation; these are listed in Table 19.

Table 19. *Major Weatherization Measure Definitions and Variable Types*

Major Measures	ORNL Definition	Variable Type
No Major Measure	Smaller but no significant measures were performed	Discrete (Yes or No)
Major Air Sealing	Air sealing to decrease leaks by 1000 CFM50	Continuous (0.0-2.0)
Wall Insulation (Single Family Homes)	Wall Insulation Added to the Majority of Walls Within the Home	Discrete (Yes or No)
Attic Insulation	Attic Insulation added evenly across the majority of the attic.	Discrete (Yes or No)
HVAC System Replacement	Replacement of major systems, does not include ducting sealing	Discrete (Yes or No)
Floor Insulation (Manufactured Homes)	Insulation added evenly across the majority of the floor framing	Discrete (Yes or No)
Duct Sealing (Manufactured Homes)	Systematic Sealing of Air Ducts	Discrete (Yes or No)

By aligning each of the homes with the appropriate type and number of measures, a representation of energy savings was available for all of the homes within the study. Study homes received varying amounts of air sealing, resulting in different amounts of energy savings. To accommodate, a sliding scale was developed to account for a range of potential energy savings. This scale converts the difference between PRE-and POST CFM50 into a major measure number. Table 20 shows how the sliding scale values are aligned with CFM50 measurements. Figure 8 shows the distribution of major measures, as defined in Table 19, for the homes in the study.

Table 20. *Change in CFM 50 to Major Measure Value Scale*

ΔCFM50	# of Homes	Major Measure Value
< 500	24	0
500-1000	17	0.5-1.0
1000-1500	7	1.0-1.5
1500-2000	3	1.5-2.0
>2000	3	2.0

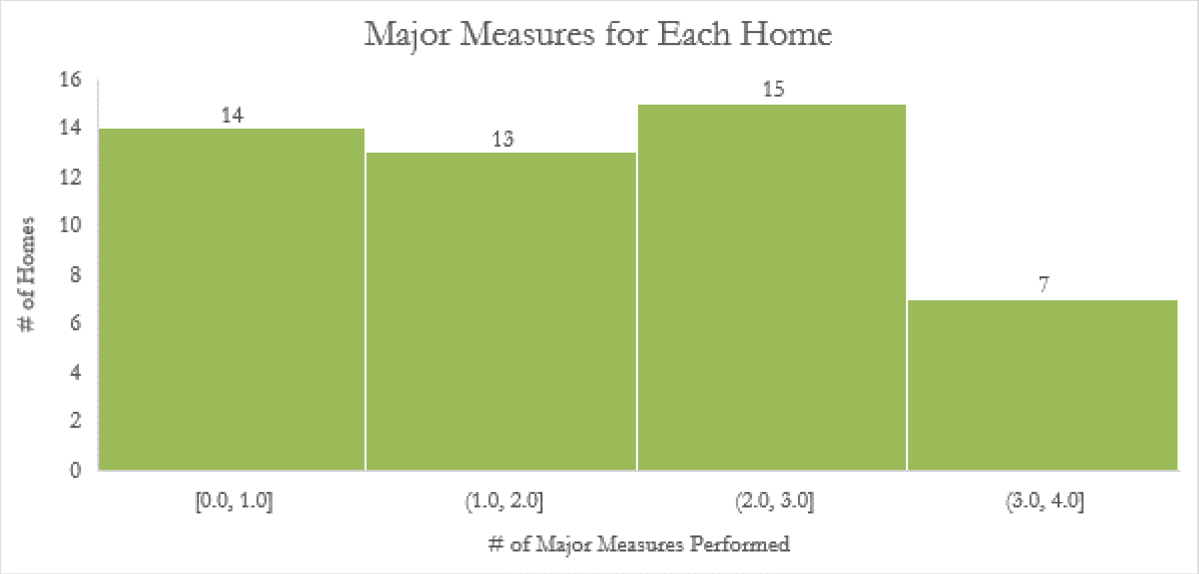


Figure 8. Breakdown of major measures within study homes.

Energy Cost for Ventilation

As each of the study homes underwent different air sealing measures and ventilation techniques, variable shifts in air changes per hour (ACH) occurred. ACH is the number of times the total volume of the home is replaced in one hour through natural ventilation, infiltration, or mechanical ventilation. ACH has significant implications for indoor air quality and convective energy loss as it exchanges contaminant-laden, conditioned indoor air with unconditioned outdoor air. Understanding the energy impact from mechanical ventilation will allow a comparison to air changes added to ensure for good indoor air quality.

ASHRAE 62.2-2010 *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings* sets a minimum required ventilation rate, based upon number of bedrooms and square footage, to achieve acceptable indoor air quality (2010c). The ASHRAE 62.2-2010 ventilation rate follows equation 7:

$$Q_{fan} = 0.01A_{floor} + 7.5(N_{br} + 1) \qquad [7]$$

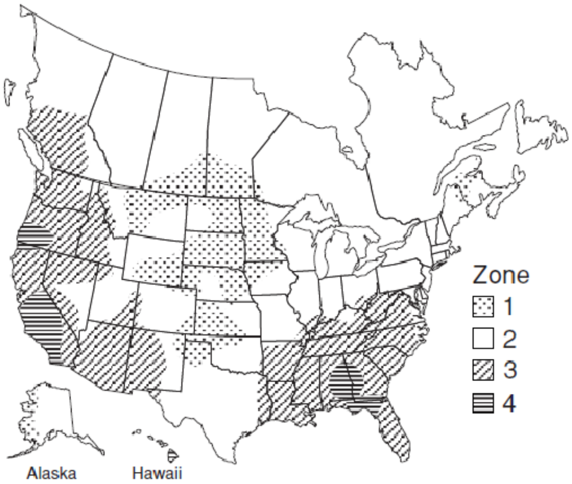
Q_{fan} = fan flow rate, cfm
A_{floor} = floor area, ft^2
N_{br} = number of bedrooms; not to be less than one

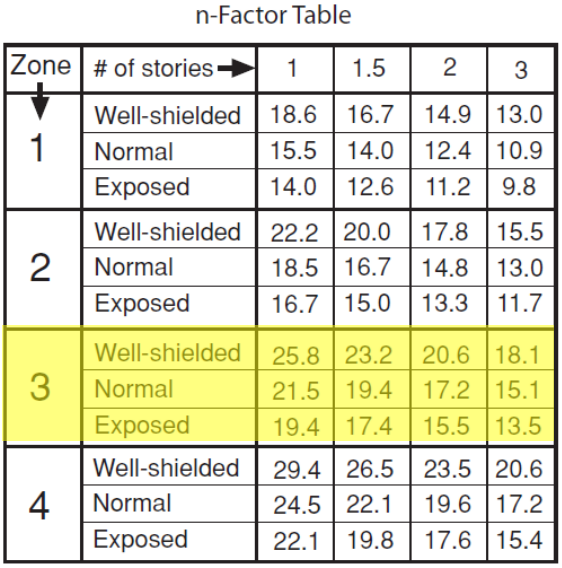
The WAP requires the use of this equation to calculate the needed mechanical ventilation rate within the homes. ASHRAE 62.2 allows for ventilation through air infiltration to reduce the mechanical ventilation required to reach the recommended ventilation rate for the home. The flow rate of mechanical ventilation is determined before installation by equation 8:

$$Q_{mech} = Q_{ASHRAE} - Q_{infil} \qquad [8]$$

Q_{mech} = Mechanical ventilation flow rate, CFM
Q_{ASHRAE} = ASHRAE 62.2 require flow rate, CFM
Q_{infil} = Infiltration flow rate, CFM

The infiltration flow rate is determined using blower door measurements, REAT form information, and the Lawrence Berkeley National Laboratory (LBNL) method for estimating natural air-leakage from blower door information. The LBNL method uses an “n” factor for converting CFM50 or ACH50 measurements to CFM_{nat} or ACH_{nat} based on geographic zone, number of building stories, and level of exposure to windy weather conditions (Krigger & Dorsi, 2013). Figure 9 shows the chart and table used to determine n-factor with Zone 3, the zone that encompasses the entirety of North Carolina, highlighted. It should be noted that these “Zones” are not the same as the seven ASHRAE climate zones.




n-Factor Table

Zone ↓	# of stories →	1	1.5	2	3
1	Well-shielded	18.6	16.7	14.9	13.0
	Normal	15.5	14.0	12.4	10.9
	Exposed	14.0	12.6	11.2	9.8
2	Well-shielded	22.2	20.0	17.8	15.5
	Normal	18.5	16.7	14.8	13.0
	Exposed	16.7	15.0	13.3	11.7
3	Well-shielded	25.8	23.2	20.6	18.1
	Normal	21.5	19.4	17.2	15.1
	Exposed	19.4	17.4	15.5	13.5
4	Well-shielded	29.4	26.5	23.5	20.6
	Normal	24.5	22.1	19.6	17.2
	Exposed	22.1	19.8	17.6	15.4

Figure 9. n-Factor map and table.

As part of the weatherization process, the minimum post-weatherization ventilation rate was calculated for each of the homes. This information was used to set run times for the installed fan flow rate in each home to achieve the ASHRAE 62.2- 2010 Standard. The addition of these fans increases air changes within the home to improve indoor air quality but at the same time will incur an energy penalty. We can estimate the annual energy loss from ventilation by calculating the total volume of air exchange and the energy required to condition the incoming air. This loss can be compared with health savings to determine if they offset the associated energy penalty, and with energy savings to determine its relative magnitude.

Convective energy loss from mechanical ventilation and air infiltration can be calculated using formulas for latent (equation 9) and sensible (equation 10) heat loss (ASHRAE, 2013):

$$q_s = C_s Q \Delta T \qquad [9]$$

$$q_l = C_l Q \Delta W \qquad [10]$$

q_s = Sensible heat transfer rate, Btu/h
q_l = Latent heat transfer rate, Btu/h
C_s = Air sensible heat factor, Btu/h * °F * cfm (1.1 at sea level)
C_l = Air latent heat factor, Btu/h * cfm (4840 at sea level)
Q = Air volumetric flow rate, cfm

Using these formulas along with typical meteorological year (TMY3) data sets, fan flow rates, and run times from the study homes, we can calculate the convection energy loss from running the fans. TMY3 data routinely used in solar and energy usage modeling includes insolation, cloud cover, dry-bulb temperature, dew point, relative humidity, and precipitation amounts (National Renewable Energy Laboratory [NREL], 2015). Unfortunately, Boone, NC is not a large enough city for TMY3 data to be available. Because of this, a stand-in with similar elevation and weather patterns needed to be chosen. The closest city with TMY3 data is Hickory, NC, but at 1142 feet above sea level there is a significant difference in the weather patterns between the two cities. Beckley, WV, another close city with available TMY3 data, has similar weather patterns and a closer elevation to give it a better approximation for Boone, NC weather (Wilcox & Marion, 2008). (See Table 21 for differences between Boone, NC; Hickory, NC; and Beckley, WV weather patterns.) For convective energy loss calculations, we were specifically interested in dry-bulb temperature and relative humidity. Using the information provided in Table 22 to correct for study location atmospheric pressure differences, and Tables 23 and 24 for indoor thermal comfort design and representative average outdoor conditions, respectively, sensible and latent heat transfer rates could be calculated.

Table 21. *Annual Average Weather Conditions for Boone, NC, Hickory, NC, and Beckley, WV*

Location	Low Temp (°F)	High Temp (°F)	Avg. Temp (°F)	Rainfall (in.)	Snowfall (in.)
Boone, NC	39.2	61.3	50.25	52.7	34
Hickory, NC	48.2	69.3	59.75	46.2	7
Beckley, WV	38.3	59.8	49.05	40.0	48

Table 22. *Elevation Corrections for Air Heat Factors and Atmospheric Pressure*

Location	Elevation (ft.)	C_s Corrected	C_l Correct	ATM Pressure (psi)
Sea Level	0	1.10	4840	14.696
Boone, NC	3,333	.97	4285	13.01
Raleigh, NC	315	1.09	4785	14.52
Wilmington, NC	30	1.10	4835	14.68

Table 23. *Indoor Air Design Conditions for Analysis*

Variable	Heating Season	Cooling Season
Temperature (°F)	68[1]	75[1]
% Relative Humidity	30	50
W (lb_w/lb_{da})	0.00438[2]	0.00932

[1]Temperatures between 68-75°F will not require conditioning.

[2] There will be limited latent heat gain or loss during the heating season and this will not be included in the calculations.

Table 24. *TMY3 Average Outdoor Conditions for Analysis*

Location	Dry-bulb (°F)	%RH	ΔT	Δ W	% Heating	% Cooling
Beckley, WV	51.8	73.0	17.6	0.0041	78%	8%
Raleigh, NC	59.5	71.1	13.2	0.0051	62%	21%
Wilmington, NC	63.4	74.6	10.4	0.0060	55%	29%

[1] Beckley, WV TMY3 data set is a close approximation to Boone, NC conditions

Using the map and chart from Figure 9 and the above information used for ventilation cost estimates, a similar calculation was performed for the amount of energy saved from air sealing. To create a conservative estimate of energy losses, all homes were considered well-shielded, with an n-factor of 25.8 to convert CFM50 data collected PRE-and POST weatherization into an approximation of the change in natural infiltration rate from weatherization. The change in amount of energy required to condition outdoor air is expressed in terms of Btu, therm, or kWh. Due to a lack of complete information on heating and cooling systems, it was not possible to correct for mechanical system efficiency, thus putting electrically heated homes at a disadvantage and those heated through fossil fuels at an advantage. The assumption of 100% efficiency is a major limitation but allowed for a comparison of savings from air sealing and losses from ventilation within each home. This limited approach also did not account for savings from conductive energy savings through the addition of insulation throughout the home. However, the importance of ventilation and infiltration to IAQ make the calculation of convective energy losses significant to the study.

Energy Cost Information

While Btu, therm, or kWh are useful numbers, they do not provide cost information. Fortunately, the Energy Information Administration collects, organizes, and distributes energy usage and energy cost information on a national, regional, and state scale. The energy cost information for the South Atlantic Region, which includes North Carolina, displayed in Table 25 for the years 2015 and 2016 shows a general decrease for all energy sources (USEIA, 2017). With each home receiving weatherization across different years, 2016 energy costs and dollars were used to calculate energy and health costs to have a consistent variable for comparison.

Table 25. *South Atlantic Residential Energy Costs for 2015 and 2016 ($/MMBtu)*

Energy Source	2015	2016
Propane	$19.015	$17.999
Distillate Fuel Oil	$19.170	$15.038
Natural Gas	$12.855	$12.511
Electricity	$34.987	$33.994

Cost of Weatherization

Determining cost of weatherization is a straightforward analysis of work orders submitted during weatherization. Total cost of weatherization is typically split between the

General Energy and Health & Safety Measures. Knowing how much actually goes towards energy saving will help to understand what effect each of these measures have on energy savings as well as indoor air quality. Detailed work orders from the weatherization agencies were obtained detailing the type, hours, and cost of work performed for each home (see Appendix A for examples of these documents). These documents, along with the administrative overhead for each of the homes, allows for an understanding of the time and effort that was applied in performing weatherization services.

Data Analysis

All statistical analysis was performed in IBM SPSS (Statistical Package for the Social Sciences), named for the original market and now popular in other fields. Three main tests were conducted to look for differences in health savings from changes in the homes' t-tests, one-way ANOVA, and Pearson correlation.

An independent-samples t-test was used to compare differences between homes, such as smoking homes vs. nonsmoking homes or homes that received a replacement heating system vs. those that did not. Using a confidence interval of 95%, the means between these groups were compared to determine statistical significance. Within each of these tests a Levene's Test for Equality of Variances was run to test for homogeneity of variance between the groups. For homes that reject the null hypothesis, equal variances were not assumed (Kent State University Library, 2017).

For home variables with more than two distinct groups a one-way ANOVA was used to look for variation between the different populations. This is helpful with characteristics like location that have three separate groups (in this case, MTN, PDT, & CST). Along with the ANOVA, Welch statistic and Least Significant Difference (LSD) Post Hoc analyses were run with each test. The Welch statistic tests for homogeneity within the groups to ensure that unequal variance is not skewing results. The LSD Post Hoc determines if there is a significant difference between any specific groups within the ANOVA (Kent State University [KSU] Library, 2017).

For variables that have continuous data, such as change in CFM50 or daily ventilation rate, a bivariate Pearson correlation was used. This test measures the strength and direction of relationships between two pairs of continuous data as well as if that relationship is statistically significant. Due to the small size of the population, a regression analysis looking for prediction of DALY or asthma impact from a home's characteristics or weatherization techniques was not be performed (KSU Library, 2017).

Financial Analysis

Three common financial tools were used when analyzing the cost effectiveness of weatherization and the DALYs economic impact. This included the simple payback, savings to investment ratio (SIR), and net present value. The simple payback, shown in equation 11, is an easy calculation comparing the costs associated with an investment or improvement and comparing it with the expected returns or savings to understand the time period for a return on investment.

$$Payback\ (years) = \frac{Cost\ of\ Improvement\ (Investment)}{Expected\ Annual\ Savings\ (Return)} \qquad [11]$$

SIR focuses on providing a long-term view of cost effectiveness of an investment and is calculated by dividing the present value of a lifetime of returns by the initial costs (Blasnik et al., 2015a). While similar to a payback, this metric, shown in equation 12, focuses what the lifetime value of returns will be in relation to the initial investment. A SIR greater than 1 indicates positive return on investment.

$$SIR = \frac{Present\ Value\ of\ Savings\ (Return)}{Cost\ of\ Improvement\ (Investment)} \qquad [12]$$

Net Present Value (NPV) is another metric used for calculating the cost effectiveness of an investment. Similar to SIR, NPV focuses on calculating the present value of a lifetime of returns and comparing it to the initial cost of investment. Shown in Equation 13, a positive NPV indicates a return on investment.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \qquad [13]$$

C_t = net cash inflow
C_o = total initial investment costs
r = discount rate
t = number of time periods

NPV, as it relates to building improvements, relies upon assumptions about a discount rate as well as the lifetime of the improvement, which can be related to the number of periods. The discount rate of 3% used for this analysis was based on recommendations from the US Office of Management and Budget (OMB) (2003). The lifetime of the improvement should relate back to the effective useful life (EUL) for the weatherization measure. EUL is the number of years after installation that 50% of measures are still in place and operational (Weitzel & Skumatz, 2001). This number is different for each of the weatherization methods as well as for climate zones, with some estimating the EUL for the combined measures as high as 20 years and others as low as ten years (Weitzel & Skumatz, 2001; Tonn et al., 2015a). For this study, a conservative approach was used, and an EUL of ten years was chosen.

CHAPTER 4: RESULTS

The overall objective of this study was to compare the relative impact of weatherization of health, representative and convective energy savings, and their associated costs. Impact of health focused primarily on the effect of weatherization on DALYs and their costs, with a simplified assessment of asthma symptoms. Statistical analyses provided an idea of how different areas of weatherization influence IAQ and health. The representative energy and convective energy savings, and costs associated with installation of required mechanical ventilation, were explored in relation to the cost of energy saving measures. Finally, a cost and savings comparison across health and energy was performed. Although estimates of cost and savings for both health and energy were determined, direct comparisons should be interpreted cautiously and readers should focus instead on the order of magnitude of effect for the different categories.

Health Cost Estimate

Regarding the two methodologies explored, DALY and Asthma Impact, both show the potential for health savings from weatherization. DALY savings have a significantly larger impact than asthma savings, but neither is insignificant. With this increased impact, the initial focus of analysis will be on DALYs and which study variables had the largest impact. This understanding will then be used when reporting the asthma impacts.

Health Costs - DALY Method

DALYs quantify the impact on the healthy life of a person and the economic cost of the loss of the life. Considering the fact that DALYs are weighted by age due to cancer impacts, three different occupant scenarios were chosen for analysis: 1 adult, 1 adult and 1 child, and the number of actual occupants in each study household. Figures 10 and 11 show the changes in DALYs calculated for a year of living at post-weatherization conditions vs. pre-weatherization conditions. It is important to note that a negative change in DALYs is a reduction in the IAQ effects on the occupants.

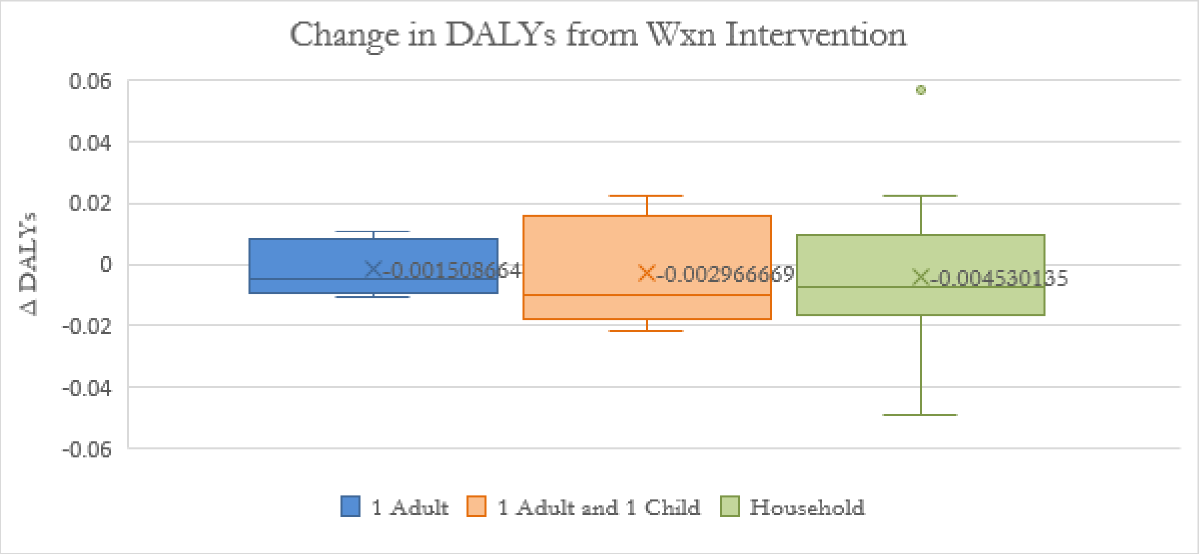


Figure 10. Median (line), Mean (x), and distribution of changes in DALYs from different occupant scenarios.

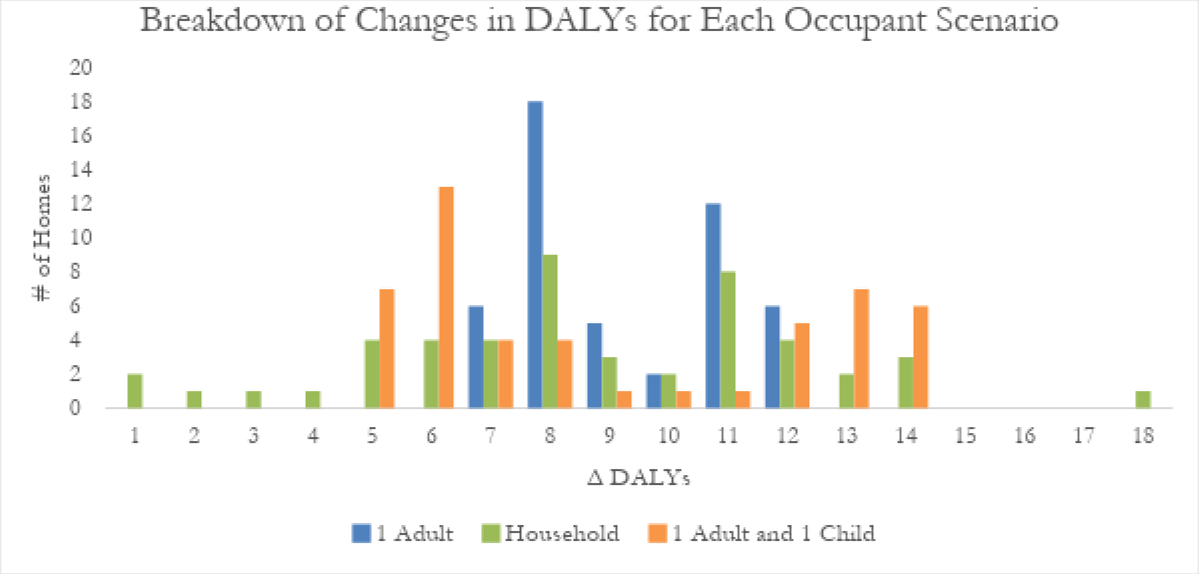


Figure 11. Histogram of changes in DALYs for different occupant scenarios.

The scenarios of 1 adult as well as 1 adult and 1 child were chosen due to the high prevalence of single person occupants and two-person occupants with a child under 16 within homes undergoing weatherization. Figure 10 shows that each of the different occupant scenarios provided a net positive benefit from the weatherization intervention; however, from Figure 11 the different scenarios have different distribution curves primarily due to the increased impact of cancer on children. Table 26 shows the relevant statistical information on DALYs for the three occupant scenarios.

Table 26. *Scenarios and Study Households DALY POST-PRE-Impact*

Groups	Mean (SD)	Median	Range	Sum
1 Adult	-0.0015 (0.0084)	-0.0050	0.0215	-0.0739
1 Adult and 1 Child	-0.0030 (-0.0169)	-0.0100	0.0446	-0.145
Study Households	-0.0045 (0.019)	-.0075	0.1059	-0.222

Understanding how much each of the contaminants impacts the overall DALY is important to understanding how different factors within the home affect IAQ and Health. This will also be important in understanding and optimizing asthma effects later on. Figure 12 shows the changes in DALYs by contaminant: Formaldehyde for Adults and Children, $PM_{2.5}$, and NO_2, which do not differentiate between adult and child. In the data set used for this study, NO_2 levels were extremely low in all but three homes.

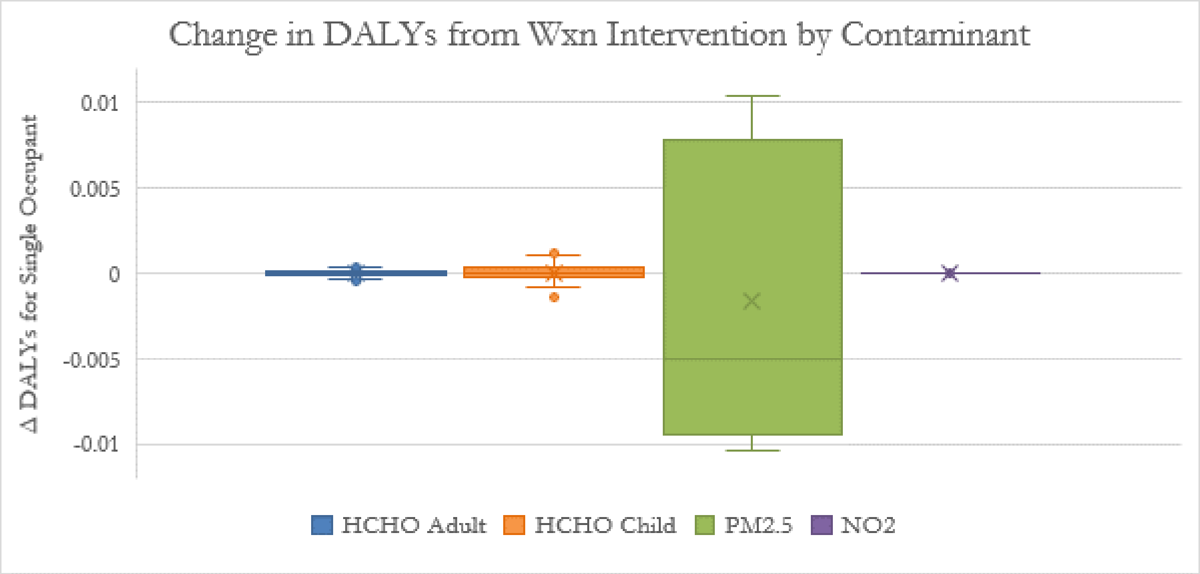


Figure 12. Distribution of changes in DALYs by contaminant.

Full population DALYs statistical analysis.

Understanding which variables have the largest effect on DALYs is important for weatherization agencies to optimize the health effects and prevent negative impacts.

Household variables effect on DALYs.

Results for the two-tailed t-tests comparing different household variables with the change in DALYs by occupant scenarios are shown in Table 27. Recall that a negative DALY indicates an improvement.

These data show that smoking is the only significant factor and has a detrimental impact on DALYs for all scenarios. While not significant, homes with forced air did show on average a decreased DALY impact compared to non-forced air homes. It is interesting to note that p-values are generally higher, except for smoking and sampling season, for the household occupant scenario than for the other two scenarios that are similar to one another. Figure 13 shows a box plot of the smoking and forced air variables.

Table 27. *Results of T-Test for Household Variables on DALYs*

			1 Adult		1 Adult & 1 Child		Study Household	
		n	**Mean**	**p-Value**	**Mean**	**p-Value**	**Mean**	**p-Value**
Smoking	**Y**	13	.00276	**.031**	.00554	**.033**	.00601	**.018**
	N	36	-.00305		-.00604		-.00834	
Pets	**Y**	22	.00066	.102	.00143	.100	-.00115	.265
	N	27	-.00328		-.00655		-.00729	
Type of Home	**S**	26	-.00194	.704	-.00388	.706	-.00484	.904
	M	23	-.00101		-.00199		-.00419	
Combustion	**Y**	17	.00039	.252	.00084	.255	-.00118	.374
	N	32	-.00251		-.00499		-.0063	
Forced Air	**Y**	41	-.00247	.068	-.00490	.069	-.00631	.140
	N	8	.00344		.00695		.00458	
Sampling Season	**HS**	34	-.00150	.991	-.00307	.950	-.00595	.435
	CS	15	-.00153		-.00273		-.00130	

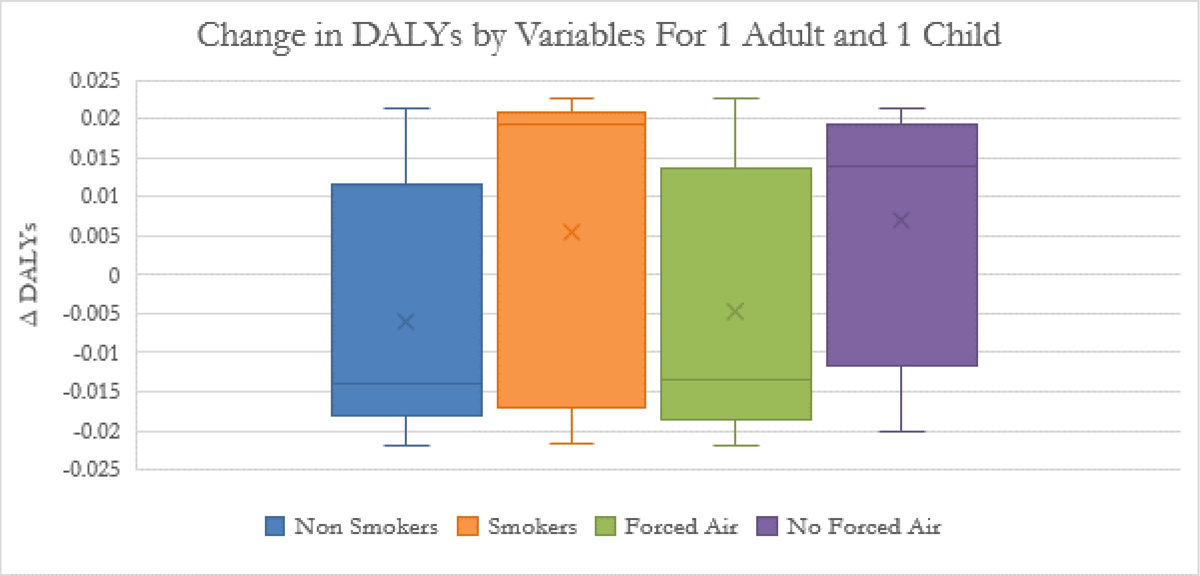


Figure 13. Distribution of changes in DALYs for smoking and forced air.

Through a series of t-tests between the contaminants and the different variables (individual results not shown) only Smoking and Sampling Season showed any significance for the contaminants. Smoking and No Smoking showed a strong significance of P = .029 for $PM_{2.5}$.

This makes perfect sense because smoking creates a large amount of fine particulate matter. Based on the information in Figure 12, we can see that $PM_{2.5}$ has the largest DALY impact of the three contaminants evaluated, with the implication that understanding how to best reduce particles within the home should help significantly reduce the health impact. The significance of the difference for the formaldehyde DALYs (HCHO) between sampling seasons is $P < .001$. This can be explained by the fact that formaldehyde is more readily released as temperature and humidity increase (Salthammer et al., 1995).

ANOVA tests were also performed to see how Location and the Type of Heating Energy affected the DALYs. Table 28 shows the one-way ANOVA for these two groups. Neither location nor Heating Energy showed significant difference between any of the groups. The low sample sizes of Natural Gas (n=4), Propane (n=4), and Fuel Oil (n=7) groups may prevent meaningful comparison to the Electric homes (n=34).

Table 28. *One-way ANOVA for Location and Heating Energy Type Effect on DALYs*

Variables	**1 Adult**		**1 Adult & 1 Child**		**Study Household**	
	F ratio	**p-value**	**F ratio**	**p-value**	**F ratio**	**p-value**
Location	F (2,46) =2.79	.072	F (2,46) =2.83	.069	F (2,46) =1.77	.181
Heating Energy Type	F (3,45) =1.35	.271	F (3,45) =1.338	.274	F (3,45) =.847	.476

Weatherization measures and improvement effect on DALYs.

Understanding impacts from changes made during weatherization will help inform weatherization agencies about which measures contribute to saving energy and improving health. Results for t-tests on changes in DALYs and individual energy measures and health and safety improvements are shown in Table 29 and 31, respectively, and correlation analysis results between DALYs and Major Air Sealing, Total Energy Measures, and Total Health and Safety Improvements are shown in Table 30.

Table 29. *Results of T-Tests for Individual Energy Measures and DALY Means*

			1 Adult		1 Adult & 1 Child		Study Household	
		n	**Mean**	**p-Value**	**Mean**	**p-Value**	**Mean**	**p-Value**
Heating System Replacement	**Y**	16	-.00003	.396	-.00001	.399	.00021	.228
	N	33	-.00223		-.00440		-.00682	
Wall Insulation	**Y**	3	-.00314	.733	-.00614	.741	-.00942	.650
	N	46	-.00140		-.00276		-.00421	
Attic Insulation	**Y**	37	-.00251	.144	-.00498	.145	-.00710	.096
	N	12	-.00159		.00323		.00341	
Floor Insulation	**Y**	13	-.00118	.870	-.00225	.860	-.00156	.516
	N	36	-.00163		-.00323		-.00560	
Duct Sealing	**Y**	11	.00020	.383	.00044	.388	-.00179	.658
	N	37	-.00232		-.00458		-.00573	

None of the individual energy measures show a significant difference for the three occupant scenarios. This is not surprising because wall, attic, and floor insulation have limited effect on the indoor air. Attic insulation showed a general trend of improvement in homes that had attic insulation installed vs. those that did not, perhaps related to the type of housing, where all site built homes had attics and manufactured had none.

Table 30. *Correlation Between Measures and DALYs (n=49)*

Measure	1 Adult		1 Adult & 1 Child		Study Household	
	r	**p-value**	***r***	**p-value**	***r***	**p-value**
Major Air Sealing	.138	.345	.140	.339	.143	.326
Total Energy Measures	.101	.488	.103	.481	.129	.376
Total HS Improvements	-.146	.318	-.144	.324	.071	.625

None of the general categories of weatherization measures showed significant correlation between DALYs for any of the occupant scenarios.

Table 31. *Results of T-Tests for Health and Safety Improvements and DALYs*

			1 Adult		1 Adult & 1 Child		Study Household	
		n	**Mean**	**p-Value**	**Mean**	**p-Value**	**Mean**	**p-Value**
CO Alarm	**Y**	46	-.00173	.466	-.00343	.454	-.00468	.831
	N	3	.00196		.00419		-.00222	
Range Hood	**Y**	9	-.00211	.814	-.00405	.834	-.00171	.628
	N	40	-.00137		-.00272		-.00516	
Vapor Barrier	**Y**	22	-.00160	.948	-.00311	.958	-.00300	.613
	N	27	-.00144		-.00285		-.00578	
Dryer Vent	**Y**	11	-.00396	.276	-.00793	.272	-.00476	.964
	N	38	-.00080		-.00153		-.00446	

None of the selected Health and Safety improvements showed any significant relationship to change in DALYs. Whole-home ventilation was not included as an individual measure in these t-tests because it was included in every home within the study.

Other home characteristics such as Occupant Density and Home Performance variables were also evaluated for their impact on changes in DALYs. Table 32 shows the results of correlations tests between these continuous variables and the DALYs of the three home occupant scenarios.

The correlation results show that none of these values had any statistically significant correlation with DALYs. However, Occupant Density showed a moderate but not statistically significant correlation. This is unsurprising because the less space available for each person, the more contaminants that will exist around them. What is worth noting is the lack of correlation between air sealing and ventilation values and DALYs. With the widely held view that increased ventilation improves indoor air quality, at least a moderate correlation between DALYs and ventilation would be expected, but only if it more than offset the number of contaminants being trapped by improved air sealing. So, the data appear to support the conclusion that additional air sealing is not increasing DALYs, and added ventilation is not decreasing DALYs.

Table 32. *Correlation Between Occupant Density, Air Sealing, and Ventilation Values and DALYs*

	1 Adult		1 Adult & 1 Child		Study Household	
Variable	***r***	**p-value**	***r***	**p-value**	***r***	**p-value**
Area	.052	.724	.058	.694	-.006	.969
Occupant Density	.236	.102	.234	.106	.275	.056
CFM50 Pre	-.007	.962	-.007	.963	-.019	.898
CFM50 Post	-.102	.486	-.102	.486	-.131	.371
Change CFM50	.093	.526	.093	.524	.103	.480
ACH50 Pre	.094	.521	.092	.528	.079	.589
ACH50 Post	-.017	.910	-.019	.895	-.036	.804
Change ACH50	.172	.237	.172	.236	.171	.241
ASHRAE Daily Ventilation (ft^3)	-.021	.887	-.019	.898	-.087	.554
Actual Daily Ventilation (ft^3)	-.038	.797	-.036	.804	-.099	.497
Difference	-.103	.479	-.109	.456	-.092	.529
Difference as % of Home Volume	-.050	.732	-.054	.714	-.074	.615
Actual/Home Volume	-.053	.720	-.053	.720	-.087	.554

Across all study homes, the only claim that can be made about significant changes in health outcomes is that the change in particles for smoking vs. nonsmoking homes is impacting health. This may not at first glance be surprising because smoking has a significant impact on indoor air quality and health, but what it actually indicates is the different impact of weatherization on changes in PM before and after weatherization.

Analysis of smoking and nonsmoking homes.

Previous t-tests have shown that smoking caused a significant difference in DALYs across all study homes. Treating smoking and non-smoking groups as separate data sets allowed for a better analysis of the factors that may be affecting IAQ, leading to improved recommendations for weatherization and home performance professionals. In this section, results for the same tests and sequence used for the study population are compared for these two groups. Figure 14 shows the distribution of DALYs in smoking and nonsmoking homes in the 1 adult and 1 adult and 1 child scenarios.

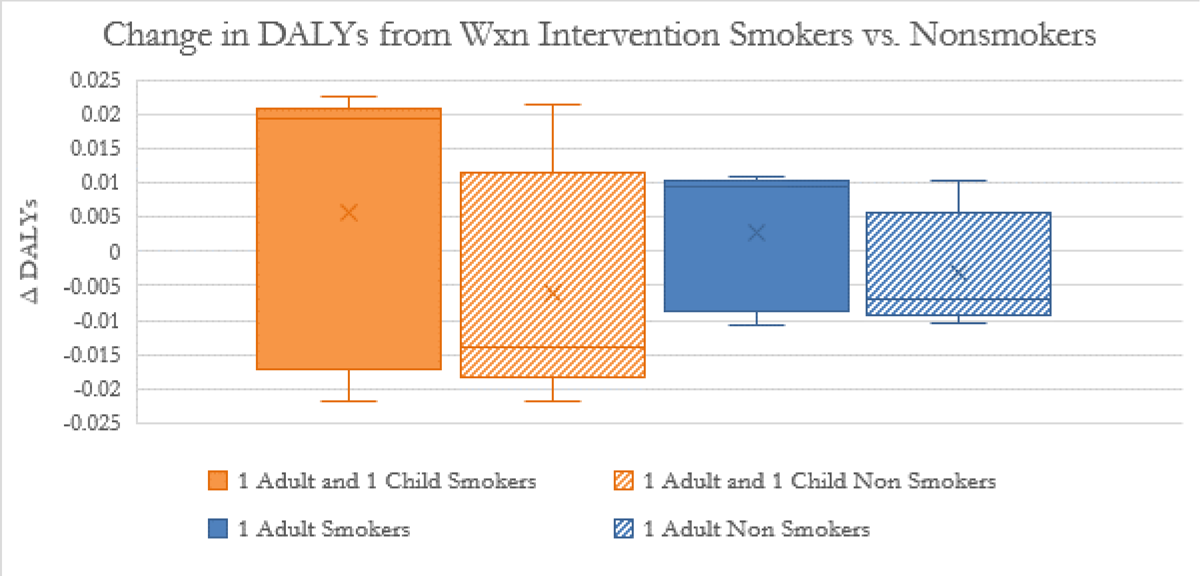


Figure 14. Distribution of changes in DALYs in smokers vs. nonsmokers.

This significant change is caused primarily by smoking but exploring what variables influence change within these groups is just as important. Looking at the change in the relationship between the mean and the median (x and middle line of the box plot, respectively) for smoking and nonsmoking homes allowed for an interesting observation. The smoking homes median was much higher than the mean, showing that there were only a few homes with significant decreases in DALYs, while the majority showed an increase. The opposite occured in nonsmoking homes, with the mean being higher than the median, showing that a few homes with large DALY increases were skewing the mean.

Smoking and nonsmoking: Household variables effect on DALYs.

Tables 33 and 34 report the smoking and non-smoking results from t-tests for household variables and a one-way ANOVA test for location and heating energy.

Table 33. *Results of T-Test for Household Variables in Smoking vs. Nonsmoking Homes*

		Smoking (n=13)			Nonsmoking (n=36)		
		n	**Mean**	**p-Value**	**n**	**Mean**	**p-Value**
Pets	**Y**	5	.0190	**.018**	17	-.00809	.397
	N	8	-.00289		19	-.00374	
Type of Home	**S**	5	-.00436	.146	21	-.00371	.257
	M	8	.0117		15	-.00930	
Combustion	**Y**	3	-.00566	.264	14	.00223	**.007**
	N	10	.00890		22	-.0113	
Forced Air	**Y**	12	.00421	.410	29	-.00867	**.031**
	N	1	.0214		7	.00489	
Sampling Season	**HS**	11	.00254	**.007**	23	-.00575	.883
	CS	2	.0220		13	-.00654	

Results in Table 33 show that separate calculations for smoking and nonsmoking homes resulted in more statistically significant differences than any of the other t-tests previously performed for the study homes as a whole. These results show that smoking homes in the cooling season and homes with pets will have a more severe impact on DALYs. It should be noted however, that there were only two smoking homes in the cooling season, so the impact of sampling season is not definitive. In nonsmoking homes there was a significantly lower impact on DALYS in homes without combustion appliances and with forced air systems. This follows what is understood in the literature because combustion appliances produce $PM_{2.5}$ and NO_2 at greater rates than electric appliances (Fisk et al., 2002). An additional t-test for homes without combustion appliances and with a forced air system (M=-.0105, SD=.0131) versus homes with combustion appliances or without a forced air system (M=-.0004, SD=.0160) showed a significant difference between the two, with p=.045.

Table 34. *One-way ANOVA for Location and Heating Energy Type Effect on DALYs by Smoking vs. Nonsmoking Homes*

Variables	Smoking		Nonsmoking	
	F ratio	p-value	F ratio	p-value
Location	F (2,10) =3.809	.059	F (2,33)1.253	.299
Heating Energy Type	F (3,9) =1.516	.276	F (3,32) =4.164	**.013**

In nonsmoking homes, the significant variance in heating energy shown in Table 34 is expressing the same difference as the t-test for combustion appliances.

Measure and improvement effect on DALYs.

Tables 35, 36, and 37 report the results of t-tests for individual energy measures, correlation analysis for categories of measures, and t-tests for individual health and safety measures, respectively.

Table 35. *Results of T-Tests for Individual Energy Measures and DALYs*

		Smoking			Nonsmoking		
		n	Mean	p-Value	n	Mean	p-Value
Heating System Replacement	**Y**	5	.00480	.918	11	-.00220	.320
	N	8	.00600		25	-.00772	
Wall Insulation	**Y**	0	-	-	3	-.00614	.991
	N	13	.00553		33	-.00603	
Attic Insulation	**Y**	7	.00415	.792	19	-.0181	.351
	N	6	.00745		5	-.0179	
Floor Insulation	**Y**	5	.01263	.310	8	-.0115	.166
	N	8	.00111		28	-.00447	
Duct Sealing	**Y**	5	.0145	.194	6	-.0112	.364
	N	8	-.00003		30	-.00500	

As with the overall study population, energy measures showed no statistically significant changes in DALYs for smoking and non-smoking groups. This is not surprising for the insulation measures because they have no direct impact on indoor air. Duct sealing, which plays a significant role in reducing air leakage and air infiltration, showed an inverse relationship between smoking and nonsmoking homes. While not statistically significant, smoking homes that received duct sealing showed an increase in DALYs over smoking homes that didn't receive duct sealing, leading to a greater decrease in DALYs in nonsmoking homes. For smoking homes, duct sealing may be trapping more environmental tobacco smoke while for nonsmoking homes it may be keeping out outdoor pollutants that could be occurring underneath the home where ducts are often located.

Table 36. *Correlation Between Measures and DALYs*

Measure	**Smoking**		**Nonsmoking**	
	r	**p-value**	***r***	**p-value**
Major Air Sealing	.378	.203	-.052	.763
Total Energy Measures	.226	.459	.094	.587
Total HS Improvements	-.075	.807	-.222	.194

While not statistically significant, the results in Table 36 are showing a weak positive correlation between Major Air Sealing and higher DALY impact, and a weak negative correlation between Total Health and Safety Improvements and DALYs in nonsmoking homes. This latter general trend indicates that effort put into Health and Safety Improvements may have potential for reducing DALYs, though unfortunately this same trend does not exist in smoking homes.

Results in Table 37 for the addition of a dryer vent in nonsmoking homes shows a highly statistically significant impact for reducing DALYs. The addition of a range hood also shows a smaller and not significant reduction in DALYs. The change due to presence of a dryer vent is important because this is a low-cost intervention with significant potential for improvement.

Table 37. *Results of T-Tests for Health and Safety Improvements and DALYs*

		Smoking			**Nonsmoking**		
		n	**Mean**	**p-Value**	**n**	**Mean**	**p-Value**
CO Alarm	**Y**	13	.00554	-	33	-.00697	.277
	N	0	-		3	.00419	
Range Hood	**Y**	1	.0227	.373	8	-.00739	.780
	N	12	.00411		28	-.00565	
Vapor Barrier	**Y**	6	.00044	.396	16	-.00444	.579
	N	7	.00990		20	-.00731	
Dryer Vent	**Y**	5	.00437	.871	6	-.0182	**>.001**
	N	8	.00627		30	-.00361	

Table 38 displays the results of correlation tests between the occupant density and key home air exchange parameters and DALYs for smoking, non-smoking, and overall study homes.

Without the effect of smoking to confound the data, a statistically significant negative moderate correlation between Occupant Density and DALYs occurred in nonsmoking homes, indicating higher density results in lower DALYs. Shown in Figure 15, the apparent increase in occupant density and corresponding decrease in DALYs suggests an interesting phenomenon that is opposite of what would be normally expected. However, it is worth noting that of the eight homes with greater than two occupants, all but three were non-smoking homes, which may account for this paradoxical trend.

Table 38. *Correlation Between Occupant Density, Air Sealing, and Ventilation Values and DALY: Smoking, Nonsmoking, and Total Study Population*

	Smoking		**Nonsmoking**		**Total Population (1 Adult and 1 Child)**	
Variable	***r***	**p-value**	***r***	**p-value**	***r***	**p-value**
Area	.144	.638	-.008	.963	.058	.694
Occupant Density	.082	.790	**-.418**	**.011**	.234	.106
CFM50 Pre	.101	.743	-.041	.811	-.007	.963
CFM50 Post	-.079	.798	-.099	.564	-.102	.486
Change CFM50	.301	.317	.032	.852	.093	.524
ACH50 Pre	.297	.324	-.002	.991	.092	.528
ACH50 Post	.177	.563	-.075	.662	-.019	.895
Change ACH50	.376	.206	-.079	.649	.172	.236
ASHRAE Daily Ventilation (ft^3)	-.227	.456	.080	.642	-.019	.898
Actual Daily Ventilation (ft^3)	-.228	.454	.048	.783	-.036	.804
Difference	-.111	.718	-.149	.387	-.109	.456
Difference as % of Home Volume	-.079	.798	-.085	.621	-.054	.714
Actual/Home Volume	-.073	.811	.001	.993	-.053	.720

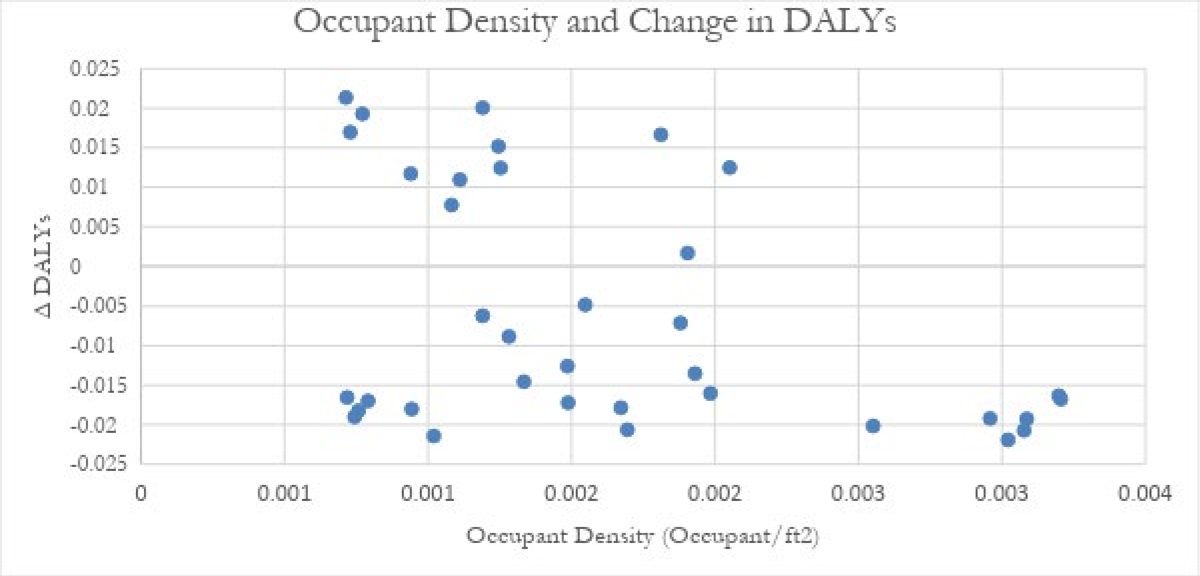


Figure 15. Scatterplot of occupant density and change in DALYs.

This analysis shows that smoking is the biggest factor when looking for differences in health impacts across all homes, and that it is important to treat smoking and nonsmoking homes separately when looking for relationships with other variables. In nonsmoking homes, a forced air system and the existence of combustion appliances provides a significant impact on the home's indoor air quality and the existing health impact, while in smoking homes no significant variable appears, showing that smoking is still the most significant impact on these homes. This information and the results from the following analysis of bimodal groups will be used to guide the analysis of the asthma impact.

Analysis of bimodal distribution.

One additional interesting finding was the bimodal DALY distribution in Figure 7, showing a group of homes with strong positive and strong negative changes and fewer homes with minimal change. Continued analysis of these two groups to look for significant variables shared by these subpopulations may provide additional insights. Figure 16 shows the bimodal breakdown of homes under the 1 adult and 1 child scenario groups of homes. The homes within the green and red circles have a Change in DALY either greater than .01 or less than -.01, respectively.

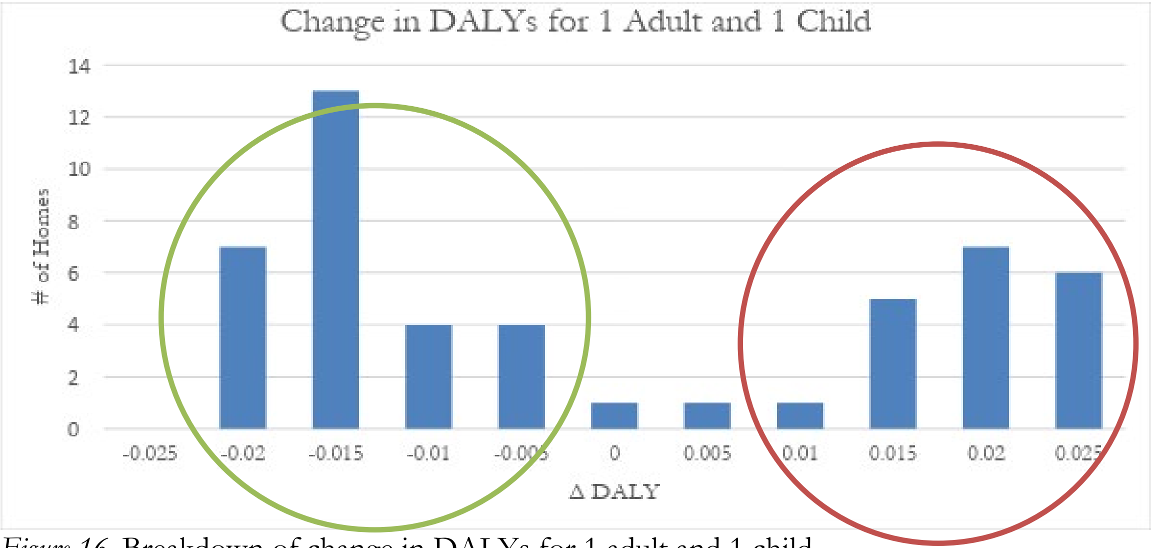


Figure 16. Breakdown of change in DALYs for 1 adult and 1 child.

Table 39 shows a highly significant difference between these two groups. Knowing how characteristics differ within these two groups could explain why they are so different and what characteristics lead to improved or degraded air quality.

Table 39. *T-Test Results for Bimodal Groups and DALY*

			1 Adult		
		n	**Mean**	**Difference**	**p-Value**
Bimodal Groups	**Δ < -0.01**	24	-.0181	-.0356	**<.001**
	Δ > 0.01	18	.0175		

The same tests performed on data for all study homes were performed, in the same sequence, and on the data set for these two separate groups to look for differences that may explain this bimodal behavior.

Bimodal data sets: Household variables effect on DALYs.

These two groups experienced opposite DALY changes, and understanding what is different between them will lead to a better understanding of what is causing these changes. Table 40 shows the distribution of variables within the two groups, with the higher value highlighted in green.

The group with an increase in DALYs is made up of more smoking homes and fewer forced air homes, both of which have been shown previously in Table 27 and 33 to have a significant effect on DALYs. While Table 40 shows the differences between these two groups, we still have little understanding of the potential impact of these different variables on DALY outcomes on each group. Results for t-tests and ANOVA for the two groups are shown in Table 41 and 42, respectively.

Table 40. *Single Value Variable Difference Between Increase and Decrease Groups*

Variables	% of Increase (n=18)	% of Decrease (n=24)
Smoker	44.4%	16.7%
Pets	61.1%	33.3%
Site Built Home	55.6%	62.5%
Manufactured Home	44.4%	37.5%
Combustion	44.4%	25.0%
Forced Air	72.2%	91.7%
Heating Season	72.2%	66.7%
Cooling Season	27.8%	33.3%

Table 41. *T-Test for Household Variables on DALYs by Bimodal Groups*

		Increase in DALYs			Decrease in DALYs		
		n	Mean	p-Value	n	Mean	p-Value
Smoking	**Y**	8	.0198	**.016**	4	-.0191	.454
	N	10	.0157		20	-.0178	
Pets	**Y**	11	.0169	.439	8	-.0189	.293
	N	7	.0184		16	-.0177	
Type of Home	**S**	10	.0168	.430	15	-.0176	.229
	M	8	.0184		9	-.0189	
Combustion	**Y**	8	.0154	**.030**	6	-.0183	.778
	N	10	.0192		18	-.0180	
Forced Air	**Y**	13	.0177	.830	22	-.0180	.570
	N	5	.0172		2	-.0190	
Sampling Season	**HS**	13	.0166	.086	16	-.0190	**.007**
	CS	5	.0199		8	-.0161	

Table 42. *One-way ANOVA for Location and Heating Energy Type Effect on DALYs by Bimodal Groups.*

Variables	**Increase in DALYs**		**Decrease in DALYs**	
	F ratio	**p-value**	**F ratio**	**p-value**
Location	F (2,15) =2.61	.106	F (2,21) =2.18	.138
Heating Energy Type	F (3,14) =1.93	.171	F (3,20) =.063	.979

From the t-test results we can see that the Increase Group showed significant difference between Smoking and Combustion Appliance while the Decrease group showed a significant difference for Heating Season. Independent-samples t-tests comparing DALYs from formaldehyde and $PM_{2.5}$ in Heating Season and Cooling Season showed statistically significant change in DALYs from $PM_{2.5}$ (t (22) =-2.45, p=.023), but no change in DALYs from formaldehyde (t (22) =-1.921, p=.068). Normally the DALYs change from Seasons could be attributed to increases in formaldehyde from increased temperature and humidity during the cooling season. But the reductions in DALYs during the heating season can be attributed to a reduction in $PM_{2.5}$. The ANOVA showed no major difference between Location and Heating Energy type in either group. Post Hoc Least Significant Difference (LSD) tests were run on all of the ANOVAs to look for differences between individuals within the groups. The LSD test could not be run on the heating energy in the Decrease Group because the fuel oil group only had one home. Shown in Table 43, these tests indicated significant mean differences within Location and Heating Energy.

Table 43. *Mean Differences and Significance for Location from LSD Test*

		Increase in DALYs		**Decrease in DALYs**	
Variables		**Mean Difference**	**p-Value**	**Mean Difference**	**p-Value**
MTN	**CST**	-.00390	**.045**	-.00099	.454
PDT	**CST**	-.00325	.184	-.00231	**.050**

Homes within the CST group were significantly higher than MTN and PDT. This is mostly likely attributed to climate or local influences. Within both the Increase and Decrease group there was a significant difference between homes in cold or moderate climates (MTN or PDT) with homes in warm and humid climates. A similar significance was found by Doll et al. between warm humid areas and cooler areas (2016).

Measure and improvement effect on DALYs.

Although the different energy measures and health and safety improvements showed no significant change in the study population, breaking down into bimodal subgroups may show something that was obscured in the study population. Tables 44, 45, and 46 show t-tests between DALYs and individual energy measures, DALYs and health and safety improvements, and a correlation analysis between DALYs and Total Measures and Improvements, and Major Air Sealing, respectively.

Table 44. *Results of T-Tests for Individual Energy Measures and DALYs*

		Increase in DALYs			**Decrease in DALYs**		
		n	**Mean**	**p-Value**	**n**	**Mean**	**p-Value**
Heating System Replacement	**Y**	8	.0177	.862	7	-.0177	.286
	N	10	.0173		17	-.0190	
Wall Insulation	**Y**	1	.0201	.505	2	-.0192	.516
	N	17	.0174		22	-.0179	
Attic Insulation	**Y**	11	.0170	.498	19	-.0181	.873
	N	7	.0183		5	-.0179	
Floor Insulation	**Y**	5	-.0188	.386	6	-.0183	.781
	N	13	.0170		18	-.0180	
Duct Sealing	**Y**	5	.0189	.337	4	-.0203	**.046**
	N	13	.0170		20	-.0176	

While the sample size of the duct sealing in the Decrease group in Table 44 is not evenly divided, a statistically significant decrease in DALYs could be explained for a variety of reasons.

T-tests looking at changes from DALYs by formaldehyde and $PM_{2.5}$ individually showed no significance change in formaldehyde DALYs, but did show a significant change in $PM_{2.5}$ DALYs. An independent-samples t-test showed a significant difference in DALYs for Duct Sealing (M=-.0102, SD=.00013) and No Duct Sealing (M=-.0087, SD=.0011) conditions; t (20.9) =5.25, p < .001. All homes with duct sealing were also mobile homes, which typically have ducts located underneath the home, and providing sealing can prevent significant loss as well as particulate matter infiltration.

Table 45. *Correlation Between Measures and DALYs*

Measure	Increase in DALYS		Decrease in DALYS	
	r	p-value	*r*	p-value
Major Air Sealing	.108	.670	.006	.977
Total Energy Measures	.182	.469	-.336	.109
Total HS Improvements	.252	.314	-.067	.756

While not statistically significant, the decrease group in Table 45 showed a moderate negative correlation between Energy Measures performed and the change in DALYs. This could be related to the improvements in DALYs seen from duct sealing.

Table 46. *Results of T-Tests for Health and Safety Improvements and DALYs*

		Increase in DALYS			Decrease in DALYs		
		n	Mean	p-Value	n	Mean	p-Value
CO Alarm	**Y**	16	.0177	.536	23	-.0180	.649
	N	2	.0159		1	-.0193	
Range Hood	**Y**	4	.0145	.060	5	-.0188	.457
	N	14	.0184		19	-.0178	
Vapor Barrier	**Y**	8	.0193	.070	12	-.0175	.270
	N	10	.0161		12	-.0187	
Dryer Vent	**Y**	3	.0214	**.001**	8	-.0189	.249
	N	15	.0168		16	-.0176	

The t-test results in Table 46 show a statistically significant change between homes with a dryer vent installed and homes without a dryer vent installed. The change, however, is in an unexpected direction, with homes without a dryer vent installed having a lower mean DALY increase than the homes with a dryer vent installed. Upon further inspection of all of the homes with dryer vents installed, none were nonsmoking homes. The homes without the dryer vent installed were actually 66% nonsmoking homes. The small sample size of the dryer vent homes and the presence of the protective influence of not smoking explains this difference.

Again, looking to other home characteristics such as Occupant Density and Home Performance variables may provide information on the difference in DALY between the bimodal groups. Table 47 shows the average values for these different groups and the percent different between the two.

Table 47. *Occupant Density, Air Sealing, and Ventilation Averages*

Variable	Increase (n=18)	Decrease (n=24)	Percent Difference
Area (ft^2)	1160	1145	1.3%
Occupant Density (ft^2)	884	717	**20.9%**
CFM50 PRE	2574	2608	-1.3%
CFM50 POST	1736	1931	**-10.6%**
Change CFM50	837	678	**21.0%**
ACH50 PRE	18.3	16.9	8%
ACH50 POST	12.4	12.6	-1.6%
Change ACH50	5.9	4.3	**31.4%**
ASHRAE Daily Ventilation (ft^3)	41092	41040	0.1%
Actual Daily Ventilation (ft^3)	38916	39693	-2.0%
Difference (ASHRAE - actual)	-2176	-1317	**49.2%**
Difference as % of Home Volume	-24%	-19%	**23.3%**
Daily Air Changes	4.6	4.5	2.2%

There are important differences between these two groups in key air infiltration and air sealing categories, including greater occupant density, change in CFM50, change in ACH50, and deficit in actual versus ASHRAE daily ventilation for the Increase group. The correlation analysis results, in Table 48, show no significant correlation between any of the continuous home characteristics and DALYs.

Among these two groups, variables to be mindful of are smoking, combustion, season, and duct sealing. During these tests smoking homes continually confounded the results, which again shows that even among these distinct bimodal groups, smoking has a large impact on the IAQ and health outcomes.

Table 48. *Correlation Between Occupant Density, Air Sealing, and Ventilation Values and DALY Between Increase Group, Decrease Group, and Total Study Population*

	Increase in DALYs Group		**Decrease in DALYs Group**		**Total Population (1 Adult and 1 Child)**	
Variable	***r***	**p-value**	***r***	**p-value**	***r***	**p-value**
Area	.268	.283	167	.434	.058	.694
Occupant Density	.107	.672	.103	.632	.234	.106
CFM50 Pre	.192	.446	.045	.833	-.007	.963
CFM50 Post	.222	.377	.136	.527	-.102	.486
Change CFM50	.102	.686	-.109	.611	.093	.524
ACH50 Pre	.030	.907	.024	.910	.092	.528
ACH50 Post	-.004	.989	.095	.660	-.019	.895
Change ACH50	.045	.859	-.106	.621	.172	.236
ASHRAE Daily Ventilation (ft^3)	-.128	.612	-.311	.139	-.019	.898
Actual Daily Ventilation (ft^3)	-.179	.477	-.313	.136	-.036	.804
Difference	-.235	.347	-.085	.693	-.109	.456
Difference as % of Home Volume	-.231	.355	-.100	.643	-.054	.714
Daily Air Changes	-.385	.115	-.267	.207	-.053	.720

DALY economic impact estimate.

When valuing the DALY at $218,723, small reductions can have significant influences on the economic impacts of the DALY. Figures 17 and 18 show the economic impacts for individual homes and total savings from DALYS, respectively, for the different occupant scenarios.

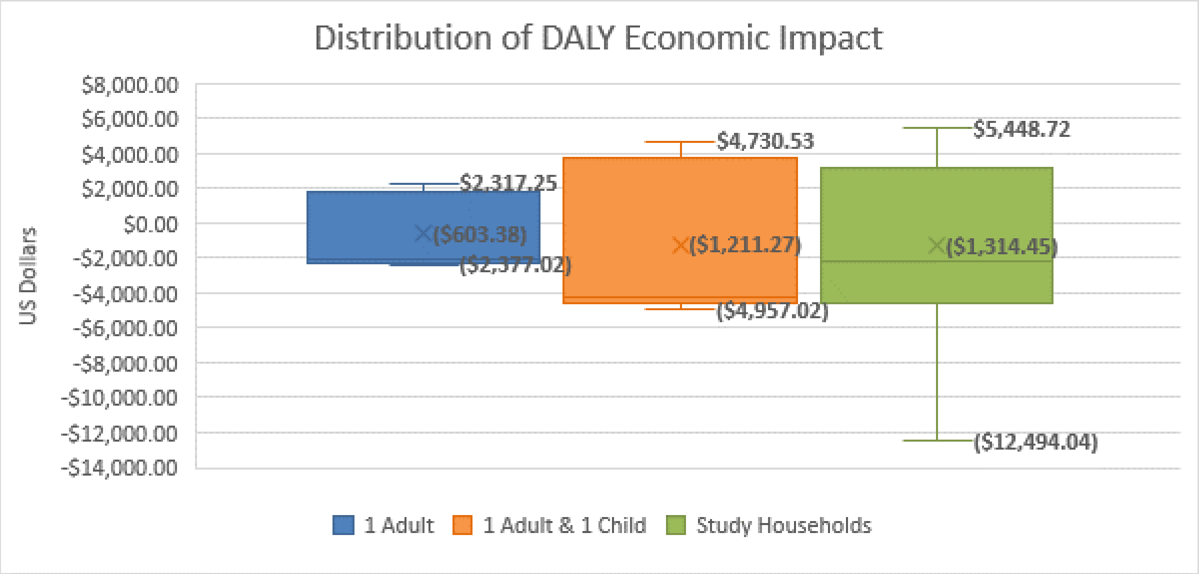


Figure 17. Distribution of DALY economic impact in different scenarios.

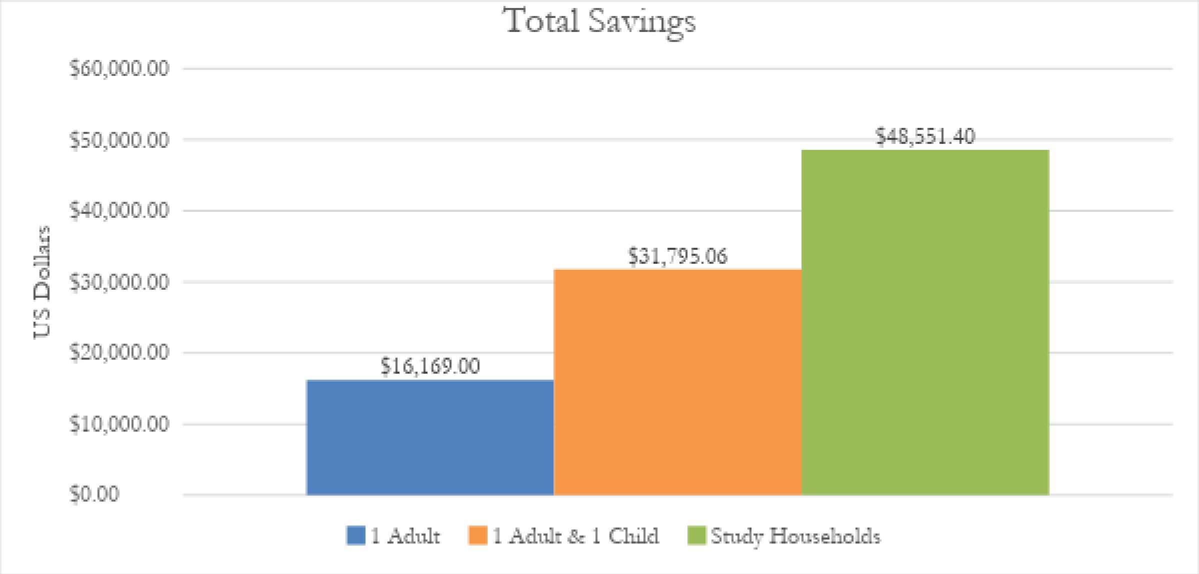


Figure 18. Total savings from DALY.

Although not every household received a positive benefit from the DALY Economic impact, the total study population had both positive savings and a total health savings from the DALY impacts. Profiles can be developed from the previous analysis for the best and worst-case scenarios for health savings. Using the study home occupant scenario, Table 49 shows the expected best and worst-case groups.

Table 49. *Best to Worst Case DALY Groupings for the Study Home Scenario*

Group and Variables	n	Mean DALYs	Median DALYs	Mean Economic Value per Home
1. No smoking, no combustion, Dryer vent installed	6	-0.0182	-0.0148	$ 3,977.00
2. No smoking, no combustion	22	-0.0136	-0.0117	$ 2,978.00
3. No smoking	36	-.00083	-0.0085	$ 1,823.00
4. No combustion	32	-0.0063	-0.0093	$ 1,380.00
5. Study population	49	-0.0045	-0.0075	$ 991.00
6. Combustion	17	-0.0012	0.0038	$ 258.00
7. Smoking	13	0.0060	0.0097	$ -1314.00

Asthma Impact Estimate

Weatherization may prove to be an integral intervention in an asthma treatment plan, but our understanding of weatherization's effect on asthma is just at its beginning stages. Knowing what features within a home will provide the best improvement for asthma sufferers will inform improved treatment plans in the future. Using the method for estimating asthma symptom days and % serious events we calculated the impact of weatherization on a moderate asthma sufferer with an assumed starting FEV1% of 80% before the weatherization intervention. Figures 19 and 20 show the impact on a single pediatric asthma sufferer across the study population represented as changes in asthma symptom-free days and % of serious asthma events, respectively.

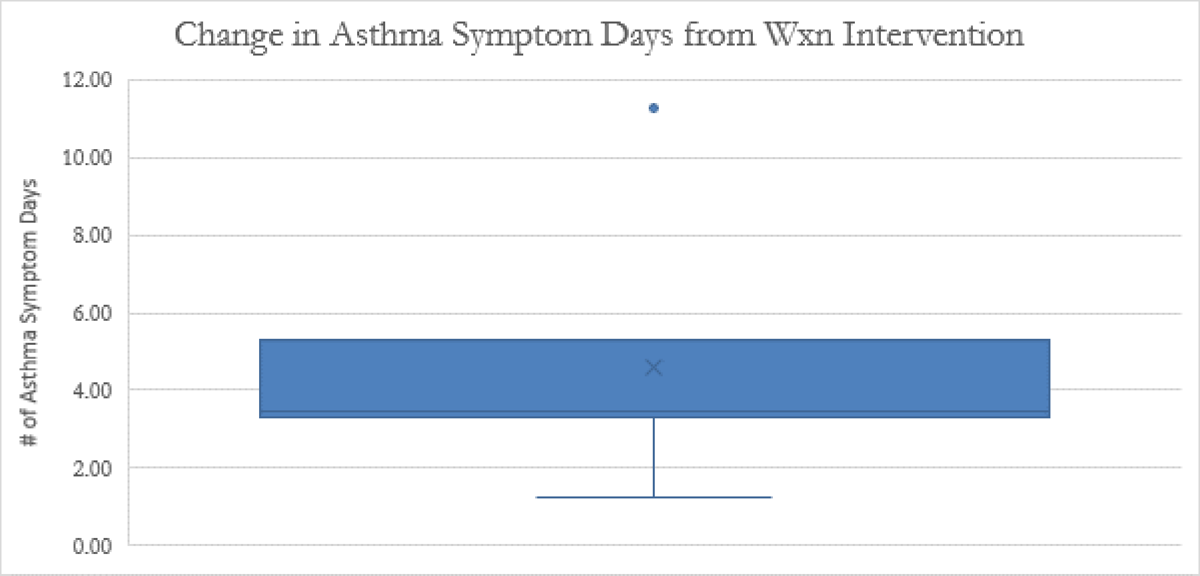


Figure 19. Change in asthma symptom days from weatherization; study population.

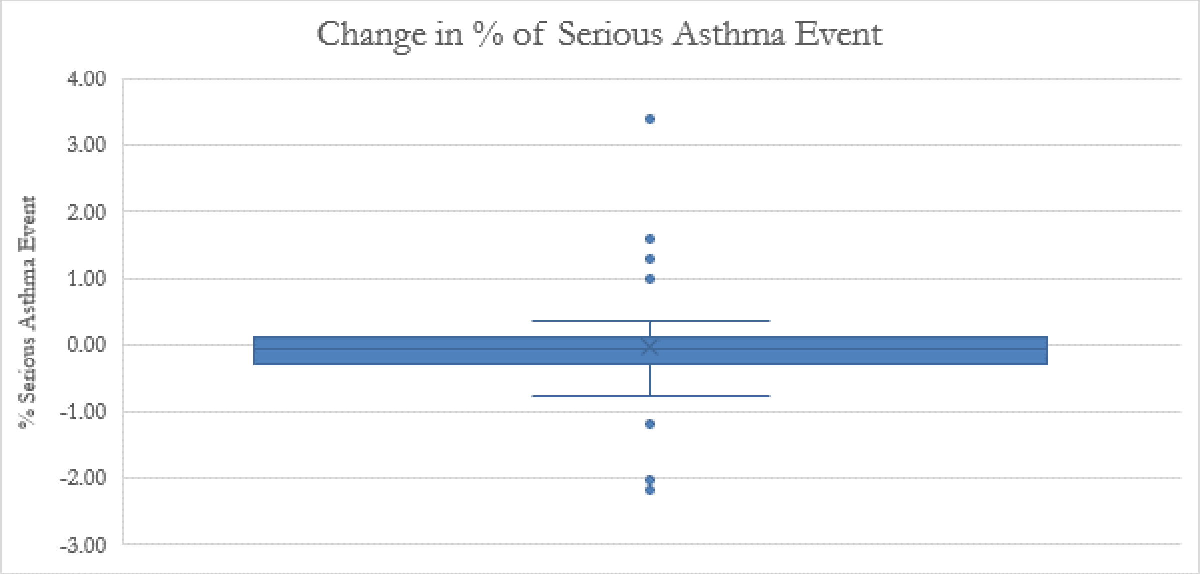


Figure 20. Change in % of serious asthma events from weatherization; study population.

From Figures 19 and 20 it can be seen that there was generally an increase in asthma symptom days but only a minimal change for the percentage of serious asthma events. Table 50 shows the relevant statistical values for the study population as a whole.

Table 50. *Statistical Descriptors for Study Population Asthma Impact*

	Mean (SD)	Median	1st Quartile	3^{rd} Quartile	Min	Max
Change in Asthma Symptom Days	-0.06 (2.71)	-0.20	-1.00	0.40	-7.23	11.24
Change in % of Serious Asthma Events	-0.02(.082)	-0.06	-0.30	0.12	-2.19	3.40

Using the information gathered from the analysis of DALYs helped inform the analysis for the asthma sufferers. Shown in Table 51 are results from t-tests performed on the change from smoking and combustion appliances to identify the strongest factors impacting asthma sufferers.

Table 51. *Results of T-Tests for Asthma Effects; Study Population*

			Asthma Symptom Days		% of Serious Asthma Events	
		n	Mean	p-Value	Mean	p-Value
Smoking	**Y**	13	1.85	**.002**	.559	**.002**
	N	36	-.75		-.226	
Combustion	**Y**	17	-.97	.088	-.292	.088
	N	32	.42		.128	

At the study population level, smoking homes showed highly significant changes in symptom days and serious asthma events. Combustion also showed an impact at the 90% significance level. As with the DALYs, breaking the groups into smoking and nonsmoking showed whether combustion has an effect on these homes. Figure 21 visually shows the distribution and difference between these two groups for change in asthma symptom days and change in percent of serious events. T-tests in Table 52 show the differences in smoking and nonsmoking homes for combustion and forced air.

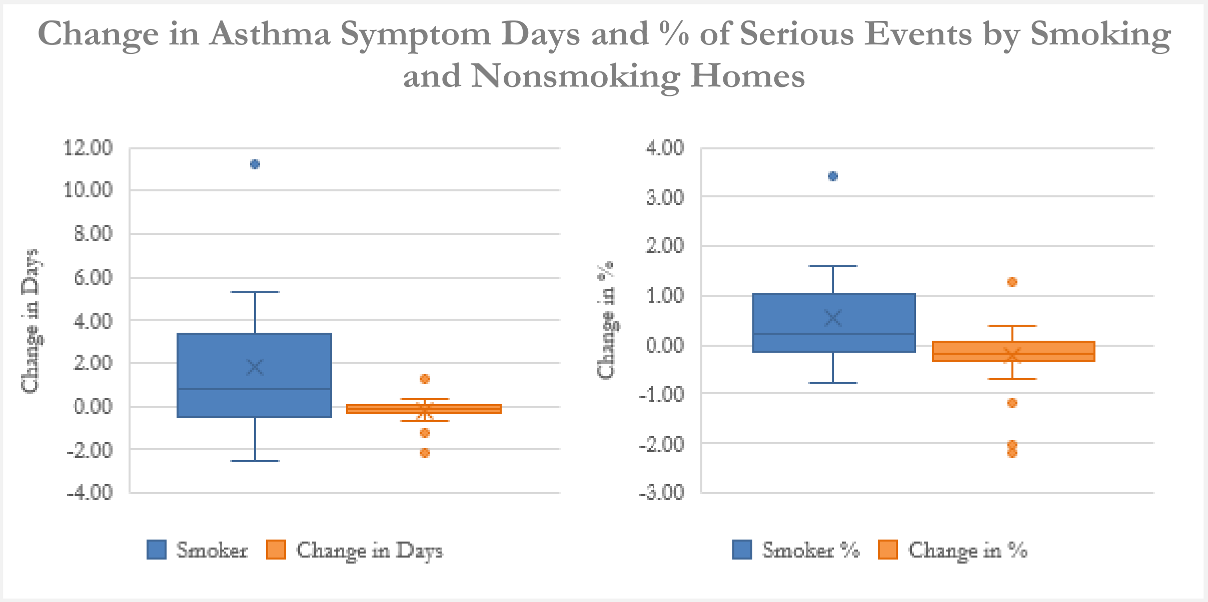


Figure 21. Change in asthma effects by smoking and nonsmoking homes.

Table 52. *Results of T-Tests for Asthma Symptom Days; Smoking, Nonsmoking Homes*

		Smoking			Nonsmoking		
		n	**Mean**	**p-Value**	**n**	**Mean**	**p-Value**
Combustion	**Y**	3	-.60	.189	14	-1.04	.567
	N	10	2.58		33	-.56	
Forced Air	**Y**	12	1.73	.690	29	-.42	.234
	N	1	3.31		7	-2.12	

The results in Table 52 show no significant differences for Combustion or Forced Air in either Smoking or Nonsmoking groups. DALYs put significantly more emphasis on $PM_{2.5}$ while the asthma impact methods weight $PM_{2.5}$ and NO_2 more evenly. The introductory method for estimating these impacts, when related to building and household variables, is much less sensitive than the DALY methods. Improving upon these methods and expanding the understanding of long term impacts from weatherization is another area for future research. Shown in Figure 22, there was a net positive impact on asthma from weatherization that increased significantly when separating homes into smoking and nonsmoking homes. It is our hope that homes with asthmatics would take precautions to avoid smoking around them.

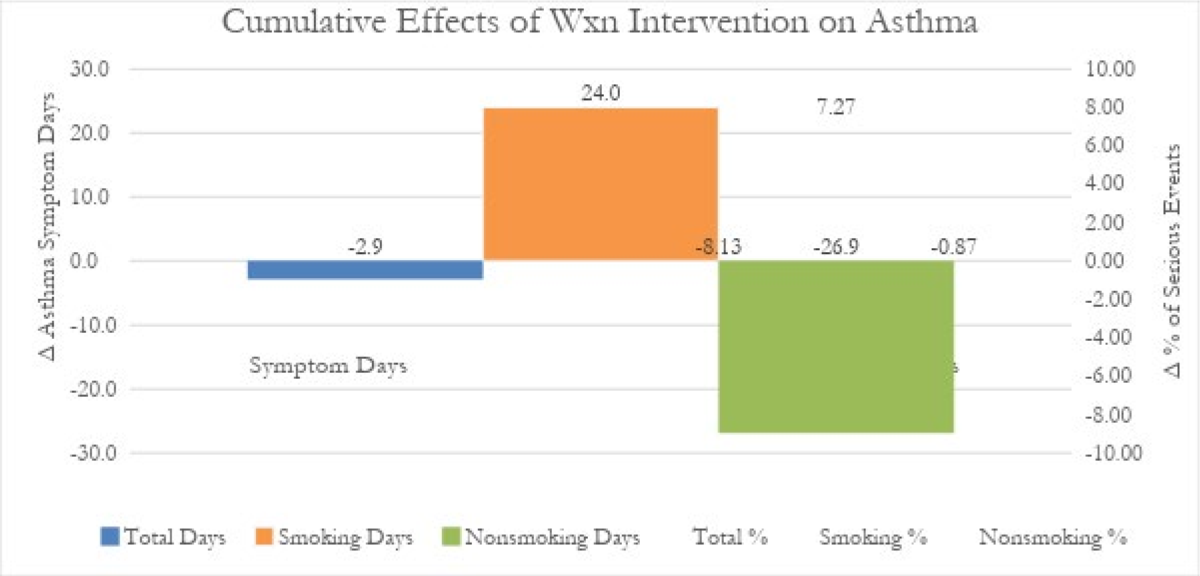


Figure 22. Cumulative effects of weatherization on asthma; symptom days, % serious events.

Energy Costs

Two methods were used to estimate energy savings within the homes: a representative energy savings, using available data from a national evaluation; and an estimate of convective energy savings using air sealing and ventilation data. Without energy bills from these homes these can only be considered estimates and should not be taken as exact energy savings.

Representative Energy Savings

Using information from the PY 2010 WAP National Evaluation, home characteristics from study homes were matched with evaluation data to calculate energy estimates for the study homes (Blasnik et al., 2015a; Blasnik et al., 2015b). Unfortunately, insufficient data exists from the National Evaluation to get reliable results for homes heated from Propane or Fuel Oil. This reduced the population number to 38 homes. Table 53 shows the representative energy savings for the homes.

Table 53. *Average Annual Representative Savings by National Average, Climate Zone, and # of Measures (MMBtus)*

Homes	n	National Average	By Climate Zone	By # of Measures
Natural Gas Site Built Home	4	17.14	15.69	22.91
Electric Site Built Home	15	6.28	6.60	7.79
Electric Manufactured	19	5.77	5.93	9.20

In each of these types of homes there was a wide variation in energy savings between the national average, climate zone breakdown, and number of measures performed. When looking at each of the homes individually during the cost comparison it made the most sense to look at each of the homes by their best- and worst-case scenario for energy savings. This gave an ample range with which to gauge possible energy savings. Of the three groups, savings by number of measures had the largest variation within the groups themselves. Figure 23 shows the distribution of savings by measure in Natural Gas Site Built Homes, Electric Site Built Homes, and Electric Manufactured Homes.

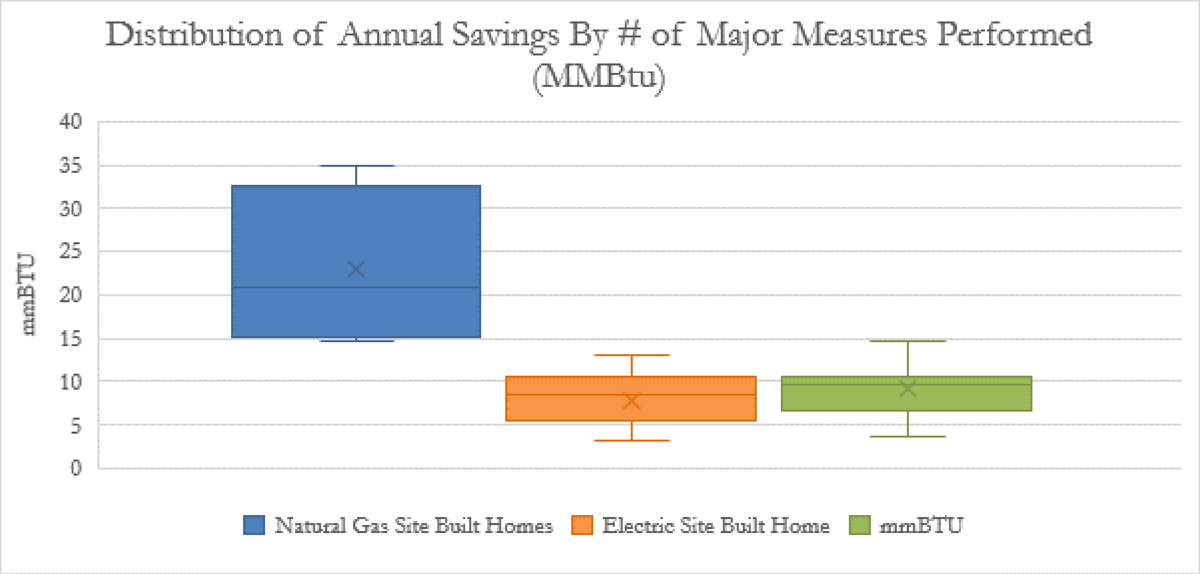


Figure 23. Annual savings by # of major measures preformed (MMBtu).

Although natural gas homes have significantly higher amounts of energy savings in terms of site MMBtus, the savings in terms of dollars is much different. Table 54 lays out the average savings in dollars for homes based on the representative energy savings.

Table 54. *Average Annual Representative Cost Savings by National Average, Climate Zone, and # of Measures (2016 US Dollars)*

Homes	n	National Average	By Climate Zone	By # of Measures
Natural Gas Site Built Home	4	$214.44	$196.30	$286.63
Electric Site Built Home	15	$213.48	$224.36	$264.81
Electric Manufactured	19	$196.15	$201.58	$312.74

As a cost savings level this leads to more consistent savings between Natural Gas and Electricity. Throughout all of the 38 homes that could successfully be calculated with this method, a significant cost savings was achieved throughout the homes. Figure 24 shows the total annual cost savings of all the homes broken down by type of home and heating source, and Figure 25 show the total annual cost among all homes.

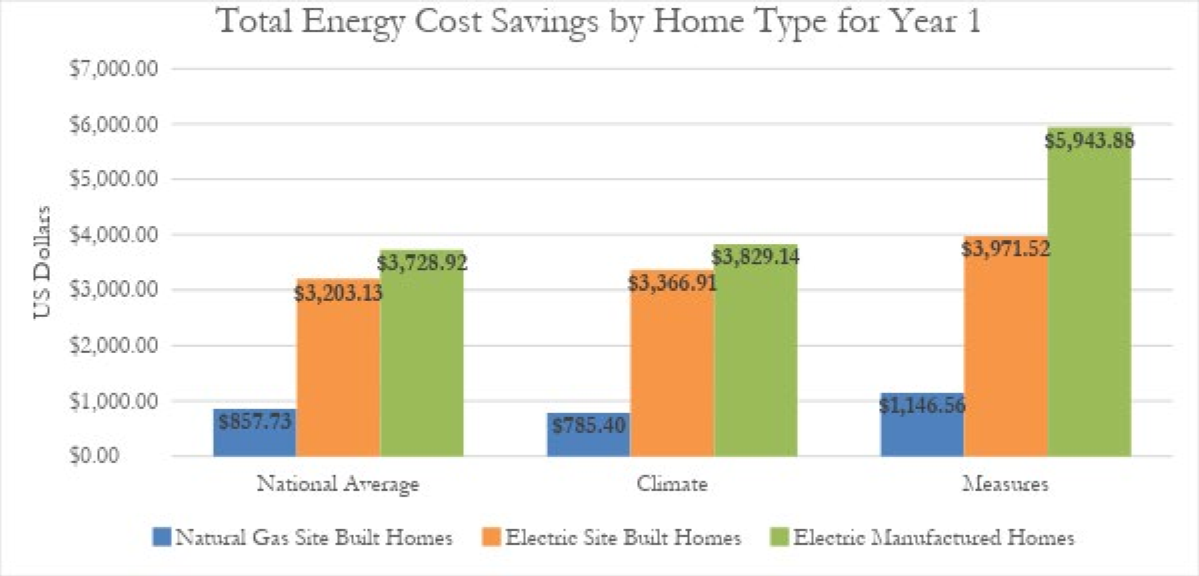


Figure 24. Total energy cost savings by home type for year 1.

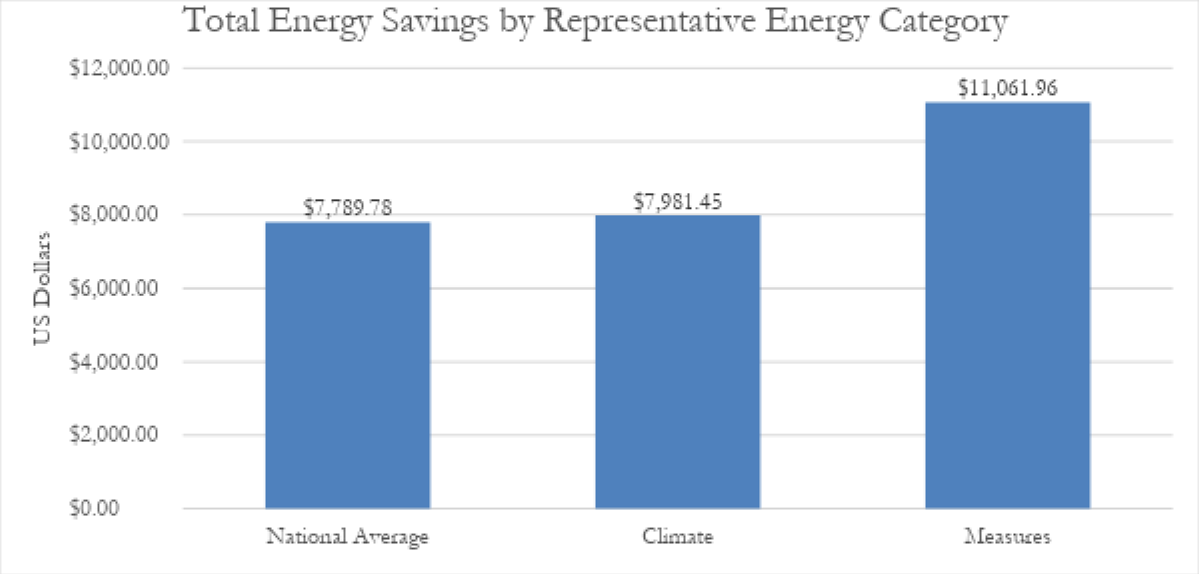


Figure 25. Total energy cost savings by representative energy category.

These representative energy savings show significant savings among each of the different types of homes and will be useful when comparing health savings impacts and costs later on.

Convective Energy Costs

One of the biggest concerns from energy auditors and weatherization professionals is the energy lost from adding ventilation to a home. It feels counterintuitive to put in work to increase air tightness of a building and then add a fan to pull air into the building; however, the addition of ventilation is vital for improving indoor air quality. While ventilation can add a serious energy penalty it is not as significant as thought. Table 55 shows the breakdown among the study homes of an estimate of the reductions in ACH for air sealing against the addition of ACH from ventilation.

Table 55. *Number of Homes by Air Sealing Change and Ventilation Categories*

Air Sealing Change	**n**	**n**	**Ventilation Category**
High (ACH >0.30)	10	12	High (ACH >0.30)
Medium (ACH 0.15-0.30)	13	16	Medium (ACH 0.15-0.30)
Low (ACH 0.0-0.15)	26	21	Low (ACH 0.0-0.15)
Average ACH	.190	.196	Average ACH

Figures 26 and 27 shows the additional Btu/hour, Btu/year, and yearly costs of conditioning the added air from ventilation.

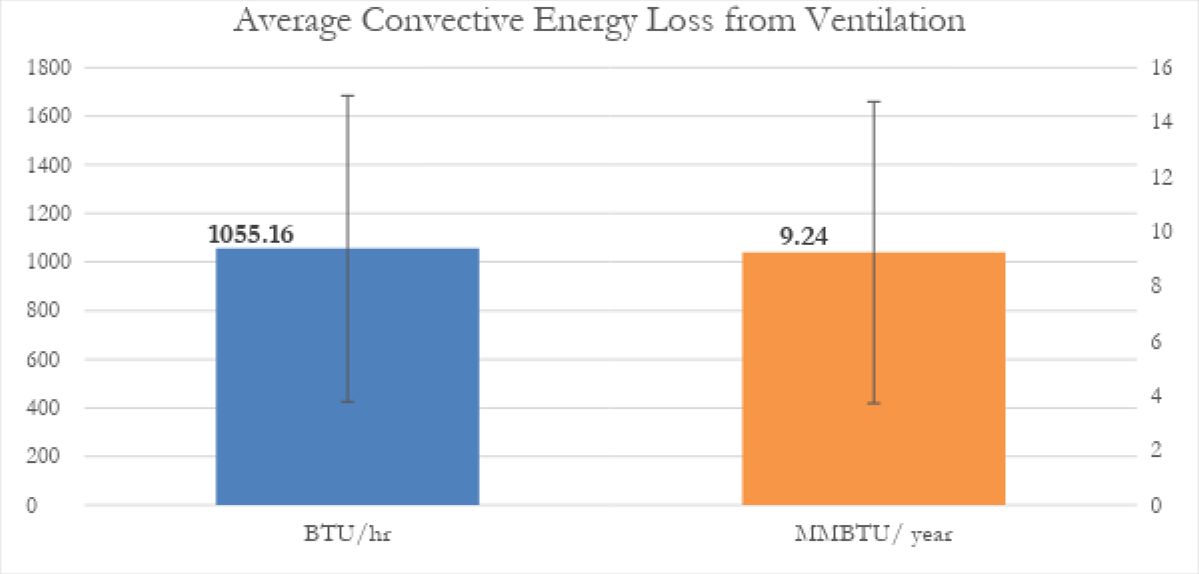


Figure 26. Convective energy loss from ventilation by hour and year.

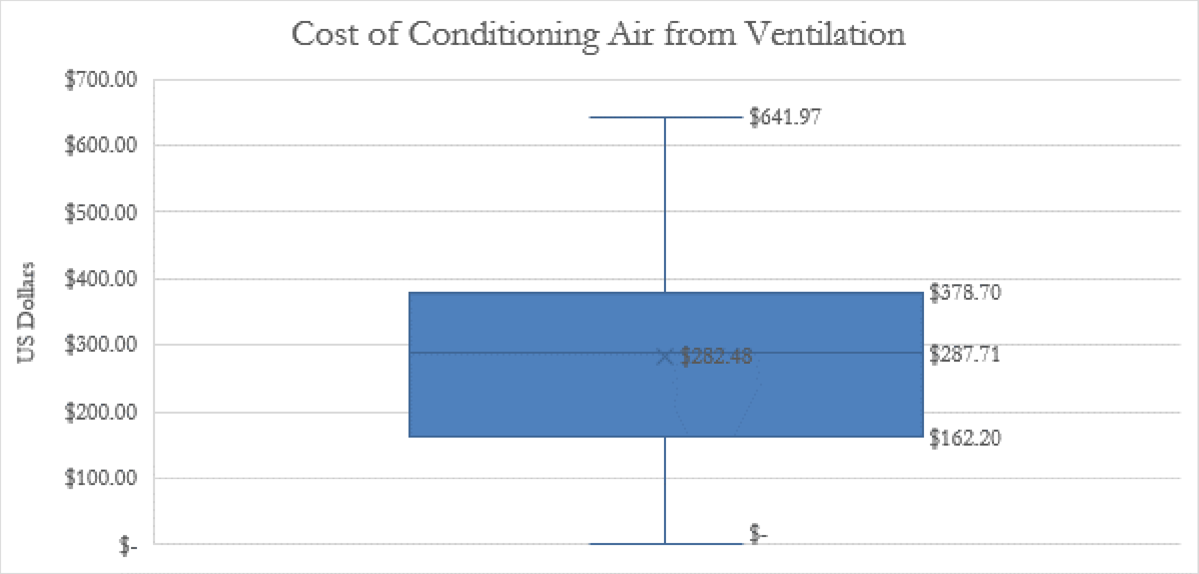


Figure 27. Average yearly cost of conditioning air from ventilation.

Although this may seem like a large amount of energy and money spent on conditioning the air from ventilation, it cannot be viewed as a standalone component. Using the exact same weather information, Figure 28 shows an approximation of the convective energy savings from air sealing within the homes in BTU/hr. and MMBtu/year. Figure 29 shows the average energy savings from air sealing.

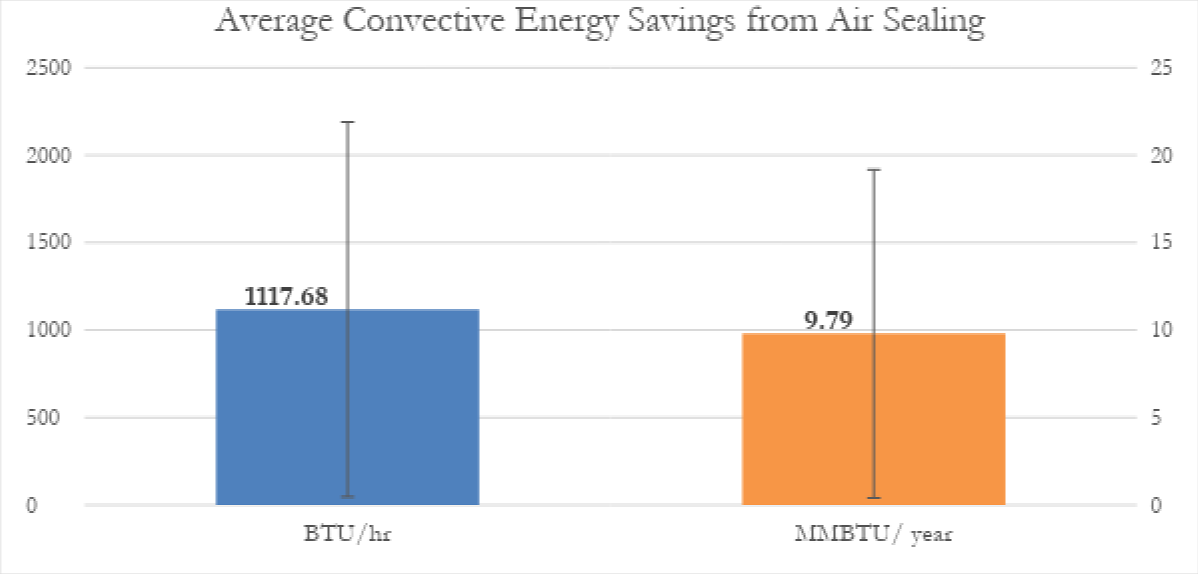


Figure 28. Average convective energy savings from air sealing.

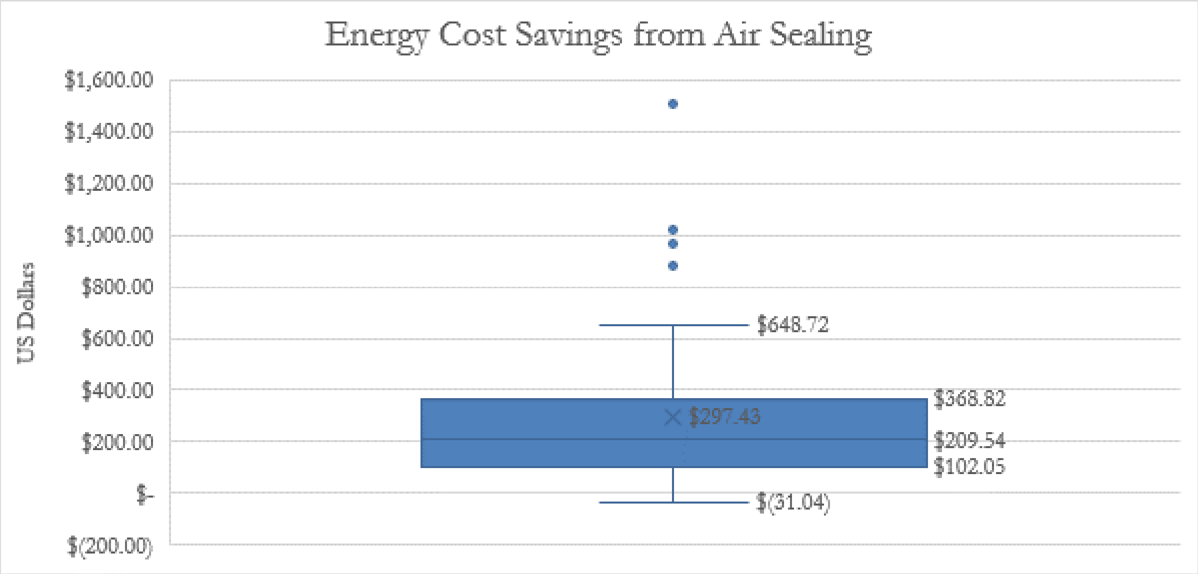


Figure 29. Distribution of energy cost savings from air sealing.

A direct comparison of energy and cost savings between air sealing and ventilation shows that even with the significant energy penalty from ventilation that energy is still being saved within the homes. Figure 30 shows the overall energy impact from the combination of air sealing and ventilation.

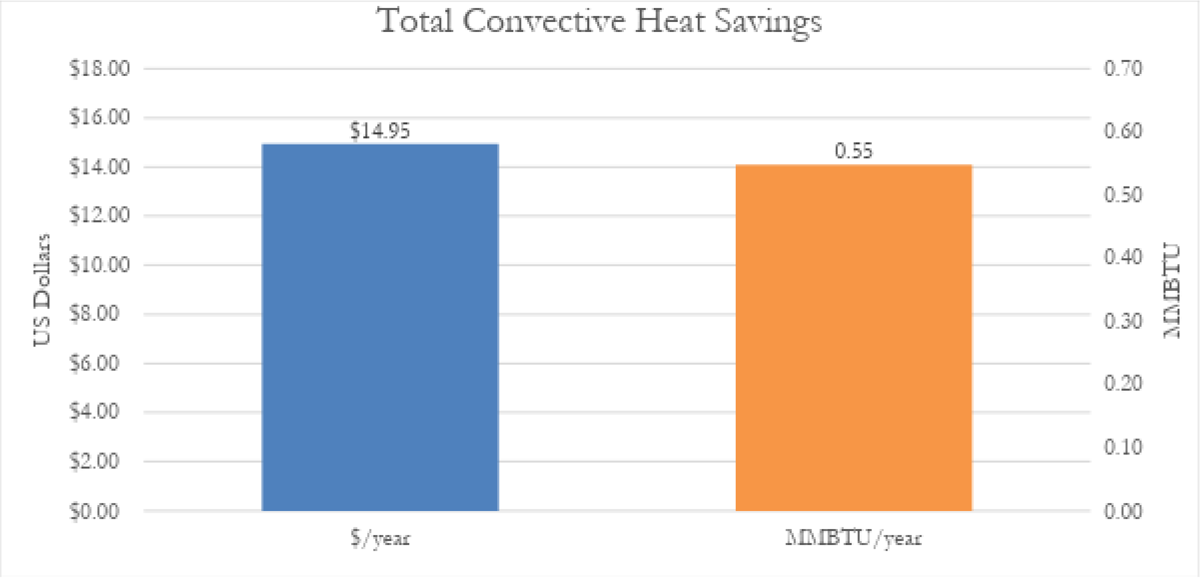


Figure 30. Total convective heat loss savings (air sealing – ventilation).

When done properly weatherization should end with an increase in controllable ventilation and a decrease in overall convective heat loss. This will lead to the potential for both energy savings and health impact savings.

Cost of Weatherization

Work orders, material lists, and reports from the Partner CAAs provide the costs and measures preformed in all of the study homes. The cost of weatherization can be broken down into three main categories: Energy, Health and Safety, and Administrative. Energy measures include items like air sealing, heating system replacement, insulation, and duct sealing, while health and safety measures include items like adding a CO alarm, installing an exhaust ventilation fan, repairing a crawl space vapor barrier, and repairing plumbing or electrical issues. Figures 31, 32, and 33 show the total costs, number of homes by cost per home, and average cost for individual homes, respectively, for each weatherization cost category.

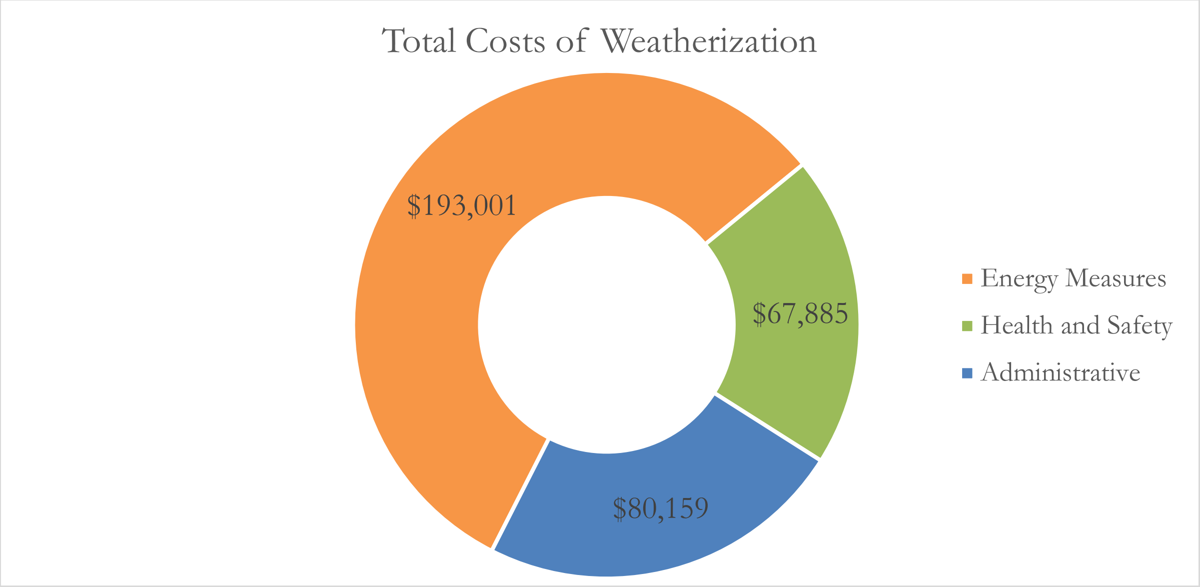


Figure 31. Total cost of weatherization.

At a total of $341,045 across the 49 homes within the study, 56.5% of funds were spent on energy measures, 20% of funds on health and safety measures, and 23.5% of funds allocated to administrative costs. These overall percentages provide potential insight into the allocations and priorities of weatherization agencies:

- Prioritization of energy measures over H&S measures
- Lack of available funding for performing health and safety measures
- Lower overall cost of H&S measures as compared to administrative costs

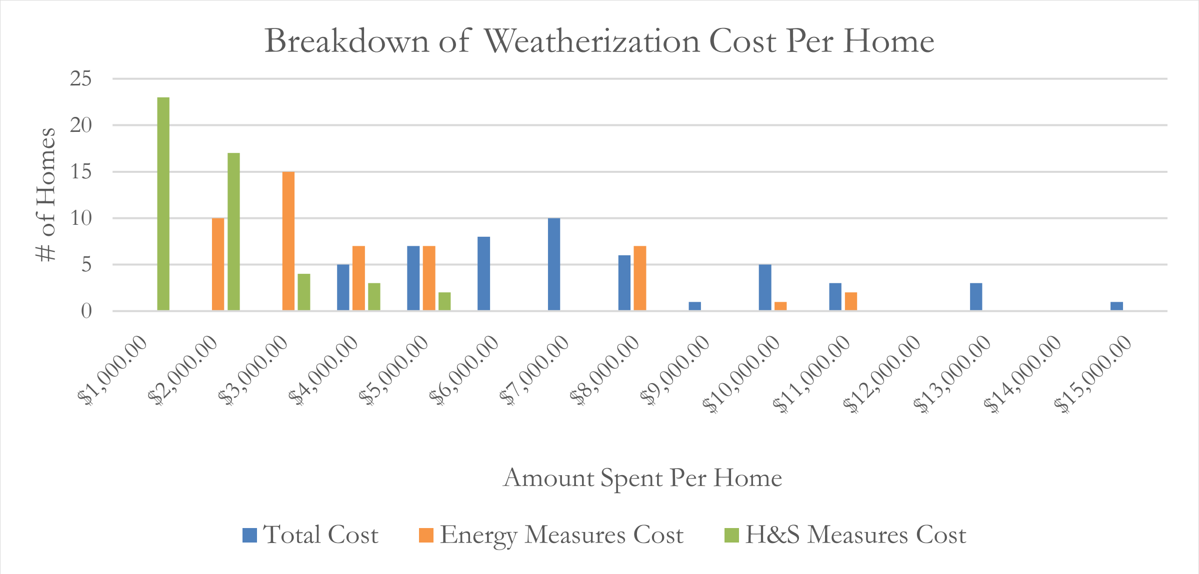


Figure 32. Histogram of cost per home by total and measure categories.

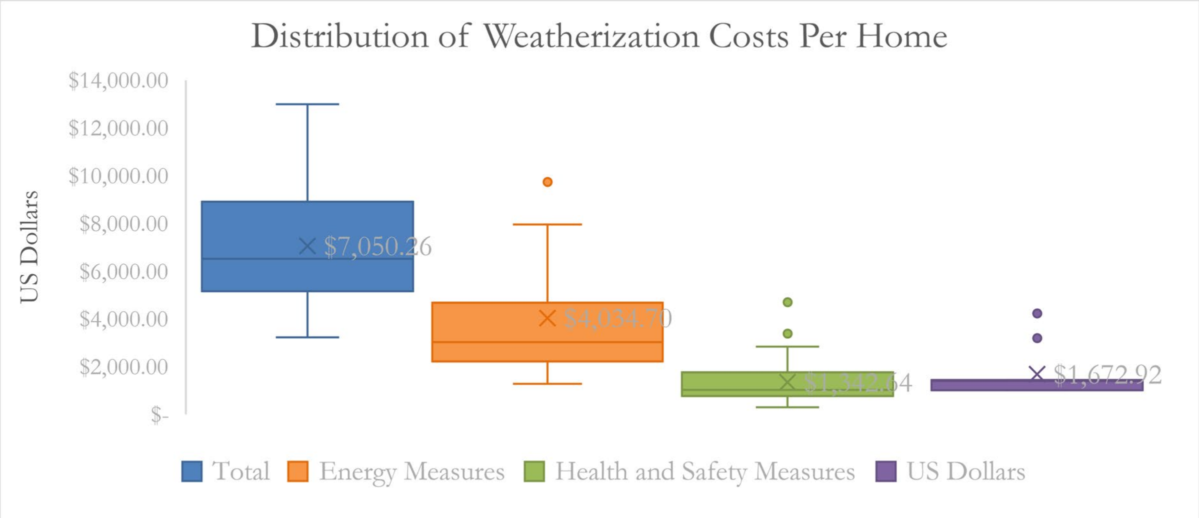


Figure 33. Distribution of costs per home by total and cost categories.

Figures 32 and 33 show greater spending on energy measures vs. health and safety improvements. This is expected since the main goal of the WAP is to increase the energy efficiency of homes and the secondary goal is to improve health and safety within the home. This shows that significantly more money was spent on energy measures but this could be explained by energy measures costing more than health and safety improvements, or simply fewer available interventions for Health & Safety.

Figures 34-36 show the total number of H&S improvements and Energy measures performed in study homes, and the average cost per home for H&S and Energy measures. Table 56 summarizes average weatherization cost information across all study homes.

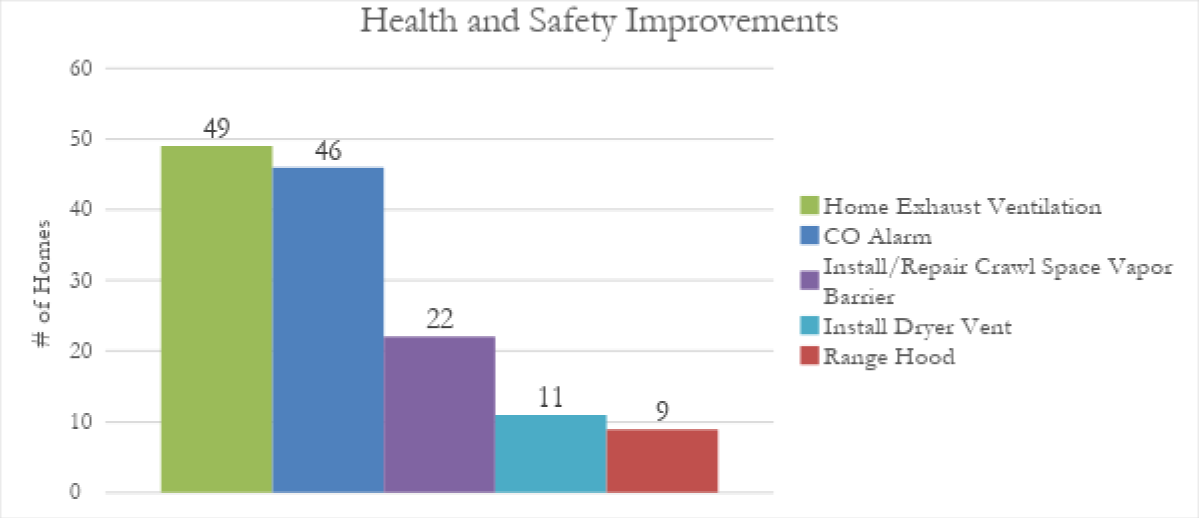


Figure 34. Total health and safety improvements.

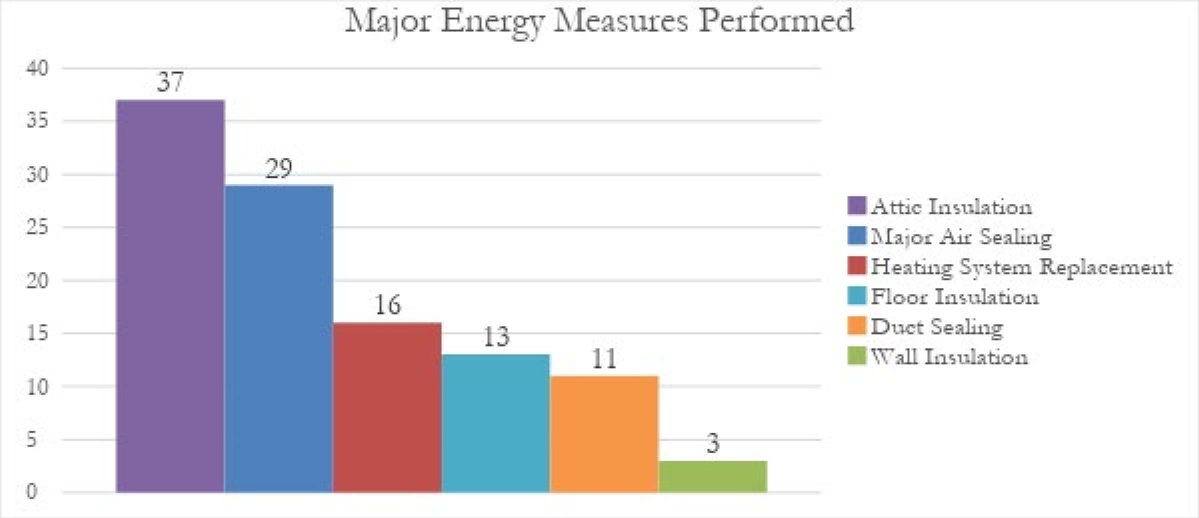


Figure 35. Total major energy measures performed.

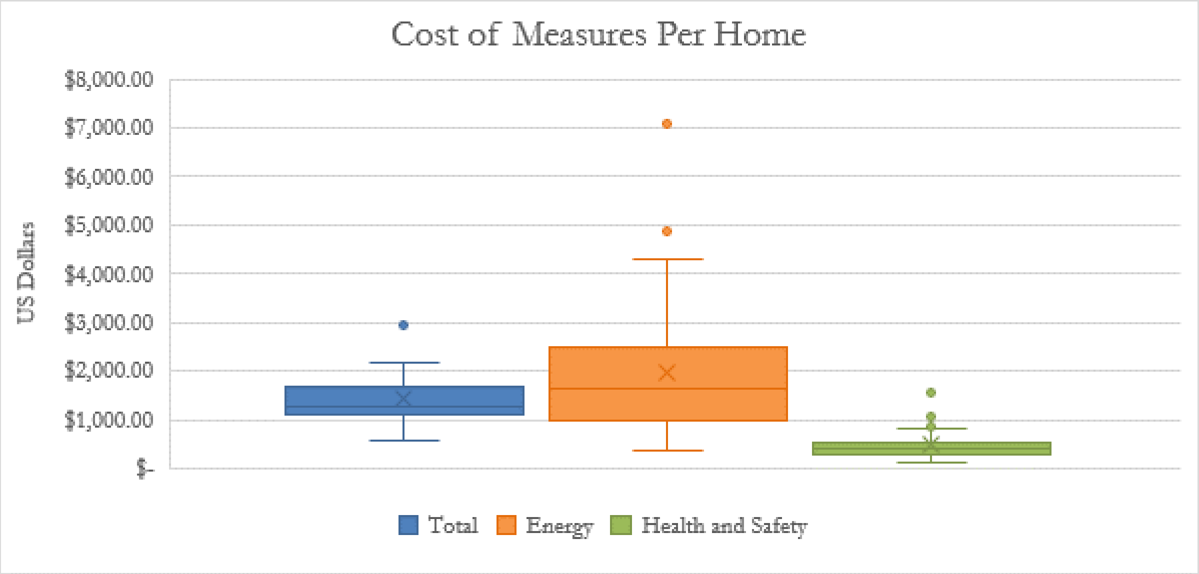


Figure 36. Distribution of cost per measure per home.

TABLE 56. *Amount and Cost of Measures Performed*

	Total Measures	Energy Measures	Health and Safety Improvements
Total Number	246	109	137
Average Per Home	5.0	2.2	2.8
Total Cost	$ 341,044	$ 193,000	$ 67,885
Average Cost Per Home	$ 6,960	$ 3,939	$ 1,385
Average Cost of Measure Per Home	$ 1,416	$ 1,986	$ 475

Looking through both the Energy Measures and Health and Safety Improvements, a consistent pattern emerged showing that more Health and Safety improvements are performed on each home, but these are generally lower cost than Energy Measures. This fit within the WAP Community Action Agencies' goals of improving the overall quality of life for their clients through increased energy efficiency.

Cost and Savings Comparison

Using the calculated health impacts, energy savings, and cost of weatherization we conducted a comparison to look for variables that influenced a maximum net benefit. Understanding that DALYs are an economic measure of lost productivity, while energy savings are direct consumer savings, will be a factor when considering which variables relate to the best overall impact.

Energy Cost Savings and DALY Economic Savings

Understanding the order of magnitude of these different savings is important. The overall comparison between the cost, representative energy savings, and the associated DALYs from these homes, shown in Figure 38, portrays a large difference in savings from these homes.

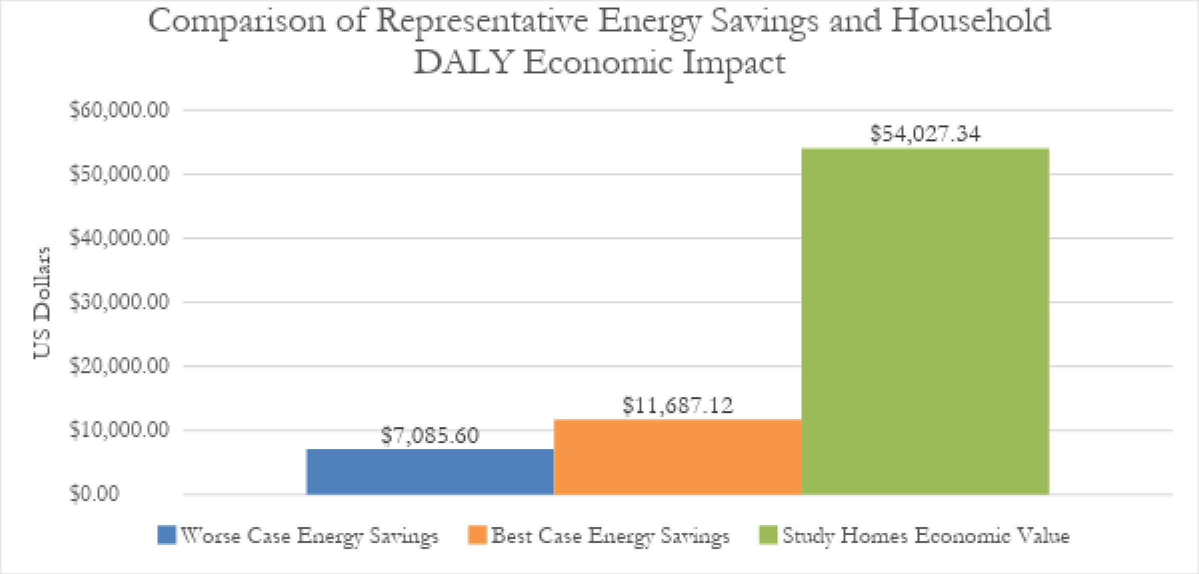


Figure 38. Total annual representative energy savings and DALY economic impact.

In Figure 38, we can see that the DALY value has a much higher impact across the 38 homes in the Energy Analysis data set. Recall that the low end of the range for DALY cost of life was approximately half of the value used for calculations in this study, which would still result in a DALY value that is higher than the best-case energy savings. From the previous analysis of DALYs and different household variables, energy measures, and health and safety improvements, a list of overall best to worst performing groups of household parameters is show in Table 57. The data presented compare economic value of changes in DALYs and best- and worst-case energy savings for each group.

Table 57. *Best to Worst Variable Grouping Comparing DALY and Energy Cost Savings*

Group and Variables	**n**	**Mean DALY Economic Value per Home**	**Mean Best Case Energy Savings**	**Mean Worst Case Energy Savings**
1. No smoking, no combustion, Dryer vent	6	$ 3,977.00	$293.00	$161.00
2. No smoking, no combustion	22	$ 2,978.00	$308.00	$189.00
3. No smoking	27	$ 2,617.00	$309.00	$188.00
4. No combustion	32	$ 1,380.00	$306.00	$187.00
5. Study population	38	$ 1422.00	$308.00	$186.00
6. Combustion Only	6	$ 1644.00	$316.00	$184.00
7. Smoking Only	11	$ -1512.00	$304.00	$184.00

While the DALY health impacts showed a significant effect across the group and variable categories, the best and worse energy savings were fairly consistent. Therefore, including even a partial value from DALYs into cost-benefit equations would generally show significant savings and an increase in the cost effectiveness of the WAP.

Cost of Weatherization, Energy Cost Savings, and DALY Economic Savings

A simple payback analysis was used to demonstrate just how large the savings from DALYs impact was on the overall cost effectiveness of weatherization. A simple payback looks at the money spent on improvements along with the annual money saved from the improvements (found in Figure 38) to calculate the number of years until the costs of the improvements are recovered.

Since participants within the WAP receive weatherization services at no cost, this exercise was performed to show the enormous impact that the DALYs have on calculating cost effectiveness. Figure 39 shows the reduction in years between energy savings only and energy plus DALY savings across the homes in the Representative Energy population. The inclusion of DALYs shows a substantial reduction in years until payback. When broken out into the non-smoking population you can also see a significant drop in the time for payback. Not shown is the negative payback for the smoking homes; the DALY economic impacts of smoking outweigh the energy savings and prevent a payback from ever being achieved.

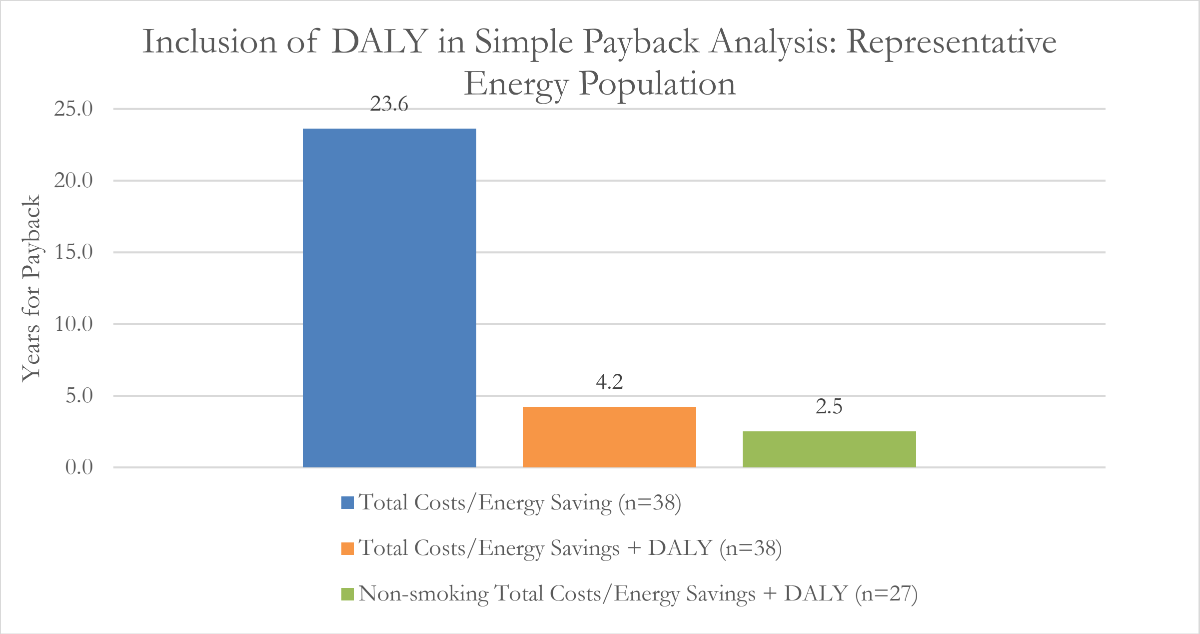


Figure 39. Impact of DALY on simple payback.

Although the simple payback is a quick method for analyzing the potential and timeline for a return on investment, it does not consider the cost of money and the long-term impacts of the investment in improvements. Analysis using a savings-to-investment ratio and net present value of the investment would allow for a better understanding of the cost effectiveness of weatherization.

By discounting both the best- and worst-case energy savings along with the DALY economic impact over an average lifetime of 10 years and comparing it with both the costs of energy measures and the total costs of weatherization, an accurate idea of the cost effectiveness of weatherization can be found. Table 58 shows the results of these calculations. The significant increase in the SIR with the addition of the economic value of the DALY would allow for an increase in spending per home to increase effective energy and health benefits on a larger scale.

Table 58. *Net Present Value and Savings to Investment Ratio for Energy and DALY Savings (n=38)*

	First Year Average Savings	**Present Value of Savings**	**Costs**	**Net Present Value**	**SIR**
Best Case Energy Savings	\$307.56	\$2,623.51	\$4007.70[1]	-\$1,384.19	.65
Worst Case Energy Savings	\$186.46	\$1,590.57	\$4007.70[1]	-\$2,417.13	.40
DALY Savings Study Population	\$1,421.77	\$12,128.01	\$7,266.13[2]	\$4,861.88	1.66
DALY Savings Smoking	- \$1.512.07	- \$12,898.26	\$7,266.13[2]	- \$20,164.39	-1.78
DALY Savings Non-Smoking	\$2,617.04	\$22,323.88	\$7,266.13[2]	\$15,057.75	3.07

[1] Energy measure costs of weatherization

[2] Total costs of weatherization

It is also important to note that even though the energy savings, with SIR less than 1, do not meet requirements for cost effectiveness, this category of savings from weatherization does reduce the high burden of energy bills typical of low income families.

CHAPTER 5: CONCLUSIONS

Within this chapter, the major findings of the study are summarized and compared with the existing literature, and how this information can inform policy decisions is explored. Insights for future research topics gained from conducting this study are expanded upon as well.

Summary of Findings

Using data collected from a HUD Healthy Homes study, a comparison of health impacts from changes in IAQ due to weatherization, energy savings, and cost of weatherization has been achieved. Three major findings from this study include: (1) monetized weatherization impact on health shows a net positive effect; (2) key variables that affect DALYs and Asthma Outcomes, in particular smoking, combustion appliances, and forced air systems; and (3) the relative magnitude of the economic impact of change in DALYs, energy savings, and weatherization costs.

Weatherization as a Health Intervention

The weatherization conducted for the study homes led to an average reduction of 0.00453 DALYs per home with an average economic benefit of $991 per home. This resulted in a total of $48,551.00 in economic benefit from weatherization across the 49 study homes. This positive impact shows that weatherization may have a potential benefit as a health intervention, especially for those within vulnerable populations such as asthma and COPD sufferers. It is important to note that across the study there were varying impacts from the IAQ changes across homes. Table 59 shows the number of homes with positive, minimal, and negative economic impact of changes in DALYs based on conditions before and after weatherization.

Table 59. *Change in DALYs Throughout Study Population*

Change in DALYs	**Number of Homes**	**Mean (SD) DALY**	**Total Economic Impact**
Decrease in DALYs (<-.01)	17	-0.0235 (0.0112)	$ 85,016.00
Minimal change (-.01 to .01)	22	-0.0009 (0.0078)	$ 4,319.00
Increase in DALYs (>.01)	10	0.0197 (0.0140)	$ -43,089.00

Fortunately, few homes saw minimal increase in DALYs, with 39 of the homes (80%) seeing a minimal change or decrease in DALYs from weatherization. This same trend, shown in Table 60, occurs in the asthma impact analysis, with the majority of homes (86%) having minimal change or decrease in asthma symptom days and serious events. Knowing which variables have the largest effects will allow for appropriate treatment options for asthma sufferers.

Table 60. *Change in Asthma Impacts Throughout Study Population*

Change in Asthma Impacts	**Number of Homes**	**Asthma Symptom Days**	**% Serious Event**
Decrease in Impacts (<-1 Days)	12	-2.66	-0.8%
Minimal change (-1 to 1)	30	-0.11	-0.03%
Increase in Impacts (>1 Day)	7	+4.60	+1.39%

Effect of Smoking and Combustion Appliances

The two variables with the largest effects on DALYs and asthma were smoking in the home and the presence of a combustion appliance. Throughout the different combinations of the study population these two continued to have a large effect. Across the whole population, smoking was the only variable to cause a statistically significant change within the study homes in both DALYs and asthma impacts. Unfortunately, smoking is a complicated public health issue, and it will take a multi-pronged approach to eliminate smoking and its effects on IAQ from within homes.

When separated into smoking vs. nonsmoking groups, the presence of combustion appliances and a forced air heating system showed a significant change within the nonsmoking study population. With the small sample size, it is difficult to make any definitive statement about the impact of forced air systems on indoor air quality; however, homes with combustion appliances showed a highly statistically significant change in DALYs. Therefore, removing the presence of unvented combustion appliances and increasing source exhaust ventilation are key to improving IAQ and reducing health risk.

Magnitude of DALYs

While monetizing DALYs cannot be taken as direct dollars saved by the occupant, the economic impact of DALYs is significant enough to consider inclusion into cost effectiveness evaluation for weatherization or other home intervention techniques. As concluded in the cost comparison discussion, DALYs have the possibility of delivering a significantly higher savings when added to energy savings, to the point of outweighing energy savings completely. As more research into the non-energy impacts of common energy savings techniques continues, this will be a valuable tool for judging effectiveness.

Relation to Existing Literature

This study worked to answer several questions that exist within the literature including:

- Can weatherization be a successful health intervention?
- What IAQ contaminants in the home are causing the largest health impacts?
- What is the best way to value the non-energy impacts (NEIs) of weatherization?

All of these issues form into the bigger question of what is the role of building science professionals when it comes to issues of health and IAQ? New studies are showing that energy efficiency has a large possibility to affect households outside of energy savings (E4 the Future, 2016).

Weatherization as a Health Intervention

Within the greater home performance community, weatherization is viewed as a series of methods and products, all with the end goal of increasing energy efficiency in the home. This study showed that weatherization can also have significant health impacts on household occupants, but in order to achieve a positive impact you must look at all factors within the home. Even with the WAP stated mission of “Increasing the energy efficiency of dwellings owned or occupied by low-income persons to … reduce their total residential expenditures, and improve their health and safety,” more of an effort should be made to view the home as a system rather than as separate energy-related components in order to maximize overall energy, health, and cost benefits (Weatherization Assistance for Low Income Persons, 2006, para. 1). This idea is consistent within the literature, and further research to value interventions within an integrated system is currently underway (Fabian et al., 2014; Hawkins et al., 2016, Rose et al., 2015). This study falls in between the current methods being performed. It does not go as far as some, which look to health care visits and Medicaid claims before and after weatherization, but with the collection of field data made use of actual data rather than modeled estimates to evaluate the effect of interventions. However, the collection of IAQ data within the home can inform both study types. Relying on information gleaned from health records and Medicaid claims is time intensive and difficult given privacy laws. It can also limit the population sample extensively, and provides limited information on what weatherization methods are providing the largest impacts within the home. Amassing IAQ data along with health information will allow for generalization to the larger population and will lead to increased understanding of what the major improvements and stressors within the home are. Rigidness within the software and incorrect assumptions can lead to unrealistic and unhelpful results. Results based on field data from this study can inform new modeling studies and increase the generalization of the results.

IAQ Contaminants and Largest Health Impacts

With a variety of different IAQ contaminants, understanding which have the largest effect on health can be difficult to tease out. The results from this study show that of the parameters studied, $PM_{2.5}$ has the largest impact on occupant health. This corroborates with an extensive study from Lawrence Berkley National Lab (Logue et al., 2012). The LBNL study looked at common air pollutants and their concentrations and used DALYs to rank their impact on the population. The study ranked, in order of highest health impact, $PM_{2.5}$, second-hand smoke, radon, formaldehyde, and acrolein as the five worst contaminants for occupant health. Our results showed $PM_{2.5}$ as having the highest health impact by a large margin. From Doll et al. (2016), $PM_{2.5}$ was the most likely contaminant to be out of compliance by a larger margin when compared to IAQ guidelines. This helps to explain the large divide between smoking and nonsmoking homes in terms of health impacts. Recall that Figure 12 showed the extremes in differences between each of the contaminants and showed that reducing $PM_{2.5}$ will go a long way towards improving the health impacts from IAQ.

Valuing NEIs of Weatherization

As efforts continue to value the NEIs from weatherization and energy efficiency measures, a standard methodology must be developed within the field. Currently three different methods exist for valuing these benefits: Medicare claims, surveying, and health impacts from IAQ pollutants (Hawkins et al., 2016, Rose et al., 2015, Logue et al., 2012). Each of these has their value within the larger understanding of the value of NEIs, but they all certainly have limitations as well. Exploring Medicare claims is the most stringent method for measuring health impacts from weatherization and shows directly the value of reduction in health care costs from weatherization. This method cannot show any impacts that do not involve direct interaction with a healthcare provider and cannot show impacts such as decreased stress or increased financial well-being. Surveying can capture the widest extent of impacts within the study populations and can be effective at teasing out new impacts that were previously unexplored. The major drawback with these surveys is that they require participants to understand and respond appropriately to the questions within the survey. Contacting appropriate populations to gain a baseline to compare to the sample population is another difficulty to overcome. Looking at changes in IAQ and their potential health impacts is a middle ground between these two methods. Collecting indoor air data can be time consuming, but not as difficult as acquiring health care information. DALYs can also present more quantitative results than surveying information. However, like collecting Medicaid information, IAQ information can be limited in the scope it provides. This study chose this method because of the ability to compare home variables and the impact of methods. Each strategy has its strengths and weaknesses when valuing all of the NEIs from weatherization, and ultimately all three methods should be used in conjunction when possible.

DALYs as a Consistent Metric

Currently DALYs are used significantly more when looking at a global burden of disease within developing countries; however, these results show that this metric can be an effective tool for evaluating the effectiveness of building interventions from a health standpoint. Increased use of this tool can push the home performance industry towards developing innovative solutions focused on a more holistic impact from their products and methods. Pushing for this level of analysis across the industry will allow for a standard metric for comparison in common building performance issues. The sensitivity of this metric can accommodate for even small changes with indoor air quality in the home and as more and more low-hanging fruit within the building performance industry becomes standard, methods for judging new products and ideas will be paramount. Before the DALY can be used as a metric more work needs to be done on selecting consistent and repeatable variables on the economic impact of the DALY.

Policy Implications

Three key policy suggestions came out of this study: (1) develop new methods for smoking homes, (2) reduce the effect of combustion appliances on IAQ, and (3) increase emphasis of compliance with IAQ guidelines.

Smoking and Combustion Appliances

Two factors within a home had the majority of the effect on DALYs and asthma impacts across the study population. Reducing the effect of both of these variables within homes can have the largest impact for increasing the health benefits of weatherization. Currently no policy exists for differentiating between smoking and nonsmoking homes in respect to weatherization. While smoking bans can be an effective method for decreasing particulates and second-hand smoke within multifamily buildings, it is unreasonable to expect homeowners or tenants to place a ban on themselves. With this in mind, new methods need to be developed to treat these homes in a way that does not cause a detrimental effect on the occupant. If the approach for reducing the impact of smoking was to add more standard exhaust fan ventilation, the energy penalty would be extreme, which would negatively influence compliance by the occupant. This opens the possibility of recovery ventilators being re-examined within ventilation standards to increase fresh air exchange with a reduced energy penalty. Working with the public health community, new ideas and methodologies to reduce the impact of smoking must occur.

Smoking is a behavioral issue, which increases the difficulties associated with making significant change, but the presence of combustion appliances is a physical characteristic of the home that is more easily remedied. The biggest culprits, among combustion appliances, for introducing contaminants into the home are unvented combustion heaters and gas stoves. WAP has policies in place to eliminate unvented combustion heaters to reduce the risk of CO poisoning, but minimal emphasis has been placed on reducing the chronic effect of gas stoves on occupants. Homes are required to be equipped with a vented range hood under ASHRAE 62.2, but the large effect still remains (ASHRAE, 2010c). Researchers at LBNL have put significant effort towards understanding the capture efficiency of range hoods and developing standards that manufacturers understand (Delp & Singer, 2012). This is a significant step forward but still requires that occupants regularly use and maintain this equipment. New policies should focus on increasing the effectiveness of range hoods through better design, noise reduction, and if necessary removing control from the occupants.

100% Compliance

From looking through the IAQ guidelines and compliance information reported by Doll et al. (2016), a significant number of homes within this study were shown to be out of compliance for formaldehyde and particulate matter. A quick look at Figure 2 shows that only 10% of pre-weatherization homes and less than 15% of the post-weatherization homes were compliant with the 15 $\mu g/m^3$ guidelines for particulate matter, and none of the smoking homes were compliant pre- or post-weatherization. This study and a few others have shown that across the board weatherization is not having an overall negative impact on the indoor environment, but there is still significant progress to be made in IAQ (Doll et al., 2016; Pigg et al., 2014). By slightly adjusting the data set so that all post-weatherization homes are compliant with IAQ guidelines for $PM_{2.5}$, NO_2, and formaldehyde, we can see the potential benefits from bringing all homes into 100% compliance. Figure 40 showcases these results by showing the difference in DALY savings between the study population and the hypothetical 100% compliant post-weatherization population.

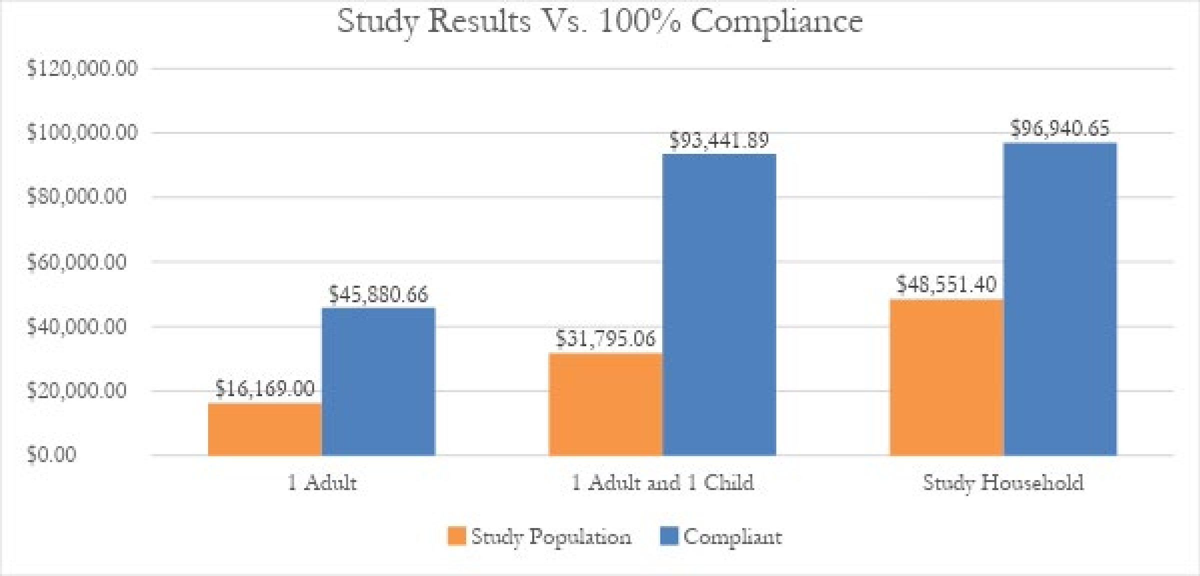


Figure 40. Annual DALY economic impact savings.

This significant difference shows how immense the possible savings could be and that much more work needs to be done to reach these levels of savings. Reaching this goal will be very difficult and would require a significant push from building science and public health professionals. Table 61 lays out a possible strategy for bringing these homes into compliance. In this table, BS stands for Building Science and PH stands for Public Health. Hypothetical feasibility is ranked on a scale from 1-5, with 1 being low effort and possible, while 5 is high effort and currently not possible.

Table 61. *Strategies for Increasing IAQ Guideline Compliance in Weatherization (Wxn) Homes*

Strategies	Responsible Party	Outcome	Hypothetical Feasibility
1. Eliminate smoking in homes through education and bans.	PH	Reduce ETS and particle levels.	5+
2. Change ASHRAE 62.2 Standard to account for smoking and combustion appliances.	BS	Increase fresh air in homes that need it most. Energy expenditure is unknown.	4-5
3. Remove and replace non-direct vented combustion appliances from the home.	BS	Reduce particle and NO_2 levels within the homes. Increase cost of Wxn.	4-5
4. Increase effectiveness and reduce price of ventilation equipment	BS	Increase fresh air in homes. Possible increased energy expenditure.	3
5. Educate to gain 100% compliance for source pollutant exhaust fans	BS & PH	Decrease particle, VOC, and humidity levels at the source to prevent spread.	2-3
6. Advocate for the increase of the WAP budget to allow for added H&S Improvements	BS & PH	Increase training and ability of Wxn professionals and improve homes.	2-3
7. Expanded studies into Wxn, IAQ, and Health. Focus on impacted populations.	BS & PH	Increased understanding of relationship between Wxn and health.	2-3
8. Include low cost air filtration systems as a H&S Improvements	BS	Reduction of particle load within local airs in the home.	2-3
9. Innovative methods to increase source pollutant exhaust fan use	BS	Decrease particle, VOC, and humidity levels at the source. Possible occupant dissatisfaction from lack of control.	1-2

None of these strategies are the perfect solution to improving IAQ and health within low income and impacted populations, but increased work needs to be done. Based on the variables that caused the largest impact on health values (smoking, combustion appliances, and forced air), these strategies focus on combating $PM_{2.5}$ The first step in moving forward is to increase partnerships with building science and public health professionals. Each of these groups has relevant expertise and advice to share with the other, thus facilitating working partnerships and outcomes such as the BPI Healthy Home Evaluator, that will increase energy efficiency and promote healthy homes and occupants at the same time.

Future Research Opportunities

This study has shown that information is lacking when looking to understand health impact within homes. The following are potential future research opportunities to expand the field.

Indoor airPLUS Verification Study

Indoor airPLUS is a certification offered by the EPA for new construction homes. It follows accepted best practices for improving the IAQ within homes; however, little has been done to verify that these homes are actually seeing reductions in pollutants when compared to the existing housing stock or to new code-minimum homes. Collecting IAQ data within Indoor airPLUS homes along with code homes, and using methods similar to those described in this thesis, could show the potential benefit to homeowners and builders looking to pursue this certification.

Modeling Long-Term Impact of Weatherization Measures on Single Family Homes

Currently available information on the long-term impact of weatherization on IAQ within a home is limited. Modeling homes from within this study using CONTAM could provide some clarity into the long-term impact of weatherization as it relates to IAQ and the associated potential health impacts. Using the methods detailed by Fabian et al. (2014), a similar model could be developed for low-income single family homes. This model could be used to model the effectiveness of different building interventions on the home, as well as the impact of compliance when using exhaust fans in the home.

Year-long IAQ Data Collection Study

Currently most indoor sampling for pollutants is done in short bursts over days or at most weeks. While this can tell us a lot about the home it does little to tell us about the yearly contaminant levels or about when there are fluctuations in contaminants throughout the year. Consistently sampling within homes over an extended period of time can tell us more about what the overall effect of interventions may be, as well as whether current sampling techniques are providing useful information.

A Predictive Model for Estimating Year IAQ Contaminant Levels and Health Impact

Understanding that it is financially and logistically difficult to have long-term IAQ sampling within a home, what if software could be developed to provide yearly estimates of IAQ levels? A program similar to REM/Rate or BeOPT could, with specific inputs, provide information about year-round IAQ levels. Pulling together information such as short-term IAQ testing, location, building characteristics and performance information, and self-reported occupant behavior to model long-term results could lead to a moderately accurate measure of long-term IAQ levels.

Each of these different studies could provide relevant information to the building industry and to public health professionals, as both work to reduce health risks and improve indoor air quality while also reducing energy and health care costs for occupants.

REFERENCES

Abbey, D.E., Ostro, B.E., Petersen, F., & Burchette, R.J. (1995). Chronic respiratory symptoms associated with estimated long-term ambient concentrations of fine particulates less than 2.5 microns in aerodynamic diameter (PM2.5) and other air pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, *5*(2), 137-159.

Adamkiewicz, G., Spengler, J.D., Harley, A.E., Stoddard, A., Yang, M., Alvares-Reeves, M., & Sorensen, G. (2014). Environmental conditions in low-income urban housing: clustering and associations with self-reported health. *American Journal of Public Health*, *104*(9), 1650-1656.

Ahrentzen, S., Erickson, J., & Fonseca, E. (2016). Thermal and health outcomes of energy efficiency retrofits of homes of older adults. *Indoor Air*, 26(4), 582–593. doi: 10.1111/ina.12239

Akinbami, L.J., Lynch, C.D., Parker, J.D., & Woodruff, T.J. (2010). The association between childhood asthma prevalence and monitored air pollutants in metropolitan areas, United States, 2001-2004. *Journal of Environmental Research*, 111, 294-301. DOI: 10.1016/j.envres.2010.01.001

American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). (2010a). *ANSI/ASHRAE Standard-62.1: Ventilation for acceptable indoor air quality*. Atlanta, GA: ASHRAE.

American Society of Heating, Refrigeration, and Air Conditioning Engineers. (2010b). *ANSI/ASHRAE Standard 55: Thermal environmental conditions for human occupancy*. Atlanta, GA: ASHRAE.

American Society of Heating, Refrigeration, and Air Conditioning Engineers. (2010c). *ANSI/ASHRAE Standard-62.2: Ventilation and acceptable indoor air quality in low-rise residential buildings*. Atlanta, GA: ASHRAE.

American Society of Heating, Refrigeration, and Air Conditioning Engineers. (2013). *2013 ASHRAE handbook fundamentals*. Atlanta, GA: ASHRAE.

Anderson, M.S. (2017). Co-benefits of climate mitigation: Counting statistical lives or life-years? *Ecological Indicators*, 79, 11-18. doi: 10.1016/j.ecolind.2017.03.051

Bensch, I., Keene, A., Cowan, C., & Koski, K. (2014). *National Weatherization Assistance Program characterization: Describing the pre-ARRA program*. Retrieved from http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2013_188.pdf

Blasnik, M., Dalhoff, G., Carroll, D., & Ucar, F. (2014a). *National Weatherization Assistance Program impact evaluation: Energy impacts for mobile homes*. Retrieved from http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_84.pdf

Blasnik, M., Dalhoff, G., Carroll, D., Ucar, F., & Bausch, D. (2015a). *Evaluation of the Weatherization Assistance Program during program years 2009-2011 (American Recovery and Reinvestment Act period): Energy impacts for single family homes*. Retrieved from http://weatherization.ornl.gov/RecoveryActpdfs/ORNL_TM-2014_582.pdf

Blasnik, M., Dalhoff, G., Carroll, D., Ucar, F., Bausch, D., & Johnson, D. (2015b). *Evaluation of the Weatherization Assistance program during program years 2009-2011 (American Recovery and Reinvestment Act Period): Energy impacts for mobile homes*. Retrieved from http://weatherization.ornl.gov/RecoveryActpdfs/ORNL_TM-2014_558.pdf

Blasnik, M., Dalhoff, G., Pigg, S., Mendyk, A., Carroll, D., & Ucar, F. (2014b). *National Weatherization Assistance Program impact evaluation: Energy impacts for single family homes*. Retrieved from http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2015_13.pdf

Braithwaite, R. S., Meltzer, D. O., King, J. T., Leslie, D., & Roberts, M. S. (2008). What does the value of modern medicine say about the $50,000 per quality-adjusted life-year decision rule? *Medical Care*, 46(4), 349–356.

Breysse, J., Dixon, S.L., Jacobs, D.E., Lopez, J., & Weber, W. (2015). Self-reported health outcomes associated with green-renovated public housing among primarily elderly residents. *Journal of Public Health Management Practice*, *21*(74), 355-367. doi: 10.1097/PHH.0000000000000199

Brown, D.W. (2008). Economic value of disability-adjusted life years lost to violence: Estimates for WHO member states. *Pan American Journal of Public Health*, *24*(3), 203-209. doi: 10.1590/S1020-49892008000900007

Burnett, R.T., Smith-Doiron, D., Stieb, D., Cakmak, S., & Brook, JR. (1999). Effects of particulate and gaseous air pollution on cardiorespiratory hospitalizations. *Archives of Environmental Health*, *54*(2), 130-139.

Campbell-Lendrum, D.H. & Woodruff, R. (2007). *Climate change: Quantifying the health impact at national and local levels.* Geneva, Switzerland: World Health Organization Public Health and the Environment. Retrieved from http://apps.who.int/iris/bitstream/10665/43708/1/9789241595674_eng.pdf

Carroll, D., Berger J., Miller, C., & Driscoll, C. (2015). *National Weatherization Assistance Program impact evaluation -- baseline occupant survey: Assessment of client status and needs*. Retrieved from http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2015_22.pdf

Crocker, D.D., Kinyota, S., Dumitru, G.G. Ligon, C.B., Herman, E.J., Ferdinands, J.M. …Sipe, T.A. (2011). Effectiveness of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity a community guide systematic review. *American Journal of Preventive Medicine, 41*(2), S5-S32. doi: 10.1016/j.amepre.2011.05.012

Delp, W.W. & Singer, B.C. (2012). *Performance assessment of U.S. residential cooking exhaust hoods*. Berkeley, CA: Lawrence Berkeley National Laboratory. Retrieved from https://buildings.lbl.gov/sites/all/files/lbnl-5545e.pdf

Drehobl, A., & Ross, L. (2016). *Lifting the high energy burden in America's largest cities: How energy efficiency can improve low income and underserved communities*. Retrieved from http://energyefficiencyforall.org/sites/default/files/Lifting%20the%20High%20Energy%20Burden_0.pdf

Doll, S.C., Davidson E.L., & Painting B.R. (2016). Weatherization impacts and baseline indoor environmental quality in low income single-family homes. *Building and Environment*, 107, 181-190. doi: 10.106/j.buildenv.2016.06.021

Eggleston, K.N., Shah, N.D., Smith, S.A. Berndt, E.R., & Newhouse, J.P. (2011). Quality adjustment for health care spending on chronic disease: Evidence from diabetes treatment, 1999-2009. *American Economic Review*, *101*(3), 206-211. doi: 10.1257/aer.101.3.206

E4 the Future. (2016). *Occupant health benefits of residential energy efficiency*. Retrieved from: https://e4thefuture.org/wp-content/uploads/2016/11/Occupant-Health-Benefits-Residential-EE.pdf

Fabian, M.P., Adamkiewicz, G., Stout, N.K., Sandel, M., & Levy, J.I., (2014). A simulation model of building intervention impacts on indoor environmental quality, pediatric asthma, and costs. *Journal of Allergy and Clinical Immunology*, *133*(1), 77-84. Retrieved from http://dx.doi.org/10.1016/j.jaci.2013.03.003

Fisk, W.J., Faulkner, D., Paloen, J., Seppanen, O., (2002). Performance and costs of particle air filtration technologies. *Indoor Air, 12(4),* 223-234.

Frey, S.E., Destaillats, H., Cohn, S., Ahrentzen S., & Fraser, M.P. (2015). The effects of an energy efficiency retrofit on indoor air quality. *Indoor Air,* 25, 210-219. doi:10.1111/ina.12134

Fuhlbrigge, A.L., Weis, S.T., Kuntz, K.M., & Paltiel, A.D. (2006). Forced expiratory volume in 1 second percentage improves the classification of severity among children with asthma. *PEDIATRICS,* 118, e347-e355. doi:10.1542/peds.2005-2962

Hasselblad, V., Eddy, D.M., & Kotchmar, D.J. (1992). Synthesis of environmental evidence - nitrogen dioxide epidemiology studies. *Journal of Air and Waste Management*, *42*(5), 662-671.

Hawkins, B.A, Tonn, B.E., Rose, E.M, Clendenning, G., & Abraham, L., (2016). *Massachusetts special and cross-cutting research area: Low-income single-family health and safety related non-energy impacts (NEIs) study*. Retrieved from http://www.threecubed.org/publications.html

Herbarth, O., Matysik, S., (2010). Decreasing concentrations of volatile organic compounds (VOC) emitted following home renovations. *Indoor Air, 20*(2), 141-146. doi: 10.1111/j.1600-0668.2009.00631.x

Hirth, R. A., Chernew, M. E., Miller, E., Fendrick, A. M., & Weissert, W. G. (2000). Willingness to pay for a quality-adjusted life year. *Medical Decision Making*, 20(3), 332–342. doi: 10.1177/0272989X0002000310

Hong, K.-S., Saver, J.L., Kang, D.-W., Bae, H.-J., Yu, K.-H., Koo, J …Lee, B.C. (2010). Years of optimum health lost due to complications after acute ischemic stroke: Disability-adjusted life-years analysis. *Stroke*, *41*(8), 1758-1765. doi: 10.1161/STROKEAHA.109.576066

Huijbregts, M.A.J., Rombouts, L.J.A., Ragas, A.M.J., & van de Meent, D. (2005). Human-toxicological effect and damage factors of carcinogenic and noncarcinogenic chemicals for life cycle impact assessment. *Integrated Environmental Assessment and Management, 1*(3): 181-244.

Industrial Economics, Incorporated (IEc). (2010). *Health and welfare benefits analyses to support the second section 812: Benefit-cost analysis of the clean air act.* Cambridge MA: IEc.

Kent State University Library. (2017). *SPSS tutorials.* Retrieved from http://libguides.library.kent.edu/SPSS

Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P. … Engelmann, W.H. (2001). The national human activity pattern survey (NHAPS): A resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, 11, 231-252. doi: 10.1038/sj.jea.7500165

Krigger, J. & Dorsi, C. (2013). *Residential energy: Cost savings and comfort for existing buildings* (6th ed.). New York, NY: Pearson.

Logue, J., Price, P., Sherman, M., & Singer, B. (2012). A method to estimate the chronic health impact of air pollutant in U.S. residences. *Environmental Health Perspectives*, *120*(2), 216-222. doi: 10.1289/ehp.1104035

Lvovsky, K., Huges, G., Maddison, D., Ostro, B., & Pearce, D. (2000). *Environmental costs of fossil fuels: A rapid assessment method with application to six cities.* Washington, D.C.: The World Bank Environment Department.

Melse, J.M., Essink-Bot, M.L., Kramers, P.G.N., & Hoeymans, N. (2010). A national burden of disease calculation: Dutch disability-adjusted life-years. *American Journal of Public Health 90*(8), 1241-1247.

Merrill, C.T. & Elixhauser, A. (2005) *Hospitalization in the United States: HCUP fact book no. 6.* Rockville, MD: Agency for Healthcare Research and Quality.

Murray, C.L. & Lopez, A.D. (1996). *The global burden of disease: A comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020.* Cambridge, MA: Harvard University.

National Ambient Air Quality Standards (NAAQS). 2000. 40 CFR 50.

National Renewable Energy Laboratory. (2015). National solar radiation data base typical meteorological year 3 [Data file]. Retrieved from http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

Neumann, P.J., Cohen, J.T., & Weinstein, M.C. (2014). Updating cost-effectiveness – the curious resilience of the $50,000-per-QALY threshold. *New England Journal of Medicine,* 371, 796-797. doi: 10.1056/NEJMp1405158

North Carolina Department of Environmental Quality (NCDEQ). (2016). *Weatherization assistance program forms and reports.* Retrieved from https://deq.nc.gov/about/divisions/energy-mineral-land-resources/weatherization-assistance-program-back-office

North Carolina Weatherization Assistance Program. (2012). *North Carolina weatherization installation standard work specifications.* Retrieved from https://ncdenr.s3.amazonaws.com/s3fs-public/Energy%20Mineral%20and%20Land%20Resources/Energy/WAP%20Back%20Office%20Documents/NCWAP%20Installation%20SWS%20Final%2007202015.pdf

O'Connor, G. T., Neas, L., Vaughn, B., Kattan, M., Mitchell, H., Crain, E. F. … Lippmann, M. (2008). Acute respiratory health effects of air pollution on children with asthma in US inner cities. *The Journal of Allergy and Clinical Immunology*, 121(5), 1133–1139e1.

Pearlman, D. S., Chervinsky, P., LaForce, C., Seltzer, J. M., Southern, L. D., Kemp, J. P., … van As, A. (1992). A Comparison of Salmeterol with Albuterol in the Treatment of Mild-to-Moderate Asthma. *The New England Journal of Medicine*, 327(20), 1420–1425. doi: 10.1056/NEJM199211123272004

Pearlman, D. S., Ostrom, N. K., Bronsky, E. A., Bonuccelli, C. M., & Hanby, L. A. (1999). The leukotriene D 4 -receptor antagonist zafirlukast attenuates exercise-induced bronchoconstriction in children. *The Journal of Pediatrics*, 134(3), 273–279. doi: 10.1016/S0022-3476(99)70449-X

Pigg, S., Cautley, D., Francisco, P., Hawkins, B., & Brennan, T. (2014). *Weatherization and indoor air quality: Measured impacts in single-family homes under the weatherization assistance program.* Retrieved from http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_170.pdf

Pope, C.A., Burnett, R.T., & Thun, M.J. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Journal of the American Medical Association*, *287*(9), 1132-1141.

Pope, C.A. (2007). Mortality effects of longer term exposures to fine particulate air pollution: Review of recent epidemiological evidence. *Inhalation Toxicology*, 19, 33-38.

Pope, C.A., Ezzati, M., & Dockery, D.W. (2009). Fine-particulate air pollution and life expectancy in the United States. *The New England Journal of Medicine*, *360*(4), 376-386.

Rose, E., Hawkins, B., Tonn, B., Paton, D., & Shah, L. (2015). *Exploring potential impacts of weatherization and healthy home intervention on asthma-related Medicaid clams and costs in a small* *cohort in Washington State*. Retrieved from http://weatherization.ornl.gov/RecoveryActpdfs/ORNL_TM-2015_213.pdf

Salthammer, T., Furhmann, F., Kaufhold, S., Meyer, B., & Schwarz, A. (1995). Effects of climatic parameters on formaldehyde concentration in indoor air. *Indoor Air,* 5, 120-128.

Schenck, P., Ahmed, A., Bracker, A., & DeBernardo, R. (2010). *Climate change, indoor air quality, and health*. Retrieved from https://www.epa.gov/sites/production/files/2014-08/documents/uconn_climate_health.pdf

Seppänen, O., & Fisk, W. (2004). Summary of human responses to ventilation. *Indoor Air*, 14, 102-118.

Shrubsole, C., Macmillan, A., Davies, M., & May, N. (2014). 100 Unintended consequences of policies to improve the energy efficiency of the UK housing stock. *Indoor & Built Environment*, 23(3), 340-352. doi: 10.1177/1420326X14524586

Sundell, J., Levin, H., Nazaroff, W. W., Cain, W. S., Fisk, W. J., Grimsrud, D. T. … Weschler, C. J. (2011). Ventilation rates and health: multidisciplinary review of the scientific literature. *Indoor Air*, 21(3), 191–204. doi: 10.1111/j.1600-0668.2010.00703.x

Szanton, S.L., Thorpe, R.J., Boyd, C., Tanner, E.K., Leff, B., Agree, E. … Gitlin, L.N. (2011). Community aging in place, advancing better living for elder: A bio-behavioral-environment intervention to improve function and health-related quality of life in disable older adults. *Journal of the American Geriatrics Society*, *59*(12), 2314-2320. doi: 10.1111/j.1532-5415.2011.03698.x

Tonn, B. E., Carroll, D., Pigg, S., Blasnik, M., Dalhoff, G., Berger, J. … Cowan, C. (2015a). *Weatherization works: Summary of findings from the retrospective evaluation of the U.S. DOE's Weatherization Assistance Program*. Retrieved from http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_338.pdf

Tonn, B., & Rose, E. (2014). The Health benefits of Weatherization. *Home Energy*, 31(2), 36-41.

Tonn, B.E., Rose, E.M., Hawkins, B.A. (2015b). *National Weatherization Assistance Program characterization describing the Recovery Act period*. Retrieved from https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRecoveryActEvalFinalReports/ORNL_TM-2015_195.pdf

United Nations Environment Programme Sustainable Buildings and Climate Initiative. (2009). *Buildings and climate change summary for decision-makers*. Retrieved from https://europa.eu/capacity4dev/unep/document/buildings-and-climate-change-summary-decision-makers

U.S. Department of Energy. (2012). *Lead safe weatherization curriculum*. Retrieved from https://energy.gov/eere/wipo/lead-safe-weatherization-lsw

U.S. Department of Energy. (2014). *Quality work plan requirement update* (Weatherization Program Notice 15-4). Retrieved from https://energy.gov/sites/prod/files/2014/10/f18/wpn_15_4.pdf

U.S. Department of Energy. (2015). *National evaluations: Summary of results*. Retrieved from http://weatherization.ornl.gov/WAP_NationalEvaluation_WxWorks_v14_blue_8%205%2015.pdf

U.S. Department of Energy. (2016a). *About the Weatherization Assistance Program*. Retrieved from https://energy.gov/eere/wipo/about-weatherization-assistance-program-0

U.S. Department of Energy. (2016b). *2016 poverty income guidelines and definition of income*. Retrieved from https://energy.gov/sites/prod/files/2016/02/f29/WPN%2016-3%20PIGS%20Final_0.pdf

U.S. Department of Energy. (2016c). Program funding and production. In *Weatherization Briefing Book*. Retrieved from https://energy.gov/sites/prod/files/2016/09/f33/wap_bb_funding_production_section.pdf

U.S. Department of Housing and Urban Development. (2012). *U.S. Department of Housing and Urban Development climate change adaption plan*. Retrieved from https://portal.hud.gov/hudportal/documents/huddoc?id=SSP2012_Apx_CCAdaptPlan.pdf

U.S. Department of Housing and Urban Development. (2014). *Housing and urban development climate change adaption plan*. Retrieved from https://portal.hud.gov/hudportal/documents/huddoc?id=HUD2014CCAdaptPlan.pdf

U.S. Energy Information Association. (2013). *2009 Residential energy consumption survey (RECS).* Retrieved from http://www.eia.gov/consumption/residential/index.php

U.S. Energy Information Association. (2015). *Annual energy outlook 2015 with projections to 2040*. Retrieved from http://www.eia.gov/outlooks/aeo/pdf/0383(2015).pdf

U.S. Energy Information Association. (2016a). 2*012 Commercial buildings energy consumption survey (CBECS*). Retrieved from http://www.eia.gov/consumption/commercial/

U.S. Energy Information Association. (2016b). Carbon dioxide emission from energy consumption. In *December 2016 Monthly Energy Review* (Environment). Retrieved from http://www.eia.gov/totalenergy/data/monthly/index.php#environment

U.S. Environmental Protection Agency (USEPA). (1992). *Technical support document for the 1992 citizen's guide to radon*. Washington, DC: U.S. Department of Health and Human Services.

U.S. Environmental Protection Agency (USEPA). (2005). *Supplemental guidance for assessing susceptibility from early-life exposure to carcinogens*. Washington, DC: United States Environmental Protection Agency.

U.S. Green Building Council (USGBC). (2013). EQ credit: Contamination control. In *LEED v4.*

U.S. Office of Management and Budget (OMB). (2003) *Circular A-4*. Washington, DC: United States Office of Management and Budget.

Walter, S. (1989). How useful is the FEV1%?. *Indian Journal of Chest Disease and Allied Science*, *31*(3), 159-164.

Weatherization Assistance for Low-Income Persons, 10 CFR §§440.1-440.30 (2006).

Weinstein, M.C., Torrance, G., & McGuire, A. (2009). QALYs: The basics. *Value in Health,* *12*(1), S5-S9.

Weitzel D. & Skumatz L. (2001). *Measure retention study: Revised lifetime for a residential weatherization program*. Economic Research Associates, Inc.

Wilcox, S., & Marion, W. (2008). Users manual for TMY3 data sets. [*electronic resource*] (Revised May 2008.). National Renewable Energy Laboratory.

World Health Organization (WHO). (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. Geneva, Switzerland: World Health Organization.

World Health Organization. (2010). *WHO Guidelines for indoor air quality: Selected pollutants*. Geneva, Switzerland: World Health Organization.

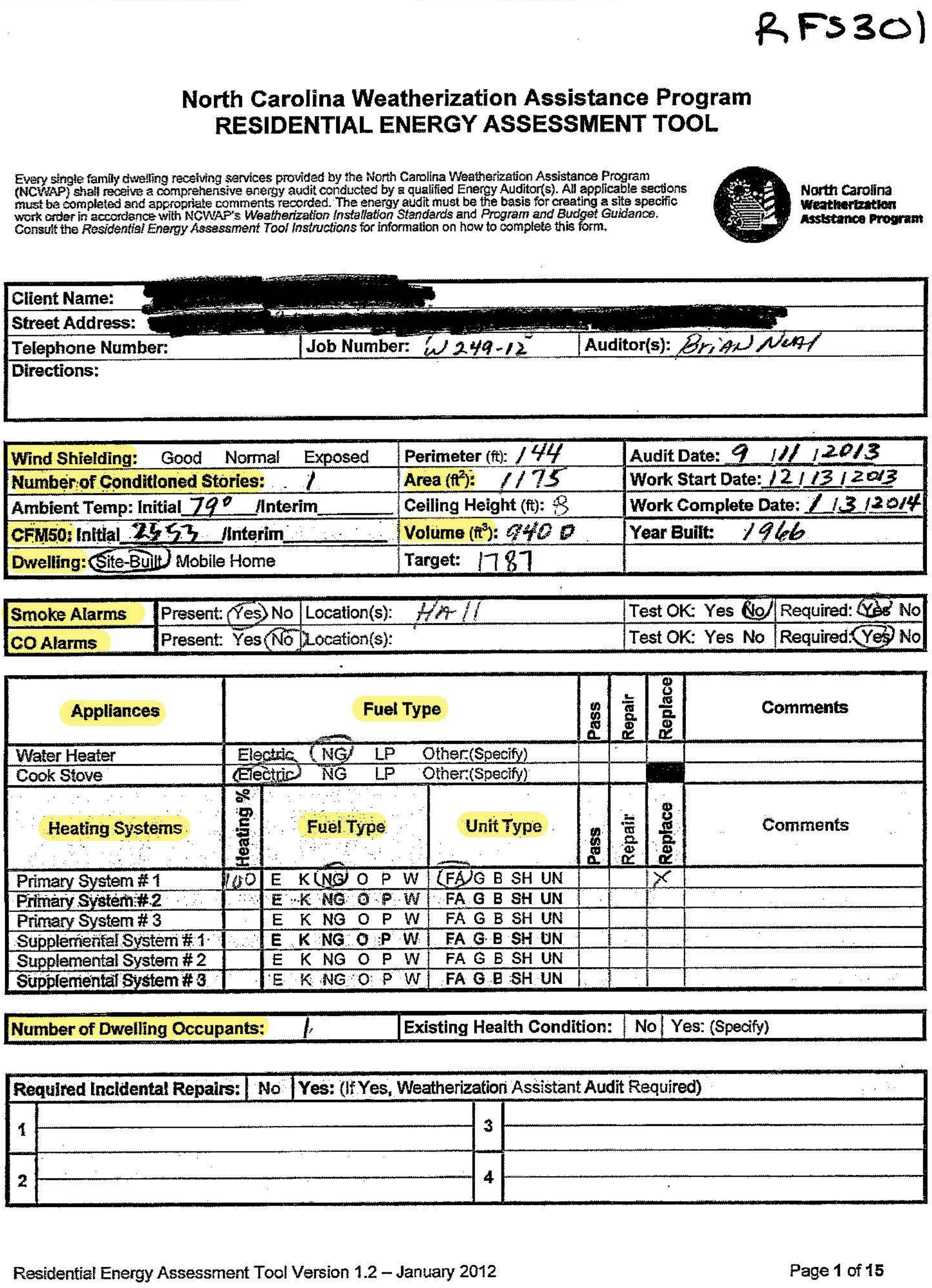
Zhang, Y., Lou, X. Wang, X., Qian, K., & Zhao, R. (2007). Influence of temperature on formaldehyde emission parameters of dry building materials. *Atmospheric Environment,* 47, 3203-3216.

Zummo, S., & Karol, M. (1996). Indoor air pollution: acute adverse health effects and host susceptibility. *Journal of Environmental Health*, 58(6), 25-29.

APPENDIX A- Examples of Forms Submitted by Partner CAAs

NOTE: Forms are highlighted to show areas of interest during the data collection period.

Example NCWAP Residential Energy Assessment Tool (REAT)



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North Carolina Weatherization Assistance Program
RESIDENTIAL ENERGY ASSESSMENT TOOL

Every single family dwelling receiving services provided by the North Carolina Weatherization Assistance Program (NCWAP) shall receive a comprehensive energy audit conducted by a qualified Energy Auditor(s). All applicable sections must be completed and appropriate comments recorded. The energy audit must be the basis for creating a site specific work order in accordance with NCWAP's *Weatherization Installation Standards* and *Program and Budget Guidance*. Consult the *Residential Energy Assessment Tool Instructions* for information on how to complete this form.

North Carolina
Weatherization Assistance Program

Client Name: [redacted]
Street Address: [redacted]
Telephone Number:
Job Number: W 249-12
Auditor(s): BriAN NeAl
Directions:

Wind Shielding: Good Normal Exposed	**Perimeter** (ft): 144	**Audit Date:** 9 /11 /2013
Number of Conditioned Stories: 1	**Area** (ft²): 1175	**Work Start Date:** 12/13/2013
Ambient Temp: Initial 79° **/Interim**	**Ceiling Height** (ft): 8	**Work Complete Date:** 1/13/2014
CFM50: Initial 2553 **/Interim**	**Volume** (ft³): 9400	**Year Built:** 1966
Dwelling: [✓ Site-Built] Mobile Home	**Target:** 1787	

Smoke Alarms	Present: [✓ Yes] No	Location(s): HAll	Test OK: Yes [✓ No]	Required: [✓ Yes] No
CO Alarms	Present: Yes [✓ No]	Location(s):	Test OK: Yes No	Required: [✓ Yes] No

Appliances	**Fuel Type**	**Pass**	**Repair**	**Replace**	**Comments**
Water Heater	Electric [✓ NG] LP Other:(Specify)				
Cook Stove	[✓ Electric] NG LP Other:(Specify)			■	

Heating Systems	**Heating %**	**Fuel Type**	**Unit Type**	**Pass**	**Repair**	**Replace**	**Comments**
Primary System # 1	100	E K [✓ NG] O P W	[✓ FA] G B SH UN			X	
Primary System # 2		E K NG O P W	FA G B SH UN				
Primary System # 3		E K NG O P W	FA G B SH UN				
Supplemental System # 1		E K NG O P W	FA G B SH UN				
Supplemental System # 2		E K NG O P W	FA G B SH UN				
Supplemental System # 3		E K NG O P W	FA G B SH UN				

Number of Dwelling Occupants: 1	**Existing Health Condition:**	No	Yes: (Specify)

Required Incidental Repairs:	No	**Yes:** (If Yes, Weatherization Assistant Audit Required)	
1		**3**	
2		**4**	

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[redacted]

Aluminum Siding

BACK - SOUTH

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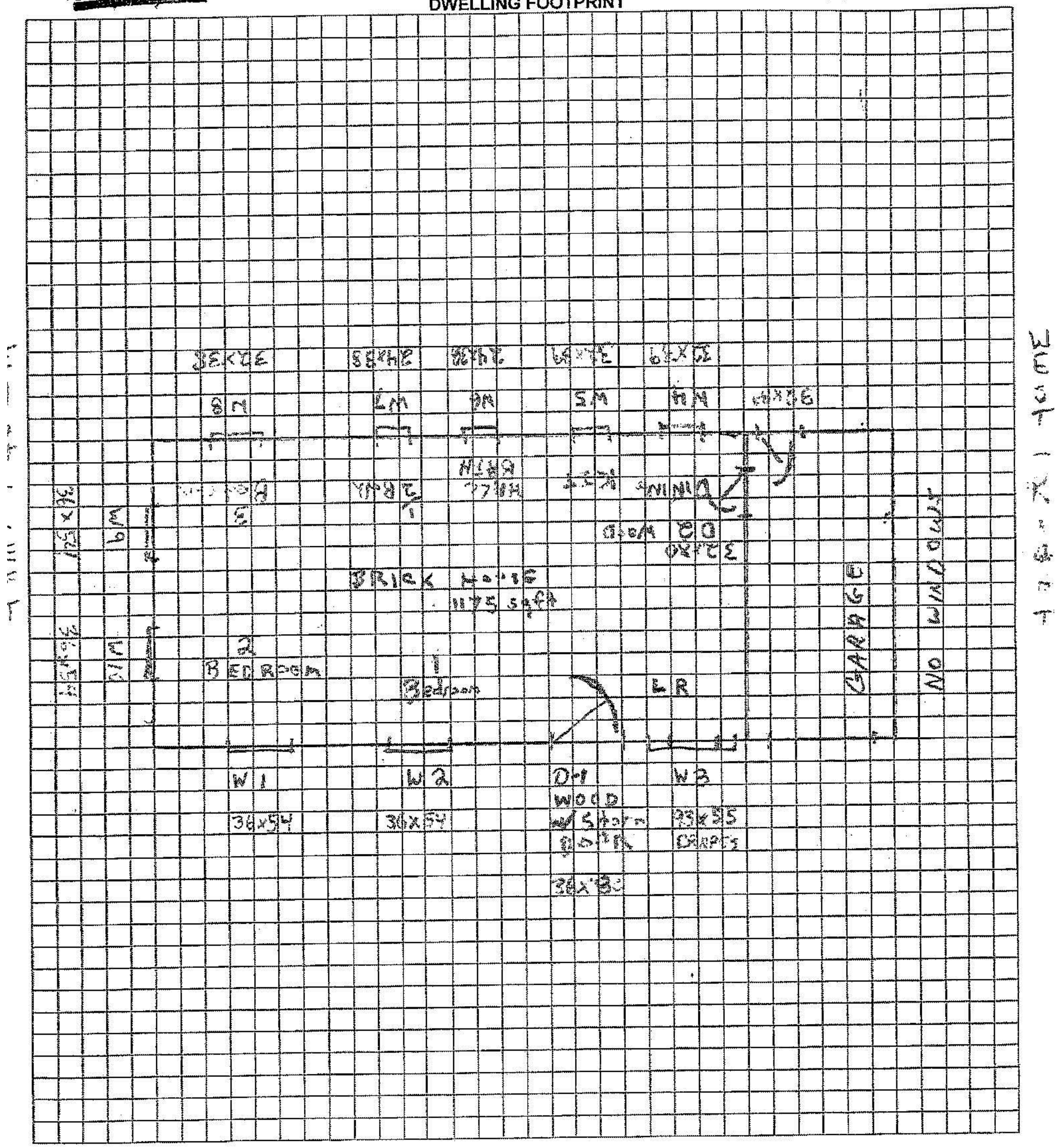
DWELLING FOOTPRINT



WOOD SASHES
w/storm aluminum windows

FRONT - NORTH

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WINDOWS

#	Location	*Window Type	*Frame Type	Orientation	Size (in)	*Glazing Type	Glass Panes: Broken (Y/N)	Glass Panes: Size (in) to Replace	*Interior Shading	*Exterior Shading	Exterior Shading %	*Leakiness
1	Bedroom 2	S	W	N	W36 H54	SM		W H	BS	N	20	M
2	Bedroom 1	S	W	N	W36 H54	SM		W H	BS	N	20	M
3	Living Rm	F	W	N	W93 H55	SM		W H	D	N	20	M
4	Dining	S	W	S	W32 H39	SM		W H	BS	N	50	M
5	Kitchen	S	W	S	W32 H39	SM		W H	BS	Trees	50	M
6	Hall Bath	S	W	S	W24 H38	SM		W H	BS	Trees	5	M
7	½ Bath	S	W	S	W24 H39	SM		W H	BS	Trees	50	M
8	Bedroom 3	S	W	S	W32 H 39	SM		W H	BS	Trees	50	M
9	Bedroom 3	S	W	E	W36 H54	SM		W H	BS	Trees	50	M
10	Bedroom 2	S	W	E	W36 H54	SM		W H	BS	Trees	50	
11					W H			W H				
12					W H			W H				
13					W H			W H				
14					W H			W H				
15					W H			W H				
16					W H			W H				
17					W H			W H				
18					W H			W H				
19					W H			W H				
20					W H			W H				

*** Window Type**

A = Awning
SL = Skylight
F = Fixed
JA = Jalousie
S = Slider
SGD = Sliding Glass Door
DW = Door Window

***Glazing Type**

SP = Single Pane
SWS = Single Wood Storm
SM = Single Metal Storm
SGS = Single w/Glass Storm
SBS = Single Bad Storm
SPS = Single w/Plastic Storm
DP = Double Pane
DGS = Double w/Glass Storm
DPS = Double w/Plastic Storm
DPLE = Double Pane Low E

***Frame Type**

IM = Improved Metal
M = Metal
WV = Wood/Vinyl

***Interior Shading**

BS = Blinds or Shades
D = Drapes
DB = Drapes w/Blinds or Shades
N = None

***Exterior Shading**

A = Awning
CP = Carport/Porch
LEF = Low E Film
N = None
SS = Sun Screen

***Leakiness**

VT = Very Tight
T = Tight
M = Medium
L = Loose
VL = Very Loose

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DOORS

#	Location	*Door Type	Orientation	Size (ft)	*Storm Door Condition	*Weather-stripping	*Door Sweep	Glass Panes	
								Broken (Y/N)	Size (in) to Replace
1	Front Door	SI	N	W 36 H 80	A				W H
2	Back Door	WSC	W	W 32 H 80	D				W H
3				W H					W H
4				W H					W H
5				W H					W H
6				W H					W H

*Door Type		*Storm Door, W/S, D/S Condition
WHC = Wood Hollow Core WSC = Wood Solid Core SI = Steel Insulated	SSG = Single Sliding Glass DSG = Double Sliding Glass SMHD = Standard Manufactured Home Door	A = Adequate D = Deteriorated N = None

Comments:

LIGHTING

#	Location	Existing Wattage	Replacement CFL Wattage	Fixture Type	Hours/Day Used	New Lighting Cost/Bulb ($)
1				Standard Flood Other		$
2				Standard Flood Other		$
3				Standard Flood Other		$
4				Standard Flood Other		$
5				Standard Flood Other		$
6				Standard Flood Other		$
7				Standard Flood Other		$
8				Standard Flood Other		$
9				Standard Flood Other		$
10				Standard Flood Other		$

Comments:

Wattage Equivalency Table

Incandescent Watts	CFL Watts	Lumens
25	5 - 7	232 - 400
40	9	480 - 600
60	13 - 18	890 - 1100
75	-	1220
100	26	1750 - 1800

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REFRIGERATORS & FREEZERS			Refrigerator 1	Refrigerator/Freezer 2	Refrigerator/Freezer 3
1	Year Manufactured		10-04		
2	Manufacturer		Whirlpool		
3	Model Number		ED29HEXNT00		
4	Serial Number		SR4049647		
5	Type (Side-by-Side, Top Freezer, Bottom Freezer)		side by side		
6	Total Cubic Feet (ft^3)				
7	Icemaker		[✓ Yes] No	Yes No	Yes No
8	Door Hinge		Left Right	Left Right	Left Right
9	Dimensions (in)		W___ D___ H___	W___ D___ H___	W___ D___ H___
10	Condition of Door Seal(s) (Good, Fair, Poor)		Good		
11	Is Water Hookup Copper Tubing		Yes No	Yes No	Yes No
12	Metering	Kilowatt Hours (kWh)			
13		Duration (minutes)			
14		Peak Kilowatts			
15		Cost per kWh ($)			
16	1	______ kWh metered ÷ ______ min. metered × 60 = ______ kWh × 8766 × 1.08* = ______ kWh per Year			
	2	______ kWh metered ÷ ______ min. metered × 60 = ______ kWh × 8766 × 1.08* = ______ kWh per Year			
	3	______ kWh metered ÷ ______ min. metered × 60 = ______ kWh × 8766 × 1.08* = ______ kWh per Year			
17	What is the narrowest sized door opening that must be passed the refrigerator: (in)			W H	

SAVINGS TO INVESTMENT RATIO (SIR) MUST BE COMPLETED ON AN APPROVED EVALUATION CALCULATOR

Comments: the Clent did not want me to meter Refrigerator

Metering

*Omit multiplying by 1.08 if metering for 24 hours.

ELECTRICAL SERVICE PANEL

Electrical Box	Location	Manufacturer	Size Amp Rating	Type	Cover
Main Panel	Garage	EQ Load	200 Amp	[✓ Circuit Breaker] Fuses	[✓ Yes] No
Sub-Panel			Amp	Circuit Breaker Fuses	Yes No

Knob and Tube Wiring Present: No Yes | Location(s): Attic Sidewalls Crawlspace Other: (Specify)________

Knob and Tube Wiring Active: No Yes | Aluminum Wiring Present: No | Yes: (If Yes, must be deferred)

Comments:

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FUEL-FIRED **COOKSTOVE** INSPECTION

1	**Fuel-Fired Stove Present**	Yes No	7	**Stove Burners**	**Initial ppm**	**Interim ppm**
					CO | AF	CO | AF
2	**Fuel Leak Present**	Yes No		Oven		
3	**If so, Location of Leak**			Front Left		
4	**Type of Fuel**	NG LP		Front Right		
5	**Stove Manufacturer**			Rear Left		
6	**Flex Connector Type**	Copper Hard-Piped Epoxy-Coated Stainless Steel *Brass		Rear Right		
				*Must **Replace Brass Connectors**		

Comments:

EXHAUST VENTS

		Operational	Vented to Outside	CFM
1	**Dryer Vent**	[✓ Yes] No None	[✓ Yes] No	
2	Kitchen Exhaust	[✓ Yes] No None	[✓ Yes] No	45
3	**Bathroom 1 Exhaust**	Yes No None	Yes No	0
4	**Bathroom 2 / Other** (Specify)	Yes No	Yes No	0

Comments: Dryer Hard pipe needed vent / Dryer Hood with Damper

UNVENTED SPACE HEATERS

#	Location	Manufacturer	Model Number	Btu/ Hour	O_2 Depletion Sensor(Y/N)	CO (ppm)	Primary/ Supplemental	Fuel Shutoff	Fuel Leak No	Fuel Leak Yes: (Location)	*Compliant/ Noncompliant
1											
2											
3											
4											

Comments:

***If the unit is not compliant, action must be taken.**

FUEL TANK	Location	*Stand	*Legs	*Cap Block	*Vent Cap	*Fill Cap	*2 Line Cap	*Gauge	*Fuel Line	*Cut Off Valve
Oil Tank										
LP Gas Tank										

If tank is located in conditioned space, is vent cap run to outdoors: Yes No

Is fill cap run to outdoors: Yes No

Comments:

*Condition
A = Adequate
D = Deteriorated
N = None

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WATER HEATER INSPECTION

1	Pass	Fail (If Fail, Explain in Comments)	Repair or will Replace with:
2	Location: Garage		
3	Manufacturer: Envirotemp	Model Number: G1F4033S3NV	Type of Fuel: E [✓ NG] P
4	Rated Input: 33,000	Size (gals): 40	Serial Number: 0210129901
			Measured Temperature (°F): 122°
5	Existing Insulation Type: [✓ Fiberglass] Polyurethane None		Existing Insulation R-Value:
6	Can Water Heater be Insulated:	[✓ Yes] No	Is Pressure Relief Piping Required: [✓ Yes] No
	Can First 5 Feet of Hot Water Line be Insulated:	[✓ Yes] No	Is There Evidence of Flame Rollout: Yes [✓ No]
	Can First 5 Feet of Cold Water Line be Insulated:	[✓ Yes] No	Is Pilot Safety Shutoff OK: [✓ Yes] No
7	Is Fuel Leak Present: No	Yes: (Location of Leak) 1:08.7	
8	Is Fuel Natural Gas: No [✓ Yes]	(Clock Meter) Dial___ft³ ___sec = ____Btu	Within 10% of Rated Btu: Yes No
9 Main Vent/ Chimney	Is Main Vent/Chimney OK: [✓ Yes]	No: Type Location Clearance Height Size Cap Liner Mortar Flashing Unused-Flue-Holes Thimble Other	
	Chimney Type:	Chimney Size (in): L W	Chimney Height (ft):
	Liner: Existing Required	Liner Type:	Liner Size (in): L W
			Liner Height (ft):
10 Vent Connector	Is Vent Connector from Water Heater to Chimney OK:	Yes No: Type Connections Corroded ½-in.-Rise-per-ft Excessive-Elbows Clearance Other	
	Vent Connector Type:	Vent Connector Diameter (in):	Vent Connector Run (ft):
11	Is Added Combustion Air Required: No	Yes (If less than 50 ft³ per 1000 Btu)	Rated kBtu Input:
12	L______x W______x H______ = ______ ft³ / 50 =		kBtu Allowed:
13	Rated kBtu Input Result minus kBtu Allowed Result (#11 -		kBtu Required:
14	* in² of NFA Combustion Air Required = kBtu Required		in² Required:
15	NFA Vent Size Required (High) = W_____ x H_____ =		Size High:
16	NFA Vent Size Required (Low) = W_____ x H_____ =		Size Low:

DIAGNOSTIC INSPECTION

		INITIAL T	INTERIM TEST
17	CAZ Worst Case WRT Outside	(Complete CAZ sheet, pa worst case)	e CAZ sheet, page 9, then recreate e) Pa
18	Draft (Worst Case)	-0.0181	Pa
19	CO Living Area	0	ppm
20	CO Flue Gases (CO<100 ppm) (CF<400 ppm)	10 CO	CO CF ppm
21	Stack Temperature (each port)	301.1	TS °F
22	Oxygen Percentage (each port)	11.8	O₂%
23	Efficiency Percentage (each port)	82.2	EF%

Comments:

mbustion Air Guide

side: 1 kBtu; minimum of 100 pening

tside: 4 kBtu

side (horizontal): 2 kBtu

```
V1.17  27-1
       128217 USA

09/11/  16:09 36

-0.0181 Draft
 202.8  stack
 202.8

V1.17      testp-1
           128217 USA

09/11/2013    16:11:28

Fuel              Nat Gas
CO2 max            11.7 %

        FlueGs

 301.1  °F    T stack
  5.11  %     CO
  82.2  %     Eff
 114.7  %     ExAir
  11.8  %     Oxygen
    10  ~~ppm  CO~~
    23  ppm   CO AirFree
-0.0181 inH20 Draft
  79.2  °F    Ambient temp
  79.3  °F    Instrum temp
  ----  °F    Diff. temp.
  ----  inH20 Diff. Press
     0  ppm   CO Ambient
```

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RF5301

COMBUSTION FUEL HEATING SYSTEM INSPECTION

1	Pass | Fail (If Fail, Explain in Comments)	Repair or will Replace with:	*Type of Unit: [✓ FA] GF SB HWB VSH USH
2	Location: Closet	Type of Fuel: [✓ NG] P O W K	Serial Number: 4689A16053
3	Manufacturer: CARRIER	Model Number: 5DHC075	System: Primary or Supplemental
4	Rated Input (Btu/hour):	Rated Output (Btu/hour):	
5	Fuel Leak Present: No | Yes: (Location of Leak)		Within 10% of Rated Btu: Yes No
6	Is Fuel Natural Gas: No | Yes: (Clock Meter) Dial ft³ sec = Btu		
7	Is Clearance from Heating Unit to Combustibles OK:	Yes | No: Ceiling Walls Floors	
8	Automatic Vent Damper: Present Recommended	Oil Furnace Retention Head: Present Recommended	
9	Circuit Breaker/Fuse Size at Service Panel:	Circuit Breaker/Fuse Size at Disconnect:	
10	Thermostat Location: HALL	Thermostat Anticipator Setting:	
	Mercury: [✓ Yes] No	Smart Thermostat: Yes No	Temperature Day /Night
11	Is Heating Unit on Separate Circuit: Yes No	Visual Inspection of Safety Controls:	Yes No
	Is There an Electrical Disconnect: Yes No	Does Blower Require Cleaning:	Yes No
	Are There Any Burned Wires: Yes No	Is Blower Noisy:	Yes No
	Is Heat Exchanger OK: Yes No	Is This Unit Sealed Combustion:	Yes No
12 Filter	Filter Present: No | Yes: Location	Type:	Size (in): L W
	If Reusable, Cleaned & Replaced: Yes No	Clean Dirty	Quantity to Leave:
13 Main Vent/ Chimney	Is Main Vent/Chimney OK: Yes	No: Type Location Clearance Height Size Cap Liner Mortar Flashing Unused-Flue-Holes Thimble Other	
	Chimney Type:	Chimney Size (in): L W	Chimney Height (ft):
	Liner: Existing Required	Liner Type: | Liner Size (in): L W	Liner Height (ft):
14 Vent Connector	Is Vent Connector from Heating System to Chimney OK: Yes	No: Proper-Type-Pipe Connected-Properly Leaky-or-Corroded ¼-in.-Rise-per-ft Excessive-Elbows Clearance Other	
	Vent Connector Type:	Vent Connector Diameter (in):	Vent Connector Run (ft):
15	Is Combustion Air Venting Required: No	Yes: (If less than 50 ft³ per 1000 Btu)	Rated kBtu Input:
16	L x W x H =	ft³ / 50 = kBtu Allowed	kBtu Allowed:
17	Rated kBtu Input Result minus kBtu Allowed Result (15 -16) = kBtu Required		kBtu Required:
18	in² of NFA Combustion Air Required = Btu Required / *kBtu = x 2		in² Required:
19	NFA Vent Size Required (High) = W x H = x.75 = NFA in²		Size High:
20	NFA Vent Size Required (Low) = W x H = x.75 = NFA in²		Size Low:

DIAGNOSTIC INSPECTION		INITIAL TEST	INTERIM TEST
21	CAZ Worst Case (Complete page 9)	Pa	Pa
22	Draft (at Worst Case)	Pa	Pa
23	CO Living Area	NOT WORKIN ppm	ppm
24	Smoke Number (Oil Systems)		
25	Heat Rise (Supply – Return = Rise)	(°F)	(°F)
26	Draft Inducer & Pressure Switch:	Dr In OK: Yes No | Pr Sw OK: Yes No	Dr In OK: Yes No | Pr Sw OK: Yes No
27	CO Flue Gases (CO<100 ppm) (CF<400 ppm)	NO ppm	ppm
28	Stack Temperature (each port)		
29	Oxygen Percentage (each port)	O₂%	O₂%
30	Efficiency Percentage (each port)	EF%	EF%

Comments: Could'nt Check it wasn't working - my Hvac guy will check it for me on Oct 15 →

***Type of Unit**

HWB = Hot Water Boiler
VSH = Vented Space Heater
USH = Unvented Space Heater
FA = Forced Air
GF = Gravity Furnace
SB = Steam Boiler

Combustion Air Guide

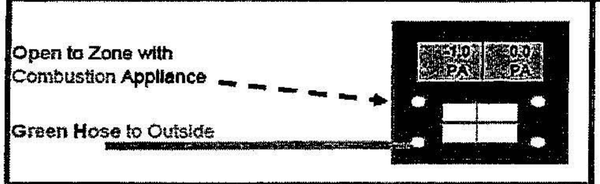
*All air from inside: 1 kBtu; minimum of 100 in² NFA each opening

*All air from outside: 4 kBtu

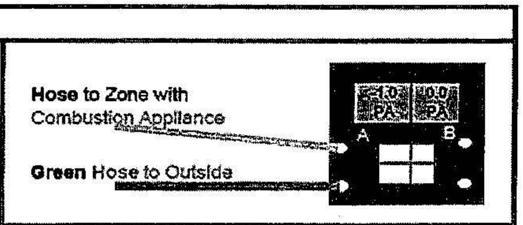
*All air from outside (horizontal): 2 kBtu

RFS301

Combustion Appliance Zone (CAZ) Testing



Use this setup when you **ARE** located in the Combustion Appliance Zone



Use this setup when you ARE NOT located in the Combustion Appliance Zone

a. VISUALLY INSPECT VENTING (of each Combustion Appliance)
b. TURN OFF ALL COMBUSTION APPLIANCES.
c. CLOSE ALL OPERABLE VENTS AND DAMPERS
d. CHECK DRYER and LINT FILTER
e. CHECK FURNANCE FILTER (clean or replace if needed.)
f. OPEN ALL INTERIOR DOORS

NOTE: IF BLOWER DOOR IS SET UP, BE SURE FAN IS COVERED.

1. Setup Manometer and Pressure hoses to measure CAZ (WRT) Outdoors
2. Adjust for Baseline Pressure
3. Turn on all exhaust fans (do not turn on whole-house fans).
4. Close all interior doors to rooms that **do not** have exhaust fans.
5. If the house has a fireplace that the client uses, turn on the blower door to 300 CFM with Ring B to simulate.

	Appliance 1		Appliance 2		Appliance 3	
	Initial	Interim	Initial	Interim	Initial	Interim
6. Open door, if present between CAZ and Main Body of house. Record reading.	0.1					
7. Close door between CAZ and Main Body of house. Record reading. (If no door, skip to Step number 8)	1.1					
8. Turn on Furnace Blower. Check position of interior doors with smoke puffer for worst case. If the smoke blows towards the CAZ, leave the door shut.	0.5					
9. Open door between CAZ and Main Body of house. Record reading. (If no door, skip step.)	0.1					
10. Recreate Worst Case Conditions for each CAZ (Complete this and following steps on each Fuel Fired Heating Section.)						
11. Perform Worst Case Draft and Combustion Tests for each appliance under this worst case condition.						

*If Ambient CO gets above 35 ppm, discontinue testing and remove CAZ from worst case conditions.

*There should be no spillage after 1 minute of Worst Case and draft should be established after 5 minutes.

FIREPLACE			N/A
Fireplace Vented: Yes No N/A	Location:	**How Often Used Monthly:**	
Damper: Open Closed None	Damper Operable: Yes No	**Seal Off If Not Used:** Yes No	

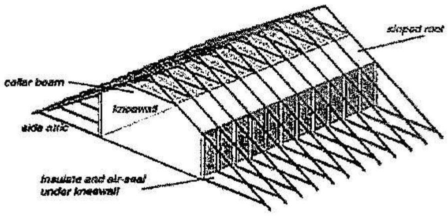
WINDOW AIR CONDITIONERS						**N/A**
#	**Location**	**Manufacturer**	**Btu**	**EER**	**Area Cooled (ft²)**	**Permanent Seal Required (Y/N)**
1						
2						
3						
Comments:						**Cleaning required for all window units.**

HEAT PUMP / CENTRAL AIR CONDITIONING					**Area Cooled** ______ (ft²)	**N/A**
Outdoor Unit Location	**Manufacturer**	**Model Number**	**Serial Number**	**SEER**	**Disconnect Present ([✓ Y]/N)**	**Suction Line Insulated ([✓ Y]/N)**
	TRANE	NZA330AKA 200	B0739163 00			
Indoor Unit Location	**Manufacturer**	**Model Number**	**Serial Number**	**HSPF**	**Heat Pump kW**	**Btu Input**
Thermostat	Location:			Mercury: Yes No	Temperature Day____/Night____	
Filter	Filter Present:	No	Yes: Location	Type: Pleated	Size: L 20 W 14	
	If Reusable, Cleaned & Replaced: Yes No			Clean Dirty	Quantity to Leave:	
Blower	Requires Cleaning: Yes No			Noisy: Yes No	***Air Conditioner Filter Type**	
Comments:		**Heating = 400 CFM per 25,000 Btu output** **Cooling = 400 CFM per 12,000 Btu (1 ton)**			**DFF = Disposable Fiberglass Filter** **DPF = Disposable Pleated Filter** **CRF = Cleanable/Reusable Filter**	

DUCTS / HEATING PIPES							**N/A**
Boots	**Registers**	**Supply Duct**	**Return Duct**	**Supply Plenum**	**Return Plenum**	**Crossover**	**Duct Insulation**
X		X	X	X	X	[illegible]	Y
Duct Location: Crawl				**Type Duct System:** Trunk [✓ Spider] Cottage-Base			
Replace Return Grill With Filter Grill: Yes [✓ No]				**Type Ductwork:** Sheet-Metal Flex-Duct Ductboard			
Duct Space: Conditioned [✓ Unconditioned]				**Duct Insulation Location:** Above Below Around None			
Comments:						**✓ = Present/Good Condition** **X = Missing/Requires Repairs**	

INDIVIDUAL ROOM PRESSURE ***(Room WRT Outdoors)***											**N/A**
	Room	**Initial**	**Interim**		**Room**	**Initial**	**Interim**		**Room**	**Initial**	**Interim**
1	Hall Bath	3.0		**5**	Mid Bed	0.9		**9**			
2	Back bed	3.2		**6**				**10**			
3	Half Bath	2.9		**7**				**11**			
4	M Bed	2.4		**8**				**12**			
Comments: Put grills,									****No room shall exceed -/+ 3 Pa WRT Outdoors****		

RFS301



		SITE BUILT HOME ATTIC	Attic 1	Attic 2	Attic 3	Finished Attic			N/A
						Collar Beam	Roof Rafter	Knee wall	Outer Ceiling Joists
1		*Attic Type	UF						
2		Dimensions (ft)	25x47						
3		Square Footage (ft²)	1175						
4		Joist Spacing (in)	16						
5		Kneewall Door Present	None						
6		*Initial Insulation Type	Fiberock						
7		*Initial Depth (in) & R-Value	3 inch						
8		*Interim Insulation Type	Cellulose						
9		Insulation Required *(# of Bags)*	30 bags						
10		*Interim Depth (in) & R-Value	R-38						
11	Condition of Attic	Water Leak	NO						
12		Recessed Light	NO						
13		Chimney/Vent Shielding	NO						
14		Condition of Wiring	Good						
15		Access	Hatch						
16	By-Passes	Open Exterior Wall Tops	NO						
17		Open Interior Wall Tops	NO						
18		Wire Chases	NO						
19		Plumbing Chases	NO						
20		HVAC Chases	NO						
21		Stairwell Drop	NO						
22		Closet Drop	NO						
23		Soffit Drop	NO						

*Initial/Interim Insulation Type	*Attic Type	*Insulation R-Value & Depth			
BC = Blown Cellulose BF = Blown Fiberglass RW = Rockwool FGB = Fiberglass Batts O = Other N = None	F = Floored UF = Unfloored C = Cathedral FT = Flat	Loose-Fill Cellulose, Fiberglass, Rock, & Slag	R-Value	Batt/Blanket Fiberglass, Rock, & Slag	R-Value
		3.5 – 5 inches	11	3 inches	11
		4 – 5.5 inches	13	4 inches	13
		5 – 8 inches	19	5.5 inches	19
		6 – 9.5 inches	22	6.5 inches	22
		8.5 – 13 inches	30	8.5 inches	30
		11 – 16.5 inches	38	11 inches	38

Comments

	SIDEWALLS	Sidewall 1	Sidewall 2	Sidewall 3	Sidewall 4	Sidewall 5	Sidewall 6
1	**Location/Orientation** (North, South, East, West)	North	west	south	East		
2	**Initial Insulation**	[✓ Yes] No	[✓ Yes] No	[✓ Yes] No	[✓ Yes] No	Yes No	Yes No
3	***Initial Insulation Type**	BB	BB	BB	BB		
4	**Initial R-Value**	11	11	11	11		
5	**Added Insulation Type** (Blown Cellulose, Other, None)	None	none	None	None		
6	**Wiring Condition**	Good	Good	Good	Good		
7	**Are Walls Weak**	Yes [✓ No]	Yes [✓ No]	Yes [✓ No]	Yes [✓ No]	Yes No	Yes No
8	**Can Sidewalls be Blown**	Yes [✓ No]	Yes [✓ No]	Yes [✓ No]	Yes [✓ No]	Yes No	Yes No
9	**Interior Type** (Drywall, Paneling, Other)	Drywall	Drywall	Drywall	Drywall		
10	**Exposure** (Exposed, Buffered, Attic)	Exposed	Buffered	Exposed	Exposed		
11	***Exterior Type**	BS	MV	MV	BS		
12	***Wall Framing Type**	PF	PF	PF	PF		
13	**Width of Cavity** (24 in. 16 in. Other)	16	16	16	16		
14	**Depth of Cavity** (2x4 2x6 Other)	2x4	2x4	2x4	2x4		
15	**Exterior Wall Surface Area** (ft²)	376	200	376	200		
16	**Less Windows/Doors Total** (ft²)	83	18	56	27		
17	**Net ft² Wall Surface Area**	293	182	320	173		
18	**Total Number of Bags Required**	10	6	10	6		

***Initial Insulation Type**

BC = Blown Cellulose
BFG = Blown Fiberglass
RW = Rockwool
FGB = Fiberglass Batts
PB = Polystyrene Board
BB = Batt/Blanket (in)
LF = Loose Fill (in)
FC = Foam Core (in)
O = Other
N = None

***Exterior Type**

W = Wood
MV = Metal/Vinyl
S = Stucco
BS = Brick/Stone
O =Other
N = None

***Wall Framing Type**

BF = Balloon Frame
PF = Platform Frame
MS = Masonry/Stone
CB = Concrete Block
A = Adobe
O = Other

Comments:

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BASEMENT / CRAWLSPACE		SECTION 1	SECTION 2
1	*Conditioned/Unconditioned Type	uncondition	
2	*Type of Foundation	Crawl	
3	Type of Subfloor	[✓ Plywood] T&G Plank	Plywood T&G Plank
4	Total Square Feet of Floor (ft²)	1175	
5	Joist Spacing (in)	24 [✓ 16] Other_____	24 16 Other_____
6	Linear Feet of Perimeter (ft)	144	
7	Average Foundation Wall Height Above Grade (ft)	1ft ½	
8	Initial Vapor Barrier	Yes [✓ No]	Yes No
9	Open Exterior Wall Bottoms	Yes [✓ No]	Yes No
10	Open Interior Wall Bottoms	Yes [✓ No]	Yes No
11	Chases	Wire Plumbing HVAC [✓ None]	Wire Plumbing HVAC None
12	Initial Floor Insulation	Yes [✓ No]	Yes No
13	Initial R-Value	6 11 13 19	6 11 13 19
14	Floor Insulation Required	[✓ Yes] No	Yes No
15	R-Value Required	11 [✓ 19]	11 19
16	Sill Plate Require Sealing	Yes [✓ No]	Yes No
17	Sill Plate Require Insulation	Yes No _____ft	Yes No _____ft
18	Initial Foundation Wall Insulation	Yes No	Yes No
19	Existing Wall Insulation R-Value		
20	Exposed Water Lines Wrapped	Yes No _____ft	Yes No _____ft
21	Wiring Condition	Good	
22	Floor Joist Size	[✓ 2x6] 2x8 2x10 2x12	2x6 2x8 2x10 2x12
23	Crawlspace Door Compliant	Yes [✓ No]	Yes No

Comments: Crawl area is to low to work under by our standards

*Foundation Type	
Crawlspace	Insulated Slab
Basement	Uninsulated Slab
Pier/Exposed Floor	

***Conditioned/Unconditioned Type**

Conditioned
Unconditioned
Vented Unconditioned
Unintentionally Conditioned

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MOBILE HOME CEILING INSULATION								N/A
1	Cathedral (ft²)		7	Roof Color	White/Reflective/Shaded or Normal/Weathered	13	Interim Insulation Type	
2	Flat (ft²)		8	Type of Roof Covering	Shingle Metal Other	14	Interim Wx R-Value	
3	Total (ft²)		9	Length of Gutter Required		15	Total Number of Bags Required	
4	Peak Height		10	Roof Blowing Access	Side Top Gable	16	Number of Peal and Seal Required	
5	Joist Size (2x4 2x6 2x8)		11	Initial Insulation Type		17	Plumbing Vent Caps (# and Size)	
6	Type of Roof Framing	Bowstring Flat Pitched	12	Initial R-Value		18	Roof Coating (gals)	

Comments:

*Insulation R-Value & Depth			
Loose-Fill Fiberglass, Rock & Slag	R-Value	Batt/Blanket Fiberglass, Rock, & Slag	R-Value
3.5 – 5 inches	11	3 inches	11
4 – 5.5 inches	13	4 inches	13
5 – 8 inches	19	5.5 inches	19
6 – 9.5 inches	22	6.5 inches	22
8.5 – 13 inches	30	8.5 inches	30
11 – 16.5 inches	38	11 inches	38

MOBILE HOME SIDEWALLS		Sidewall 1	Sidewall 2	Sidewall 3	Sidewall 4
1	Wall Stud Size (2x2 2x3 2x4 2x6)				
2	Long Wall Orientation (North, South, East, West)				
3	Wall Ventilation	Yes No	Yes No	Yes No	Yes No
4	Carport/Porch Roof (ft)	L W	L W	L W	L W
5	Initial Insulation (Batt/Blanket, Loose Fill, Foam Core)	in	in	in	in

Comments:

MOBILE HOME BELLYBOARD		SECTION 1	SECTION 2
1	Floor Area (ft²)		
2	Direction of Joists	Longways Crossways	Longways Crossways
3	Depth of Joists	2x4 2x6 2x8	2x4 2x6 2x8
4	Plumbing Leaks	Yes No	Yes No
5	Wrap Exposed Water Lines	Yes No, ____ ft	Yes No, ____ ft
6	Initial Vapor Barrier	Yes No	Yes No
7	Belly Cavity Configuration	Square Rounded Flat	
8	Belly Condition	Good Average Poor	Square Rounded Flat
9	Belly Repair Required	Yes No	Yes No
10	*Insulation Location		Good Average Poor
11	Initial Insulation Depth (in)		
12	Max. Depth of Belly Cavity (in)		
13	Total Number of Bags Required		

Comments:

***Insulation Location**

Attached to Flooring
Between Joists
Attached Under Joists
Draped Below Joists
None

RFS301

BLOWER DOOR DIAGNOSTICS

	Location	Configuration	Adjust For Baseline	Pa	CFM
Initial	Front	[✓ Open] Ring A Ring B	[✓ Yes] No	50	[illegible]
Interim		Open Ring A Ring B	Yes No		

Comments:

ZONAL PRESSURES

Zone Tested	Initial WRTH	Interim WRTH	Zone Tested	Initial WRTH	Interim WRTH
Attic 1	46.3		Basement		
Attic 2			Crawlspace	40.3	
Cavity b/w 1st & 2nd Floor			Bellyboard		
Kneewall N S E W			Other:		
Kneewall N S E W			Other:		

Comments:

PRESSURE PAN TEST (Duct WRT House) **House WRT Duct** *Location ____/____ Pa* **N/A**

#	Location	Initial	Interim	#	Location	Initial	Interim	#	Location	Initial	Interim
1	LR	12.4		8	Middle Bed	7.6		15			
2	LR	13.2		9				16			
3	Dining	8.8		10				17			
4	Bath	23.2		11				18			
5	Bed 1	15.1		12				19			
6	Bath 2	10.0		13				1	Return	12.9	
7	M Bed	9.8		14				2	Return		

Comments:

Pressure Pan Multipliers

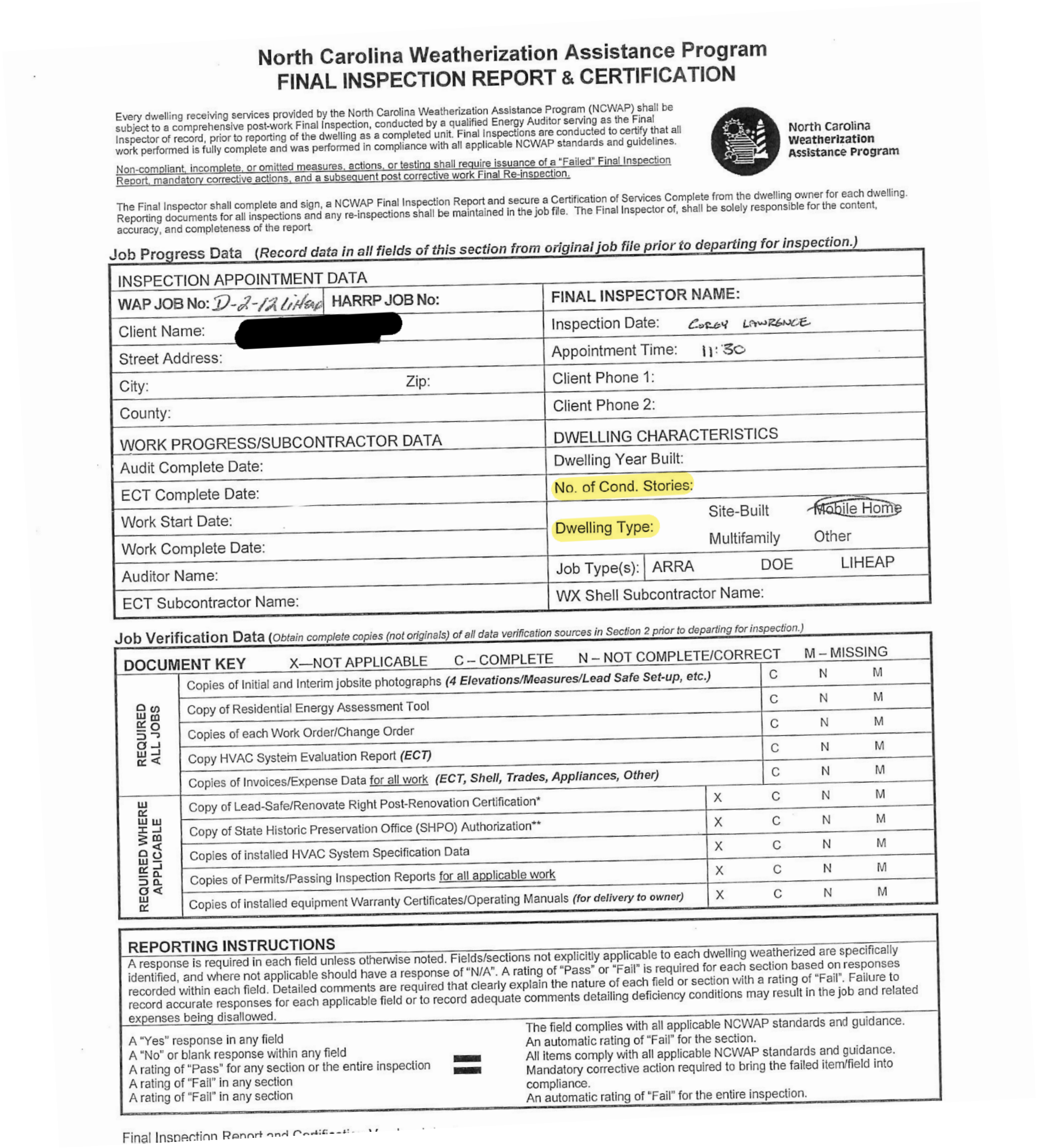
45 = 1.1	*30 = 1.66*	*15 = 3.5*
40 = 1.25	*25 = 2.0*	*10 = 5.0*
35 = 1.42	*20 = 2.5*	*5 = 10.0*

AIR SEALING COST-EFFECTIVENESS CHART (to be filled out by Crew/Shell Subcontractor Only)

Status	CFM50 Reading	CFM50 Per Hour	Cost-Effective Factor Per Hour	=	Number of People in Sealing Crew	X	Cost-Effective CFM50 Per Crew Hour
Interim Reading							
After Duct Sealing							
After Primary Air Sealing							
1st Discrete Sealing Hour				=		X	75 CFM
2nd Discrete Sealing Hour				=		X	75 CFM
3rd Discrete Sealing Hour				=		X	75 CFM
4th Discrete Sealing Hour				=		X	75 CFM

Comments:

Example of Final Inspection Report and Certification



North Carolina Weatherization Assistance Program
FINAL INSPECTION REPORT & CERTIFICATION

Every dwelling receiving services provided by the North Carolina Weatherization Assistance Program (NCWAP) shall be subject to a comprehensive post-work Final Inspection, conducted by a qualified Energy Auditor serving as the Final Inspector of record, prior to reporting of the dwelling as a completed unit. Final Inspections are conducted to certify that all work performed is fully complete and was performed in compliance with all applicable NCWAP standards and guidelines.

North Carolina
Weatherization
Assistance Program

Non-compliant, incomplete, or omitted measures, actions, or testing shall require issuance of a "Failed" Final Inspection Report, mandatory corrective actions, and a subsequent post corrective work Final Re-inspection.

The Final Inspector shall complete and sign, a NCWAP Final Inspection Report and secure a Certification of Services Complete from the dwelling owner for each dwelling. Reporting documents for all inspections and any re-inspections shall be maintained in the job file. The Final Inspector of, shall be solely responsible for the content, accuracy, and completeness of the report.

Job Progress Data ***(Record data in all fields of this section from original job file prior to departing for inspection.)***

INSPECTION APPOINTMENT DATA		
WAP JOB No: D-2-12 LiHeap	**HARRP JOB No:**	**FINAL INSPECTOR NAME:**
Client Name: [redacted]		Inspection Date: COREY LAWRENCE
Street Address:		Appointment Time: 11:30
City:	Zip:	Client Phone 1:
County:		Client Phone 2:
WORK PROGRESS/SUBCONTRACTOR DATA		DWELLING CHARACTERISTICS
Audit Complete Date:		Dwelling Year Built:
ECT Complete Date:		No. of Cond. Stories:
Work Start Date:		Dwelling Type: Site-Built ~~Mobile Home~~
Work Complete Date:		Multifamily Other
Auditor Name:		Job Type(s): ARRA DOE LIHEAP
ECT Subcontractor Name:		WX Shell Subcontractor Name:

Job Verification Data *(Obtain complete copies (not originals) of all data verification sources in Section 2 prior to departing for inspection.)*

DOCUMENT KEY	X—NOT APPLICABLE C – COMPLETE N – NOT COMPLETE/CORRECT M – MISSING				
REQUIRED ALL JOBS	Copies of Initial and Interim jobsite photographs ***(4 Elevations/Measures/Lead Safe Set-up, etc.)***		C	N	M
	Copy of Residential Energy Assessment Tool		C	N	M
	Copies of each Work Order/Change Order		C	N	M
	Copy HVAC System Evaluation Report ***(ECT)***		C	N	M
	Copies of Invoices/Expense Data for all work ***(ECT, Shell, Trades, Appliances, Other)***		C	N	M
REQUIRED WHERE APPLICABLE	Copy of Lead-Safe/Renovate Right Post-Renovation Certification*	X	C	N	M
	Copy of State Historic Preservation Office (SHPO) Authorization**	X	C	N	M
	Copies of installed HVAC System Specification Data	X	C	N	M
	Copies of Permits/Passing Inspection Reports for all applicable work	X	C	N	M
	Copies of installed equipment Warranty Certificates/Operating Manuals ***(for delivery to owner)***	X	C	N	M

REPORTING INSTRUCTIONS

A response is required in each field unless otherwise noted. Fields/sections not explicitly applicable to each dwelling weatherized are specifically identified, and where not applicable should have a response of "N/A". A rating of "Pass" or "Fail" is required for each section based on responses recorded within each field. Detailed comments are required that clearly explain the nature of each field or section with a rating of "Fail". Failure to record accurate responses for each applicable field or to record adequate comments detailing deficiency conditions may result in the job and related expenses being disallowed.

A "Yes" response in any field	=	The field complies with all applicable NCWAP standards and guidance.
A "No" or blank response within any field	=	An automatic rating of "Fail" for the section.
A rating of "Pass" for any section or the entire inspection	=	All items comply with all applicable NCWAP standards and guidance.
A rating of "Fail" in any section	=	Mandatory corrective action required to bring the failed item/field into compliance.
A rating of "Fail" in any section	=	An automatic rating of "Fail" for the entire inspection.

Final Inspection Report and

General Health and Safety Measures

SMOKE/CO ALARMS	**LOCATION(S)**	**EXISTING/INSTALLED**	**TEST OK**
Smoke Alarms	FRONT DOOR + HALL	[✓ Existing] Installed	[✓ Yes] No
Carbon Monoxide Alarms	HALL NEAR RETURN + THERMOSTAT	Existing [✓ Installed]	[✓ Yes] No
1+ devices present per Conditioned Story?	[✓ Yes] No	Installed/located per MFR Specifications?	[✓ Yes] No

VAPOR BARRIER/MOISTURE RETARDER			
Conditions suitable for Vapor Barrier install *(If No, explain reasons in Comments and omit remainder of section)*?			Yes [✓ No]
Area covered clear of obstructions/debris?	[✓ Yes] No	Poly sheeting is ≥6 mil and opaque in color?	[✓ Yes] No
Entire area covered/no exposed edges?	Yes [✓ No]	Areas below cond/uncond space separated?	[✓ Yes] No
Poly extends up walls/piers ≥6 inches?	Yes [✓ No]	Joints/edges compliantly sealed/overlapped?	Yes [✓ No]

EXHAUST VENTING	**VENTED OUTSIDE**	**DAMPER OK**	**PIPE RUN OK**	**FLOW TEST**
A. Kitchen Exhaust *(≥100 CFM Minimum)*	Yes [✓ No]	Yes No	Yes No	N/A CFM
B. Bathroom 1 Exhaust *(≥ 50 CFM Minimum)*	[✓ Yes] No	[✓ Yes] No	[✓ Yes] No	CFM
$[0.01 \times \_\_(A_{floor}) + 7.5 \times (\_\_N_{br} + 1)] + [.25 \times \_\_CFM_{Fan\ Deficient}] - [0.5 \times (\frac{(CFM_{50})}{\_\_(N)} - \frac{2\_\_(A)_{floor}}{100})]$				CFM
Clothes Dryer Exhaust [✓ N/A]	Yes No	Yes No	Yes No	

OTHER HEALTH AND SAFETY MEASURES/MINOR REPAIRS *(Record individual repair measures observed/ inspected in Comments)*

All mandatory/allowable plumbing, electrical, moisture intrusion or other Minor repairs complete/compliant? Yes No

PASS ☒

FAIL ☐

COMMENTS:

ONLY HAS TEMP. FOUNDATION
NO DRYER
KIT. FAN RECIRCULATES

HVAC System Evaluation

HEATING/COOLING SYSTEM INSPECTION **Record applicable data for each system present, use additional sheets as needed**

No. of Primary Heating Systems Present: 1	Location 1: REAR CENTER	Location 2: HALLWAY
No. of Supplemental Systems Present: 0	Location 1:	Location 2:

Each system present complies with all applicable standards for Primary and/or Supplemental Heat Sources? [✓ Yes] No

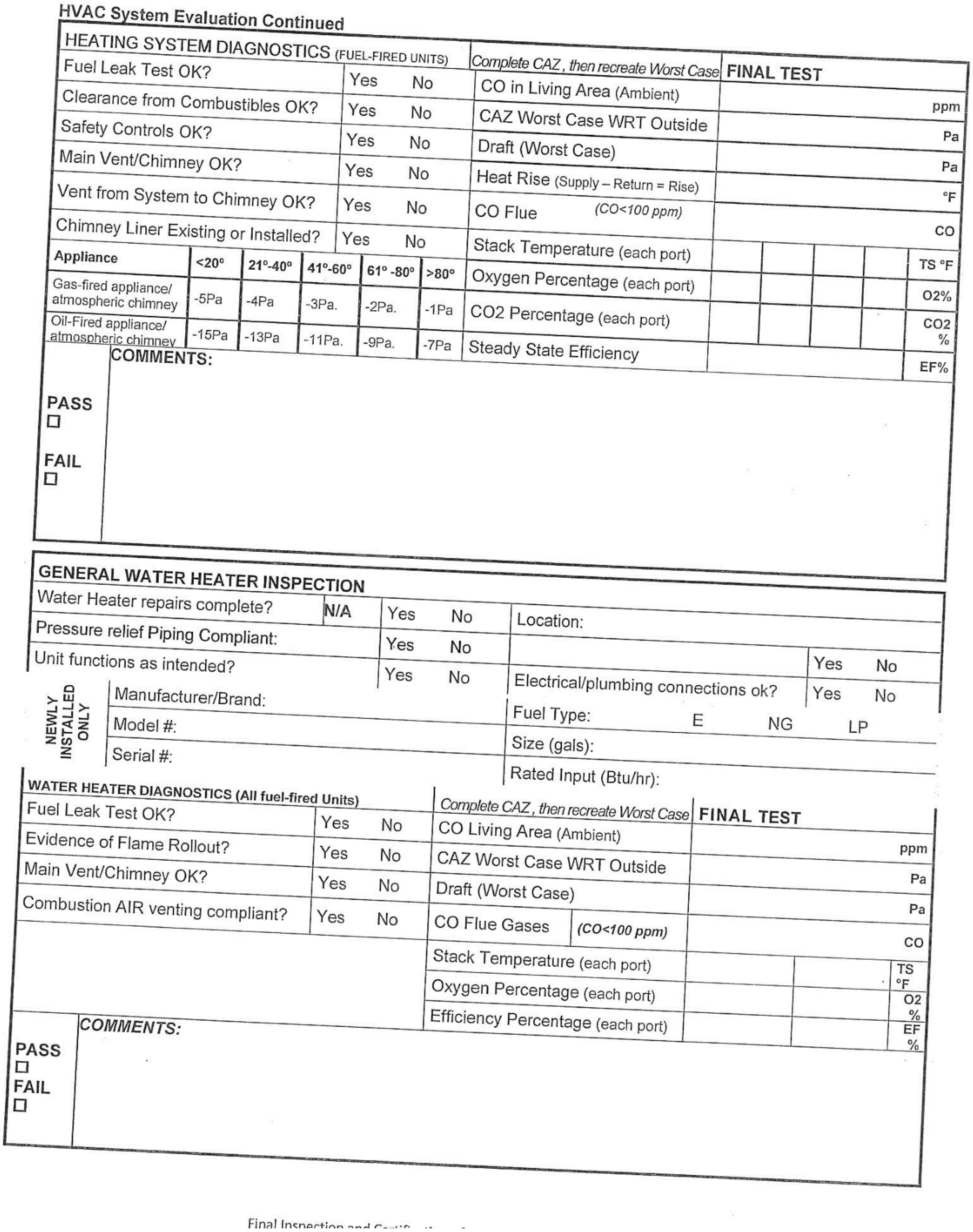
FORCED AIR SYSTEMS ONLY	Return Location(s): @ UNIT IN HALL		Filter(s) clean and installed correctly?	[✓ Yes] No
	No. of replacement filters provided: 6		Thermostat compliant/functioning properly?	✓
WINDOW AC /HEAT PUMPS ONLY	Evaporator coils cleaned?	Yes No	Unit powers on and functions as intended?	Yes No
	Coil fins straightened?	Yes No	Unit air sealed, if not removed seasonally?	Yes No
	Foam filter cleaned?	Yes No	Air sealing work is neat and of good quality?	Yes No
NEWLY INSTALLED SYSTEMS ONLY	Manufacturer/Brand:		Location:	
	Model #:		Fuel Source: E NG LP O W K	
	Serial #:		Unit Type: FA Gravity Boiler SH	
	Equipment quantities, components, and installation consistent with payment invoice?			Yes No

PASS ☒

FAIL ☐

COMMENTS:

NEW RETURN GRILL INSTALLED



HVAC System Evaluation Continued

HEATING SYSTEM DIAGNOSTICS (FUEL-FIRED UNITS)		
Fuel Leak Test OK?	Yes	No
Clearance from Combustibles OK?	Yes	No
Safety Controls OK?	Yes	No
Main Vent/Chimney OK?	Yes	No
Vent from System to Chimney OK?	Yes	No
Chimney Liner Existing or Installed?	Yes	No

Appliance	**<20°**	**21°-40°**	**41°-60°**	**61° -80°**	**>80°**
Gas-fired appliance/ atmospheric chimney	-5Pa	-4Pa	-3Pa.	-2Pa.	-1Pa
Oil-Fired appliance/ atmospheric chimney	-15Pa	-13Pa	-11Pa.	-9Pa.	-7Pa

Complete CAZ, then recreate Worst Case	**FINAL TEST**				
CO in Living Area (Ambient)					ppm
CAZ Worst Case WRT Outside					Pa
Draft (Worst Case)					Pa
Heat Rise (Supply – Return = Rise)					°F
CO Flue *(CO<100 ppm)*					CO
Stack Temperature (each port)					TS °F
Oxygen Percentage (each port)					O2%
CO2 Percentage (each port)					CO2 %
Steady State Efficiency					EF%

PASS ☐

FAIL ☐

COMMENTS:

GENERAL WATER HEATER INSPECTION

Water Heater repairs complete?	N/A	Yes	No	Location:		
Pressure relief Piping Compliant:		Yes	No			
Unit functions as intended?		Yes	No		Yes	No
				Electrical/plumbing connections ok?	Yes	No

NEWLY INSTALLED ONLY

Manufacturer/Brand:	Fuel Type: E NG LP
Model #:	Size (gals):
Serial #:	Rated Input (Btu/hr):

WATER HEATER DIAGNOSTICS (All fuel-fired Units)		
Fuel Leak Test OK?	Yes	No
Evidence of Flame Rollout?	Yes	No
Main Vent/Chimney OK?	Yes	No
Combustion AIR venting compliant?	Yes	No

Complete CAZ, then recreate Worst Case	**FINAL TEST**		
CO Living Area (Ambient)			ppm
CAZ Worst Case WRT Outside			Pa
Draft (Worst Case)			Pa
CO Flue Gases *(CO<100 ppm)*			CO
Stack Temperature (each port)			TS °F
Oxygen Percentage (each port)			O2 %
Efficiency Percentage (each port)			EF %

PASS ☐

FAIL ☐

COMMENTS:

HVAC System Evaluation Continued

COOK STOVE INSPECTION (FUEL-FIRED UNITS ONLY)					**FINAL TEST**		
Fuel Type: NG LP		*(CO≤100 ppm)*	*(CO≤400 ppm)*	*(CO≤25 ppm)*			
Fuel Leak Test OK?	Yes No	Oven	CO	AF	Front Left		Front Right	
Flex Connector OK?	Yes No				Rear Left		Rear Right	

FREESTANDING FIREPLACE/CHIMNEY INSPECTION (COMPLETE IF PRESENT)

Permanent seal installed if fireplace abandoned, and/or removable seal provided if used seasonally? Yes No

Is seal indicator flag present/visible? Yes No Location(s):

PASS ☐
FAIL ☐

COMMENTS:

ELEC. STOVE

Insulation Measures

ATTIC/KNEE WALL/VAULTED CEILING INSULATION INSPECTION

Characteristics	Attic 1	Attic 2	Knee Wall 1	Knee Wall 2			N/A
Access Location	ROOF TOP				MSDS copy posted?	Yes	[✓ No]
Attic/Ceiling Type	CATHEDRAL/ FLAT /AFRAME				Insulation Certificate posted?	Yes	[✓ No]
Square Footage	840				Depth markers visible?	Yes	[✓ No]
					Depth markers placed?	Yes	[✓ No]
Final Insulation Type	BLOWN FIBERGLASS				Junction boxes flagged?	Yes	[✓ No]
					Wind baffles installed?	Yes	[✓ No]
Final R-Value	R-24				Soffit vents unobstructed?	Yes	[✓ No]
Total Qty Added	10				Attic access air sealed?	[✓ Yes]	No
					Attic access insulated?	[✓ Yes]	No

Wall tops/plates, penetrations, and chases fully air sealed using compliant materials?		[✓ No]
Compliant blocking/clearance maintained between insulation and heat sources/mechanicals?	[✓ Yes]	No
Attic insulation uniformly installed over entire area and in alignment with the air barrier?	[✓ Yes]	No
If not uniformly installed, is deficit/justification reflected in bag count/SF invoiced and noted in job file?	[✓ Yes]	No
Final insulation thickness consistent with the quantity of insulation/bag count on invoice?	[✓ Yes]	No
MH Roof Patches properly sealed and with good workmanship?	[✓ Yes]	No

PASS ☒
FAIL ☐

COMMENTS:

ROOF/ATTIC BLOWN PATCHED AND SEALED / ROOF IS NOW HOUNDS TOOTH WHITE

Insulation Measures Cont.

SIDEWALL INSULATION INSPECTION		[✓ **N/A**]
Was Sidewall insulation installed? ***(if Yes, complete section below)***	Yes	No
If No, does IR camera inspection confirm uniform existing insulation in all wall cavities?	Yes	No
If No, does visual inspection/file documentation justify omitting the measure?	Yes	No
Indicate wall(s) that were insulated: N S E W — Work performed from interior or exterior?	Int	Ext
Inspection with IR camera confirms uniform coverage in all wall cavities with no settling?	Yes	No
Inspection of core samples from each wall confirms dense-packing uniformly achieved?	Yes	No
Walls/bottom plates properly air sealed prior to installing insulation?	Yes	No
Wall plugs, wall pops, and/or interior trim work installed or repaired in a neat and quality manner?	Yes	No
Net Wall Area calculated during initial assessment confirmed accurate?	Yes	No
Net Wall Area consistent with the quantity of insulation/bag count on invoice?	Yes	No

PASS ☐
FAIL ☐

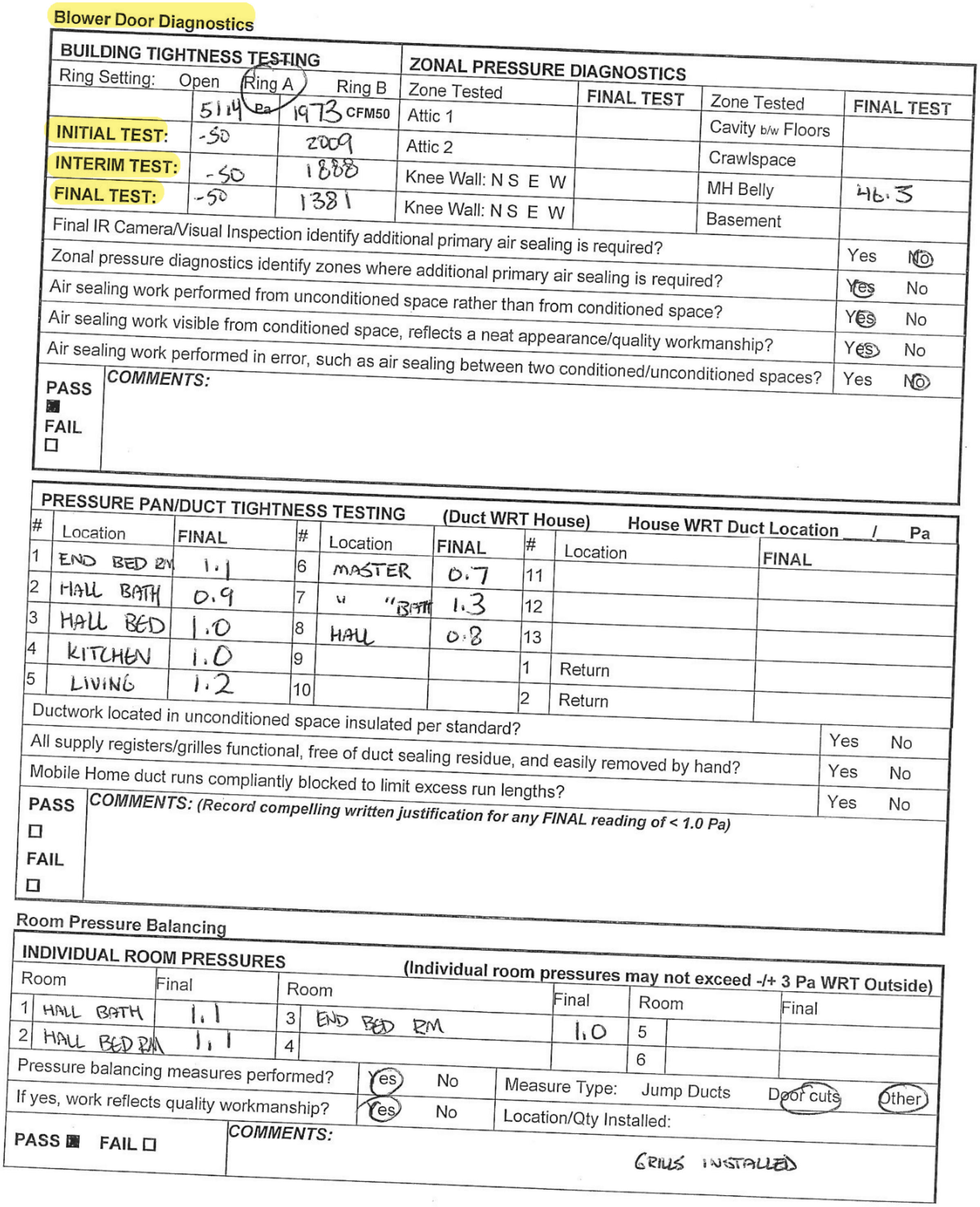
COMMENTS:

FLOOR/BAND/FOUNDATION/BELLY INSULATION			**N/A**
Foundation Type: TEMPORARY	Floor Insulation Installed or Existing?	[✓ Installed]	Existing
Square Footage: 840	Full or Partial installation?	[✓ Full]	Partial
Crawl Access Location 1: TAKE A PICK			
Crawl Access Location 2: ANYWHERE YOU WANT IT TO BE	FINAL Floor Insulation R-value: 19		
All penetrations, floor beneath bathtub, and all chases properly air sealed?		[✓ Yes]	No
Face of insulation toward subfloor and adequate supports in place?		[✓ Yes]	No
Insulation in continuous contact with the subfloor with no compressed areas?		[✓ Yes]	No
Insulation materials and workmanship are high quality?		[✓ Yes]	No

PASS ■
FAIL ☐

COMMENTS:

BELLY REPAIRS MADE IN SEVERAL AREAS.



Blower Door Diagnostics

BUILDING TIGHTNESS TESTING			ZONAL PRESSURE DIAGNOSTICS			
Ring Setting:	Open [✓ Ring A]	Ring B	Zone Tested	FINAL TEST	Zone Tested	FINAL TEST
	5114 Pa	1973 CFM50	Attic 1		Cavity b/w Floors	
INITIAL TEST:	-50	2009	Attic 2		Crawlspace	
INTERIM TEST:	-50	1888	Knee Wall: N S E W		MH Belly	46.3
FINAL TEST:	-50	1381	Knee Wall: N S E W		Basement	

Final IR Camera/Visual Inspection identify additional primary air sealing is required?	Yes [✓ No]
Zonal pressure diagnostics identify zones where additional primary air sealing is required?	[✓ Yes] No
Air sealing work performed from unconditioned space rather than from conditioned space?	[✓ Yes] No
Air sealing work visible from conditioned space, reflects a neat appearance/quality workmanship?	[✓ Yes] No
Air sealing work performed in error, such as air sealing between two conditioned/unconditioned spaces?	Yes [✓ No]

PASS ☒ **FAIL** ☐

COMMENTS:

PRESSURE PAN/DUCT TIGHTNESS TESTING **(Duct WRT House)** **House WRT Duct Location ___ / ___ Pa**

#	Location	FINAL	#	Location	FINAL	#	Location	FINAL
1	END BED RM	1.1	6	MASTER	0.7	11		
2	HALL BATH	0.9	7	" "BATH	1.3	12		
3	HALL BED	1.0	8	HALL	0.8	13		
4	KITCHEN	1.0	9			1	Return	
5	LIVING	1.2	10			2	Return	

Ductwork located in unconditioned space insulated per standard?	Yes No
All supply registers/grilles functional, free of duct sealing residue, and easily removed by hand?	Yes No
Mobile Home duct runs compliantly blocked to limit excess run lengths?	Yes No

PASS ☐ **FAIL** ☐

COMMENTS: (Record compelling written justification for any FINAL reading of < 1.0 Pa)

Room Pressure Balancing

INDIVIDUAL ROOM PRESSURES **(Individual room pressures may not exceed -/+ 3 Pa WRT Outside)**

	Room	Final		Room	Final		Room	Final
1	HALL BATH	1.1	3	END BED RM	1.0	5		
2	HALL BED RM	1.1	4			6		

Pressure balancing measures performed?	[✓ Yes] No	Measure Type: Jump Ducts [✓ Door cuts] [✓ Other]
If yes, work reflects quality workmanship?	[✓ Yes] No	Location/Qty Installed:

PASS ☒ **FAIL** ☐

COMMENTS:

GRILLS INSTALLED

Baseload Reduction Measures

REFRIGERATOR EVALUATION			
Year Manufactured:	How was year manufactured determined:		
Was refrigerator evaluated for replacement?		Yes	No
Refrigerator metered or database (DB) used to determine consumption?		Meter	DB
Metering period continued for at least 120 minutes? *(Peak watts not to exceed ≤350-400)*		Yes	No
Was refrigerator replaced? *(If yes, complete section below)*		Yes	No
Savings to Investment Ratio (SIR) was calculated based on evaluation data:			
Other appliances evaluated for replacement or the 2-for-1 replacement option used?		Yes	No
Visual inspection and file documentation confirm old appliance(s) removed from site?		Yes	No
Manufacturer:	Model No:	Serial No:	

LIGHTING INSPECTION *(Data for >8 CFLs need not be recorded)* **Total CFLs INSTALLED: ____**

	Location	Watts	Lamp Type				Location	Watts	Lamp Type		
1	END BR 4x	13	~~Standard~~	Flood	Other	5	MBR 2x	13	~~Standard~~	Flood	Other
2	HALL BATH 2x	13	~~Standard~~	Flood	Other	6			Standard	Flood	Other
3	HALL 1x	20	~~Standard~~	Flood	Other	7			Standard	Flood	Other
4	LR 5x	13	~~Standard~~	Flood	Other	8			Standard	Flood	Other

PASS ■ FAIL ☐

COMMENTS:

General Heat Waste Measures

WATER HEATER INSULATION DID NOT INSULATE TOP OFF UNIT DUE TO ELEC. ISSUES.

Water Heater Tank Insulated?	[✓ Yes]	No	Current Water Temperature reading:	118	°F
Tank insulation securely fastened?	[✓ Yes]	No	First 5 feet of water lines Insulated?	[✓ Yes]	No
Spacers installed where applicable?	[✓ Yes]	No	Pressure Relief Piping:	Existing	[✓ Installed]
Flap cut for Control Panel:	[✓ Yes]	No	Pressure relief piped to outdoors?	[✓ Yes]	No
Clearance from combustibles maintained at top/bottom of tank per requirements for type?				Yes	No

WATER FLOW REDUCTION DEVICES

Aerator installed in kitchen?	[✓ Yes]	No	Aerator installed in bathroom(s)?	Yes	[✓ No]
Low-flow Shower Head(s) installed in all actively used shower locations?				[✓ Yes]	No

PASS ■ FAIL ☐

COMMENTS: TOP OF HW TANK NOT INSULATED EXPOSED ELECTRICAL NO ROMEX CONNECTORS. WIRE NUTS INSTALLED.

Incidental Repair Measures

DESCRIPTION OF INCIDENTAL REPAIR MEASURES			**Materials**	**Labor**	**Subtotal**
No. of Windows/Doors repaired/replaced if any: Windows ________ Doors					
All repairs required for effective performance/preservation of measures/dwelling?			Yes	No	**Total**
Photo documentation and SIR cost-justification in job file for all window/door			Yes	No	

PASS ■ FAIL ☐

COMMENTS:

Final Client Education and Deliverables

WARRANTY DATA, OPERATING MANUALS, INSTRUCTIONS, & PHOTOGRAPHS	
Warranty Certificates, warranty claim instructions, and Operating Manuals delivered to dwelling owner?	[✓ Yes] No
All required/needed Client Education provided and acknowledgments of receipt collected?	[✓ Yes] No
Owner and Occupants have been consulted and all questions have been satisfactorily addressed?	[✓ Yes] No
All required photographs, notes, comments, and necessary file documentation collected?	[✓ Yes] No
COMMENTS:	

CERTIFICATION OF SERVICES COMPLETE

☐ FAIL

This post-work Inspection has identified services performed that do not comply with applicable NCWAP standards and guidelines. The details of each deficiency observed are recorded herein and each deficiency requires a compliant corrective action prior to issuance of a passing inspection. ***A mandatory Final re-Inspection will be scheduled following correction of <u>all</u> deficiencies***.

Final Inspector Signature: ______________________ **Date:** ______________

☒ PASS

This Final post-work Inspection has identified no deficiencies in material quality, workmanship, or compliance with applicable NCWAP standards and guidelines. I certify that I have personally inspected all areas of the dwelling and all measures and/or services provided, and have conducted all required diagnostic testing, and accurately recorded inspection results. I further attest that to the best of my knowledge and ability that all applicable Weatherization Assistance Program services, ***have now concluded***.

Final Inspector Signature: ______________________ **Date:** 1-29-13

CERTIFICATION OF SERVICES COMPLETE

By signing below, I, as the owner of the dwelling referenced on Page 1 herein, do hereby agree, and certify, that the Weatherization Assistance Program (WAP) services for which my dwelling was previously deemed eligible, ***have now concluded***.

The Final Inspector present before me has signed the statement written above certifying that all services rendered meet applicable WAP standards and guidelines, and he/she has permitted me the opportunity to review Pages 1-8 of the Final Inspection Report, and where requested, explained the services provided, including any deviation from the previously authorized Scope of Work.

The Inspector has provided me, and where applicable the dwelling occupants, with written and verbal instruction on the operation and maintenance of all installed equipment and/or appliances (including supplying operation manuals, warranty certificates, and warranty claim instructions) where applicable, and has addressed all questions and/or concerns, if any, to my complete satisfaction. I further understand and agree that I am fully responsible for all future maintenance of systems and/or appliances installed, including initiation and execution of future warranty claims, should any such claim be required.

Services administered on behalf of the North Carolina Weatherization Assistance Program (NCWAP) are to be provided in compliance with applicable state and federal WAP standards and guidelines, as well as applicable local building codes. Understanding this fact fully, I agree to hold the Weatherization Service Provider (WSP), its designees, and assigns, harmless from any liability known or unknown, associated with the services provided at my request and with my prior authorization, insomuch as such services were provided in good faith, and in compliance with all specified standards, guidelines, and codes.

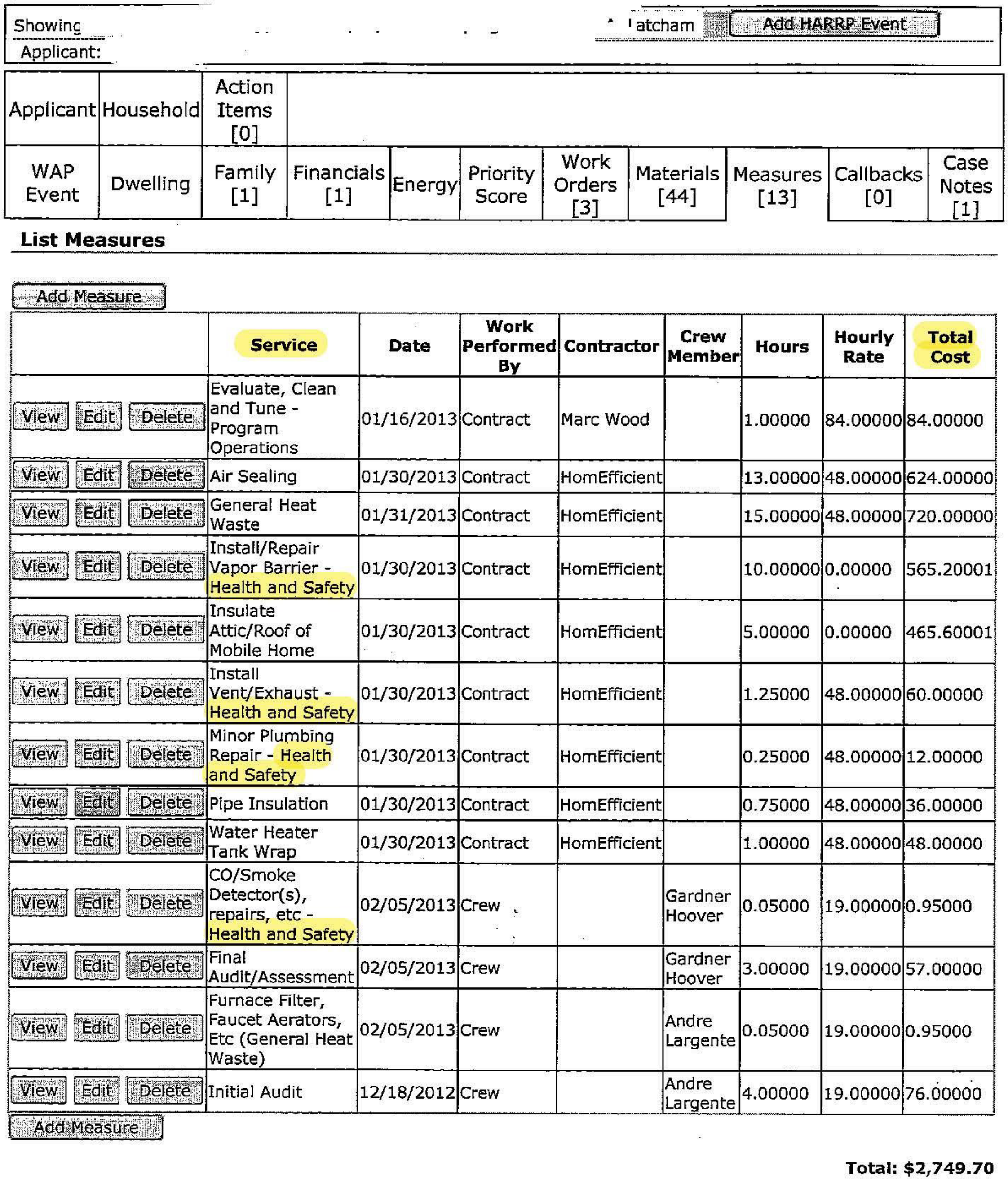
I do hereby reaffirm, my certification to comply fully with all WAP guidelines, including my continued cooperation with requests by the WSP, to provide ready access to my dwelling, at mutually agreed upon future times, for the purposes of conducting subsequent post-work inspections as required to comply with state and federal WAP guidelines. I understand that failure or refusal to provide access as requested may result in my being liable for reimbursement to the WSP for the full value of all expenses paid in association with the delivery of WAP services to my dwelling.

I further understand and agree, that my certification above withstanding, that **no promises or statements, made by any party, including the WSP, its designees, or assigns, relating to the receipt of additional, amended, pending, or future services** at my dwelling, whether such promises or statements be written, verbal, or implied, shall survive this Certification of Services Complete. I further agree and certify that the nature, condition, and quality of all services and/or equipment provided are acceptable to me.

Dwelling Owner Signature: [redacted] **Date:** 1/29/13

Example List of Measures Performed

AR4CA WAM4015 Page 1 of 1

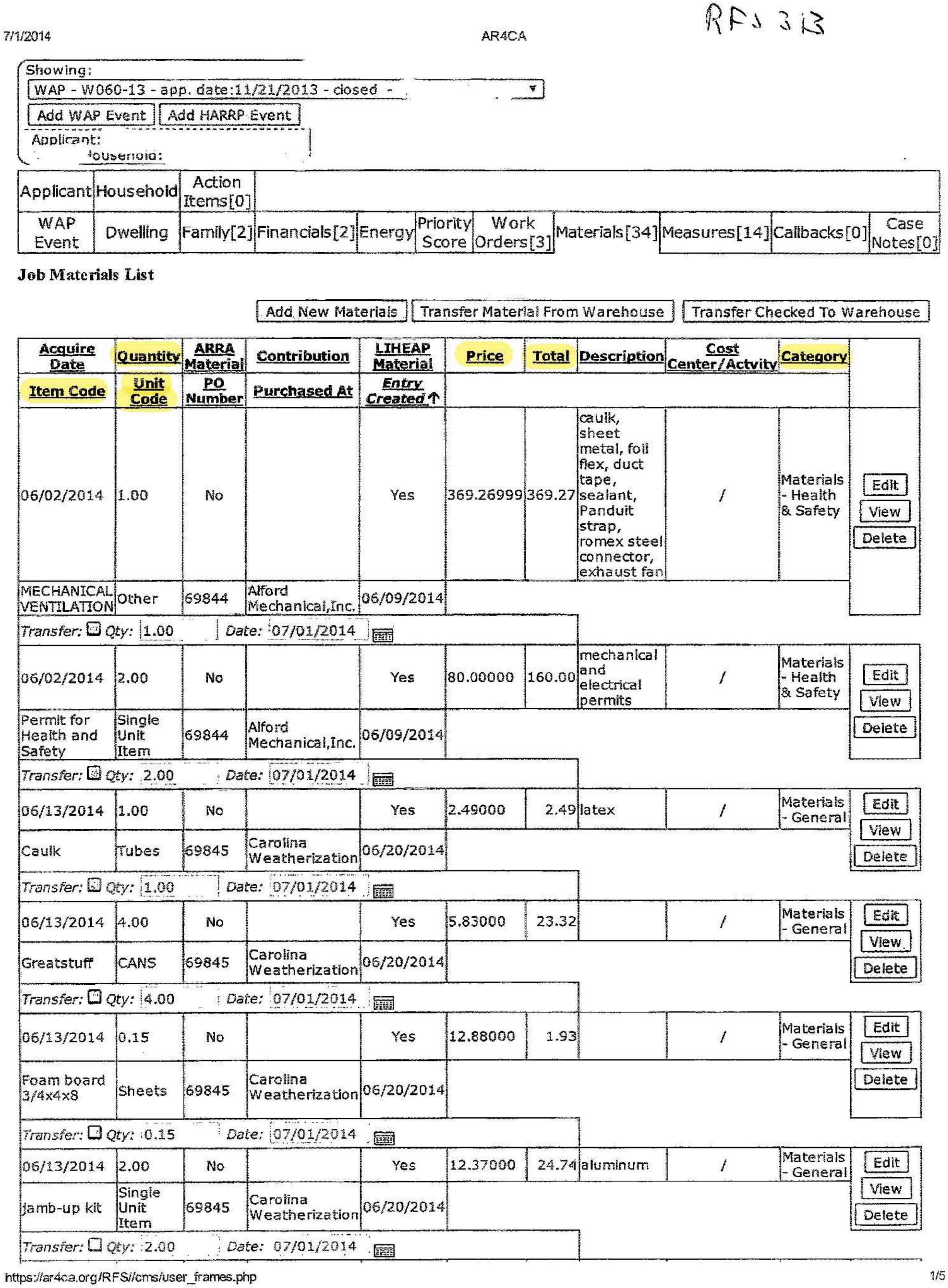


List Measures

	Service	Date	Work Performed By	Contractor	Crew Member	Hours	Hourly Rate	Total Cost
View Edit Delete	Evaluate, Clean and Tune - Program Operations	01/16/2013	Contract	Marc Wood		1.00000	84.00000	84.00000
View Edit Delete	Air Sealing	01/30/2013	Contract	HomEfficient		13.00000	48.00000	624.00000
View Edit Delete	General Heat Waste	01/31/2013	Contract	HomEfficient		15.00000	48.00000	720.00000
View Edit Delete	Install/Repair Vapor Barrier - Health and Safety	01/30/2013	Contract	HomEfficient		10.00000	0.00000	565.20001
View Edit Delete	Insulate Attic/Roof of Mobile Home	01/30/2013	Contract	HomEfficient		5.00000	0.00000	465.60001
View Edit Delete	Install Vent/Exhaust - Health and Safety	01/30/2013	Contract	HomEfficient		1.25000	48.00000	60.00000
View Edit Delete	Minor Plumbing Repair - Health and Safety	01/30/2013	Contract	HomEfficient		0.25000	48.00000	12.00000
View Edit Delete	Pipe Insulation	01/30/2013	Contract	HomEfficient		0.75000	48.00000	36.00000
View Edit Delete	Water Heater Tank Wrap	01/30/2013	Contract	HomEfficient		1.00000	48.00000	48.00000
View Edit Delete	CO/Smoke Detector(s), repairs, etc - Health and Safety	02/05/2013	Crew		Gardner Hoover	0.05000	19.00000	0.95000
View Edit Delete	Final Audit/Assessment	02/05/2013	Crew		Gardner Hoover	3.00000	19.00000	57.00000
View Edit Delete	Furnace Filter, Faucet Aerators, Etc (General Heat Waste)	02/05/2013	Crew		Andre Largente	0.05000	19.00000	0.95000
View Edit Delete	Initial Audit	12/18/2012	Crew		Andre Largente	4.00000	19.00000	76.00000

Total: $2,749.70

Example List of Materials Purchased



RFS 313

7/1/2014 AR4CA

Showing:

WAP - W060-13 - app. date:11/21/2013 - closed - ▾

Applicant:

ousehold:

Job Materials List

Acquire Date	Quantity	ARRA Material	Contribution	LIHEAP Material	Price	Total	Description	Cost Center/Actvity	Category	
Item Code	**Unit Code**	**PO Number**	**Purchased At**	***Entry Created*** ↑						
06/02/2014	1.00	No		Yes	369.26999	369.27	caulk, sheet metal, foil flex, duct tape, sealant, Panduit strap, romex steel connector, exhaust fan	/	Materials - Health & Safety	Edit View Delete
MECHANICAL VENTILATION	Other	69844	Alford Mechanical,Inc.	06/09/2014						
Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014								
06/02/2014	2.00	No		Yes	80.00000	160.00	mechanical and electrical permits	/	Materials - Health & Safety	Edit View Delete
Permit for Health and Safety	Single Unit Item	69844	Alford Mechanical,Inc.	06/09/2014						
Transfer: ☐ *Qty:* 2.00		*Date:* 07/01/2014								
06/13/2014	1.00	No		Yes	2.49000	2.49	latex	/	Materials - General	Edit View Delete
Caulk	Tubes	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014								
06/13/2014	4.00	No		Yes	5.83000	23.32		/	Materials - General	Edit View Delete
Greatstuff	CANS	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 4.00		*Date:* 07/01/2014								
06/13/2014	0.15	No		Yes	12.88000	1.93		/	Materials - General	Edit View Delete
Foam board 3/4x4x8	Sheets	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 0.15		*Date:* 07/01/2014								
06/13/2014	2.00	No		Yes	12.37000	24.74	aluminum	/	Materials - General	Edit View Delete
jamb-up kit	Single Unit Item	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 2.00		*Date:* 07/01/2014								

https://ar4ca.org/RFS//cms/user_frames.php 1/5

06/13/2014	1.50	No		Yes	4.97000	7.46		/	Materials - General	Edit View Delete
Caulk	Tubes	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 1.50 Date: 07/01/2014										
06/13/2014	0.25	No		Yes	57.70000	14.43	air seal behind chimney exhaust	/	Materials - General	Edit View Delete
Metal Flashing	Rolls	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 0.25 Date: 07/01/2014										
06/13/2014	0.25	No		Yes	57.70000	14.43	air seal barrier around chimney	/	Materials - General	Edit View Delete
Metal Flashing	Rolls	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 0.25 Date: 07/01/2014										
06/13/2014	1.00	No		Yes	5.00000	5.00	high heat	/	Materials - General	Edit View Delete
Caulk	Tubes	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 1.00 Date: 07/01/2014										
06/13/2014	0.25	No		Yes	57.70000	14.43	air seal around can lights	/	Materials - General	Edit View Delete
Metal Flashing	Rolls	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 0.25 Date: 07/01/2014										
06/13/2014	9.00	No		Yes	12.88000	115.92	air seal knee walls	/	Materials - General	Edit View Delete
Foam board 3/4x4x8	Sheets	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 9.00 Date: 07/01/2014										
06/13/2014	1.00	No		Yes	12.18000	12.18		/	Materials - General	Edit View Delete
3M foil tape	Rolls	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 1.00 Date: 07/01/2014										
06/13/2014	1.00	No		Yes	3.88000	3.88	clear squeeze	/	Materials - General	Edit View Delete
Caulk	Tubes	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 1.00 Date: 07/01/2014										
06/13/2014	4.00	No		Yes	8.97000	35.88	16x20 return air grille	/	Materials - General	Edit View Delete
return vent	Single Unit Item	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ Qty: 4.00 Date: 07/01/2014										

06/13/2014	0.50	No		Yes	12.88000	6.44		/	Materials - General	Edit View Delete
Foam board 3/4x4x8	Single Unit Item	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 0.50 *Date:* 07/01/2014										
06/13/2014	908.00	No		Yes	0.60000	544.80	blown fiberglass R-30	/	Materials - General	Edit View Delete
Blown Insulation	Sq Feet	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 908.00 *Date:* 07/01/2014										
06/13/2014	25.00	No		Yes	0.60000	15.00	R-19	/	Materials - General	Edit View Delete
BATT INSULATION	Rolls	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 25.00 *Date:* 07/01/2014										
06/13/2014	0.25	No		Yes	72.00000	18.00	100 per bundle	/	Materials - General	Edit View Delete
Baffles	Bag	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 0.25 *Date:* 07/01/2014										
06/13/2014	1.00	No		Yes	13.10000	13.10		/	Materials - General	Edit View Delete
mastic tape	Gallons	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 1.00 *Date:* 07/01/2014										
06/13/2014	1.00	No		Yes	21.99000	21.99		/	Materials - General	Edit View Delete
Water Heater jacket foil	Single Unit Item	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 1.00 *Date:* 07/01/2014										
06/13/2014	6.00	No		Yes	0.44000	2.64	36" zip ties	/	Materials - General	Edit View Delete
Cable Ties	Single Unit Item	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 6.00 *Date:* 07/01/2014										
06/13/2014	0.25	No		Yes	12.18000	3.05		/	Materials - General	Edit View Delete
FSK FOIL TAPE	Rolls	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 0.25 *Date:* 07/01/2014										
06/13/2014	3.00	No		Yes	5.83000	17.49		/	Materials - General	Edit View Delete
Greatstuff	CANS	69845	Carolina Weatherization	06/20/2014						
Transfer: ☐ *Qty:* 3.00 *Date:* 07/01/2014										
06/13/2014	1.00	No		Yes	7.94000	7.94	3 (90 day) pleated filters; 14x20x1	/	Materials - General	Edit View Delete
Air Filter	Single Unit Item	69845	Carolina Weatherization	06/23/2014						

Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014									
06/13/2014	1.00	No		Yes	7.94000	7.94	3 (90 day) pleated filters; 16x20x1		/	Materials - General	Edit View Delete
Air Filter	Single Unit Item	69845	Carolina Weatherization	06/23/2014							
Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014									
06/13/2014	1606.00	No		Yes	0.20000	321.20			/	Materials - Health & Safety	Edit View Delete
visqueen 10 x100	Sq Feet	69845	Carolina Weatherization	06/23/2014							
Transfer: ☐ *Qty:* 1606.00		*Date:* 07/01/2014									
06/13/2014	2.50	No		Yes	5.30000	13.25	3/4" x10		/	Materials - Health & Safety	Edit View Delete
PVC PIPE	Single Unit Item	69845	Carolina Weatherization	06/23/2014							
Transfer: ☐ *Qty:* 2.50		*Date:* 07/01/2014									
06/13/2014	3.00	No		Yes	0.43000	1.29	90* PVC elbow		/	Materials - Health & Safety	Edit View Delete
PVC ELBOW	Single Unit Item	69845	Carolina Weatherization	06/23/2014							
Transfer: ☐ *Qty:* 3.00		*Date:* 07/01/2014									
06/13/2014	1.00	No		Yes	0.38000	0.38			/	Materials - Health & Safety	Edit View Delete
PVC ADAPTER	Single Unit Item	69845	Carolina Weatherization	06/23/2014							
Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014									
06/13/2014	1.00	No		Yes	14.82000	14.82			/	Materials - Health & Safety	Edit View Delete
Air Break Fitting (PVC)	Single Unit Item	69845	Carolina Weatherization	06/23/2014							
Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014									
06/13/2014	1.00	No		Yes	90.00000	90.00	insulation permit cost		/	Materials - General	Edit View Delete
Misc material	Single Unit Item	69845	Carolina Weatherization	06/23/2014							
Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014									
02/17/2014	1.00	No		Yes	11.37000	11.37	I Save Water kits		/	Materials - General	Edit View Delete
Water Kit	Single Unit Item	69563	Blevins (warehouse)	06/23/2014							
Transfer: ☐ *Qty:* 1.00		*Date:* 07/01/2014									
11/29/2010	25.00	No		Yes	1.73000	43.25			/	Materials - General	Edit View Delete
CFL BULBS	Single Unit Item	61662	The Home Depot (warehouse)	06/23/2014							
Transfer: ☐ *Qty:* 25.00		*Date:* 07/01/2014									

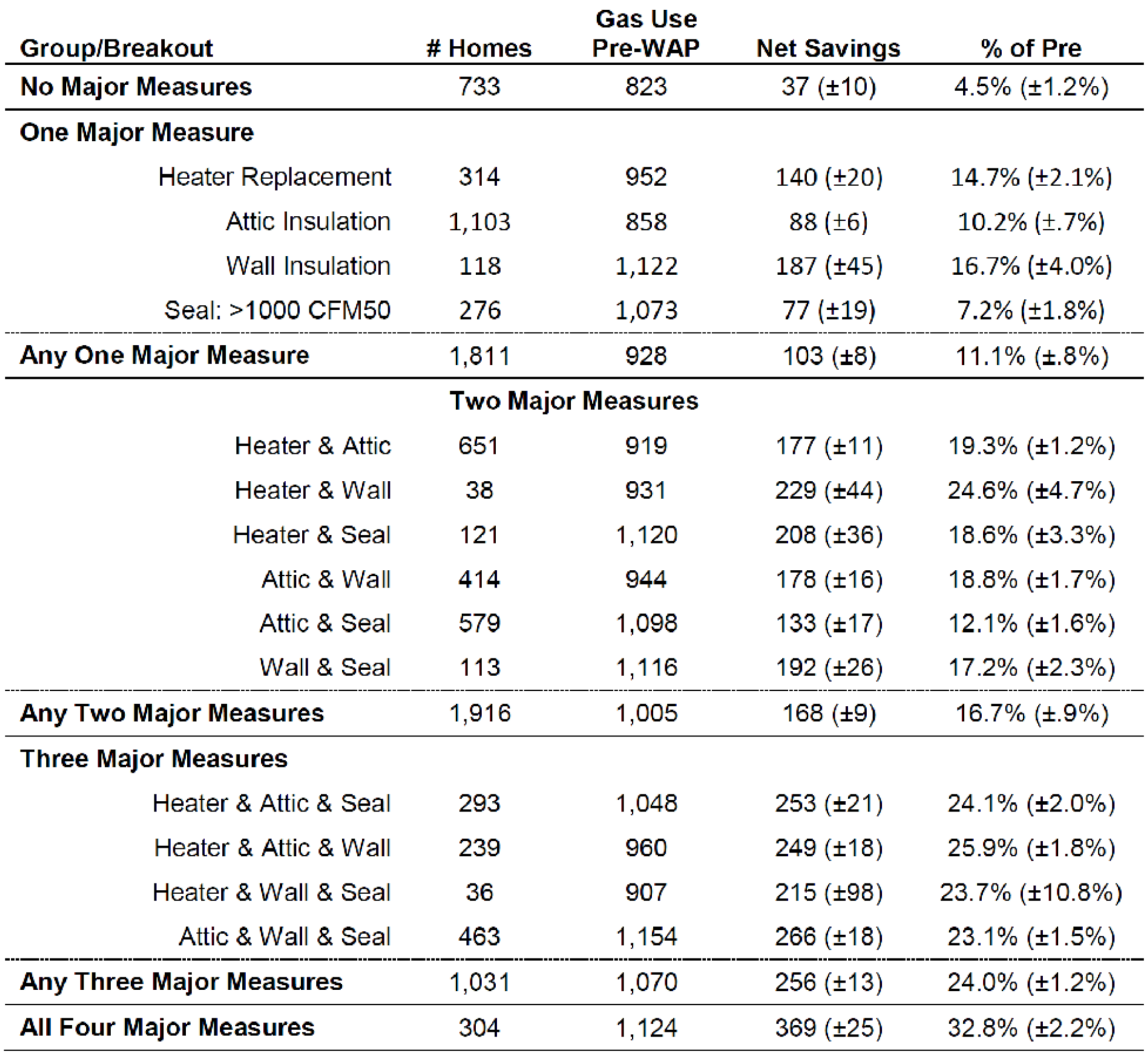
Materials - General	1,079.08
Materials - Health & Safety	880.21
Materials - Incidental Repairs	0.00
Total	1,959.29

APPENDIX B – Information Used in Representative Energy Savings Calculations

Tables for Natural Gas Site Built Homes

Blasnik, et al. (2015a)

Table 4.6 PY 2010 WAP Energy Impacts for Single Family Site-Built Homes Gas Savings for Homes with Natural Gas Main Heat By Measure Combination (therms/year)



Group/Breakout	# Homes	Gas Use Pre-WAP	Net Savings	% of Pre
No Major Measures	733	823	37 (±10)	4.5% (±1.2%)
One Major Measure				
Heater Replacement	314	952	140 (±20)	14.7% (±2.1%)
Attic Insulation	1,103	858	88 (±6)	10.2% (±.7%)
Wall Insulation	118	1,122	187 (±45)	16.7% (±4.0%)
Seal: >1000 CFM50	276	1,073	77 (±19)	7.2% (±1.8%)
Any One Major Measure	1,811	928	103 (±8)	11.1% (±.8%)
Two Major Measures				
Heater & Attic	651	919	177 (±11)	19.3% (±1.2%)
Heater & Wall	38	931	229 (±44)	24.6% (±4.7%)
Heater & Seal	121	1,120	208 (±36)	18.6% (±3.3%)
Attic & Wall	414	944	178 (±16)	18.8% (±1.7%)
Attic & Seal	579	1,098	133 (±17)	12.1% (±1.6%)
Wall & Seal	113	1,116	192 (±26)	17.2% (±2.3%)
Any Two Major Measures	1,916	1,005	168 (±9)	16.7% (±.9%)
Three Major Measures				
Heater & Attic & Seal	293	1,048	253 (±21)	24.1% (±2.0%)
Heater & Attic & Wall	239	960	249 (±18)	25.9% (±1.8%)
Heater & Wall & Seal	36	907	215 (±98)	23.7% (±10.8%)
Attic & Wall & Seal	463	1,154	266 (±18)	23.1% (±1.5%)
Any Three Major Measures	1,031	1,070	256 (±13)	24.0% (±1.2%)
All Four Major Measures	304	1,124	369 (±25)	32.8% (±2.2%)

Table 4.10 PY 2010 WAP Energy Impacts for Single Family Site-Built Homes Net Gas Savings for Natural Gas Main Heat by Climate Zone (therms/year)

Climate Zone	# Major Measures	# Homes	Gas Use Pre-WAP	Net Savings	% of Pre
All Clients	1.7	6,592	947	147 (±9)	15.5% (±.9%)
Very Cold	1.8	2,149	1,040	157 (±13)	15.1% (±1.3%)
Cold	1.8	2,990	1,091	188 (±13)	17.2% (±1.2%)
Moderate	1.6	792	828	125 (±24)	15.1% (±2.9%)
Hot/Humid	1.9	368	558	81 (±23)	14.6% (±4.1%)
Hot/Dry	0.8	293	545	12 (±17)	2.1% (±3.2%)

Note – Comparison Group, not shown, was also stratified by Climate Zone.

Table 4.14 PY 2010 WAP Energy Impacts for Single Family Site-Built Homes Electric Summer/Cooling Savings for Natural Gas Main Heat by Climate Zone (kWh/year)

Climate	# Homes	Summer/Cooling Electric Use Pre-WAP	Net Savings	% of Pre
All Clients	7,271	1,507	130 (±43)	8.6% (±2.9%)
Very Cold	1,878	719	13 (±47)	1.8% (±6.5%)
Cold	3,518	1,037	71 (±29)	6.8% (±2.8%)
Moderate	943	2,391	174 (±97)	7.3% (±4.0%)
Hot/Humid	526	3,925	563 (±294)	14.3% (±7.5%)
Hot/Dry	406	2,127	251 (±192)	11.8% (±9.0%)

Note: Comparison Group, not shown, also was stratified by Climate Zone.

Table 4.19 PY 2009 and PY 2011 WAP Energy Impacts for Single Family Site-Built Homes Gross and Net Gas Savings for Natural Gas Main Heat (Therms/year)

Program Year	# Homes	Gas Use Pre-WAP	Gas Use Post-WAP	Gross Savings	Net Savings	% of Pre
PY 2009	2,750	998	813	185 (±11)	173 (±10)	17.4% (±1.0%)
Comparison	4,210	848	836	12 (±4)		
PY 2011	3,157	996	807	189	186 (±7)	18.7% (±0.7%)
Comparison	6,148	842	839	2		

Table 4.20PY 2009 and PY 2011 WAP Energy Impacts for Single Family Site-Built Homes Gross and Net Electric Savings for Natural Gas Main Heat (kWh/year)

Program Year	# Homes	Elec Use Pre-WAP	Elec Use Post-WAP	Gross Savings	Net Savings	% of Pre
PY 2009	2,211	9,663	8,715	948 (±81)	796 (±124)	8.2% (±1.3%)
Comparison	3,693	9,276	9,124	152 (±106)		
PY 2011	3,200	9,015	8,237	778	772 (±72)	8.6% (±0.8%)
Comparison	6,274	8,385	8,379	6		

Tables for Electric Single Site Built Homes

Blasnik, et al. (2015a)

Table 5.4 PY 2010 WAP Energy Impacts for Single Family Site-Built Homes Net Electric Savings for Electric Main Heat (kWh/year) by Number of Major Measures

# Major Measures	# Homes	Elec Use Pre-WAP	Net Savings	% of Pre
No Major Measures	237	18,679	976 (±453)	5.2% (±2.4%)
One Major Measure	506	19,351	1,637 (±267)	8.5% (±1.4%)
Two Major Measures	271	20,641	2,485 (±407)	12.0% (±2.0%)
Three or Four Major Measures	91	23,554	3,109 (±861)	13.2% (±3.7%)
All Electric Heat Units	1,292	19,746	1,841 (±270)	9.3% (±1.4%)

Table 5.6 PY 2010 WAP Energy Impacts for Single Family Site-Built Homes Gross and Net Electric Savings for Electric Main Heat by Climate (kWh/year)

Pre-WAP Use	# Homes	Elec Use Pre-WAP	Net Savings	% of Pre
Warm (<3,500 HDD65)	689	18,577	1,837 (±375)	9.9% (±2.0%)
Cold (>=3,500 HDD65)	603	21,410	2,021 (±392)	9.4% (±1.8%)

Note: Comparison Group, not shown, also was stratified by HDD65.

Table 5.7 PY 2009 and PY 2011 WAP Energy Impacts for Single Family Site-Built Homes Gross and Net Electric Savings for Electric Main Heat

Program Year	# Homes	Elec Use Pre-WAP	Elec Use Post-WAP	Gross Savings	Net Savings	% of Pre
PY 2009	226	19,480	16,894	2,585 (±743)	2,323 (±765)	11.9% (±3.9%)
Comparison	341	17,945	17,682	262 (±299)		
PY 2011	624	19,456	17,406	2,050 (±251)	*	*
Comparison	*	*	*	*		

*Statistics under development. Will be included in the final report.

Tables for Natural Gas Manufactured Homes

Blasnik, et al. (2015b)

Table 4.6 PY 2010 WAP Energy Impacts for Mobile Homes Gas Savings for Homes with Natural Gas Main Heat By Number of Major Measures (therms/year)

Group/Breakout	# Homes	Gas Use Pre-WAP	Net Savings	% of Pre
No Major Measures	88	657	44 (±17)	6.6 (±2.6)
Any One Major Measure	174	696	58 (±15)	8.3 (±2.2)
Any Two Major Measures	209	735	106 (±17)	14.5 (±2.4)
Any Three Major Measures	141	752	132 (±21)	17.6 (±2.8)
Four or Five Major Measures	47	773	186 (±24)	24.1 (±3.1)

Table 4.10 PY 2010 WAP Energy Impacts for Mobile Homes Net Gas Savings for Natural Gas Main Heat by Climate Zone (therms/year)

Climate Zone	# Major Measures	# Homes	Gas Use Pre-WAP	Net Savings	% of Pre
Very Cold	2.0	306	835	104 (±19)	12.5% (±2.3%)
Cold	1.8	289	671	100 (±18)	14.8% (±2.6%)
Moderate/Hot	1.7	111	476	44 (±18)	9.1% (±3.7%)

Note: Comparison Group, not shown, also was stratified by climate zone.

Table 4.11 PY 2010 WAP Energy Impacts for Mobile Homes Electric Savings for Natural Gas Main Heat by Climate Zone (kWh/year)

Climate Zone	Refrigerator Replacement %	# Homes	Elec Use Pre-WAP	Net Savings	% of Pre
Very Cold	39%	230	7,994	698 (±313)	8.7% (±3.9)
Cold	21%	323	9,272	752 (±254)	8.1% (±2.7)
Moderate/Hot	29%	142	8,877	437 (±383)	4.9% (±4.3)

Note: Comparison Group, not shown, also was stratified by climate zone.

Table 4.15 PY 2009 and PY 2011 WAP Energy Impacts for Mobile Home Gross and Net Gas Savings (therms/year)

Program Year	# Homes	Gas Use Pre-WAP	Gas Use Post-WAP	Gross Savings	Net Savings	% of Pre
PY 2009	487	784	670	114	115 (±19)	14.6% (±2.5%)
Comparison	712	696	697	-1		
PY 2011	364	741	659	82	87 (±15)	11.8% (±2.0%)
Comparison	608	629	634	-5		

*Not Available

Table 4.16 PY 2007 and PY 2009 WAP Energy Impacts for Mobile Homes Gross and Net Electric Savings for Natural Gas Main Heat

Program Year	# Homes	Elec Use Pre-WAP	Elec Use Post-WAP	Gross Savings	Net Savings	% of Pre
PY 2009	344	8,250	7,246	1004 (±311)	1,097 (±376)	8.2% (±1.3%)
Comparison	574	8,590	8,683	-93 (±102)		
PY 2011	363	8,502	7,763	739	748 (±196)	8.8% (±2.3%)
Comparison	606	8,057	8,066	-9		

Vita

Nathan Kyle Kahre was born in Nashville, TN to Rick Kahre and Dian Luffman. He graduated from Franklin Road Academy in May 2010. The following autumn, he entered East Tennessee State University to study Construction Engineering Technology, and in May 2015 he was awarded a Bachelor of Science degree. In the fall of 2015, Mr. Kahre began study towards a Master of Science degree in Technology with a concentration in Sustainable Building Design and Construction.

In the spring of 2017, Mr. Kahre accepted a job offer from Thrive Home Builders, a Denver, CO based nationally recognized production home builder with an emphasis on energy efficient homes, to act as the High Performance and Healthy Home Manager. At Thrive, Mr. Kahre's work focused on effective methods to promote indoor air quality that can be adapted to the production home building market.