An Effort to Refine Home Energy Assessment Methods in Support of Retrofit Decision Making

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

In

Building/Construction Science and Management

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May 8th, 2013

Blacksburg, VA

Keywords: Energy Assessments, Energy Modeling, Energy Auditor, Residential

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1 Abstract

This research evaluates current home energy assessment tools and practices and investigates their applicability in terms of relevance supporting retrofit decision making in Southwest Virginia. Home energy assessments and audits are comprised of many different tools, strategies, and practices all with the same goal, to achieve accuracy in assessing performance as well as confidence in achieving energy savings from retrofit recommendations. Differing opinions, training, and standards in energy assessments have led to a reduced confidence and reliance on energy assessments, which can ultimately lead to poor retrofit decisions and undesired outcomes. This research undertook an investigation of current tools and practices as well as modeling studies to reveal insights into strengths and weaknesses, and to refine home energy assessments. The goal was to identify opportunities to increase confidence for stakeholders by analyzing energy assessments in terms of what strategies are most suitable to increase the accuracy of capturing different energy influence parameters, as well as to provide a basis for future research and development in this subject area.

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2 Introduction

According to United States (U.S.) Census data, approximately 60 percent of homes in the U.S. were constructed before 1980. Of these homes, 60 percent of the energy used by them for heating and cooling is lost due to leaky ducts, inefficient equipment, poor insulation and air leaks (ETO, 2008). The U.S. Department of Energy reports that only 20 percent of the homes built before 1980 are well insulated (DOE, 2011). The issues concerning the current energy performance in many older existing homes are emptying homeowner's pockets, spending a reported 65.63 billion dollars annually on energy (EIA, 2005). With emerging technologies, residential housing energy consumption is projected to continue increasing as reported by the U.S. Energy Information Administration in Figure 1:

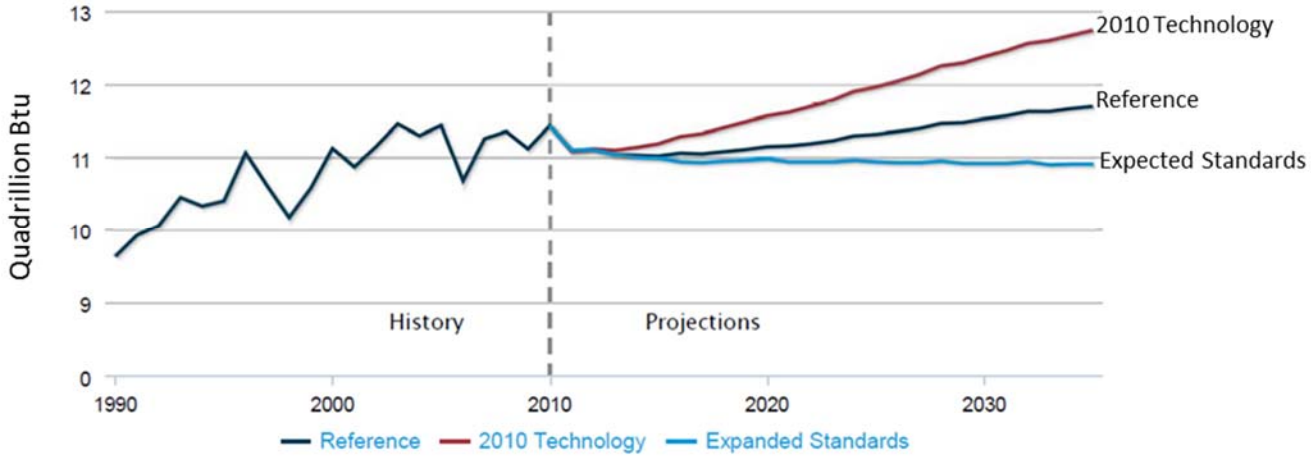

Fig. 1 Energy use in the residential sector (EIA, 2011)

This high number of homes built before 1980 also reveals another statistic, the need for residential retrofitting and the opportunity it presents for many of the involved stakeholders, including homeowners, auditors, and home builders/retrofitters. In a report prepared by the White House Council on Environmental Quality (CEQ) identifying the key barriers to the home energy retrofit market, it was proposed that home energy efficiency retrofits have the potential to reduce home energy bills by $21 billion annually, ultimately paying for themselves over time (CEQ, 2009). The potential business gained by auditors and builders through retrofitting can also similarly grow if the desire for retrofitting increases.

New technologies and strategies are being created and refined in today's market which reduces the energy consumption of homes and also reduces their impact on the environment. Homes use approximately one fifth of the total energy consumed in the U.S., and this figure has been increasing steadily since 1985 (USGBC, 2011). This does not take into account the energy used for transportation, production, and other associated processes with materials and equipment used in the residential construction industry, which would dramatically raise that fraction. The new technologies, products, incentives and techniques being developed and currently used in today's energy efficiency market can reduce energy consumption through insulation, heating and cooling efficiency, electrical efficiency in appliances and household items, and many more ways, all of which can also lead to substantial monetary savings due to improved

energy performance. But with all of these available resources and incentives, why are many homeowners not reaping the rewards of their home retrofits? One possible problem could be the step prior to retrofitting their existing spaces, the diagnosis. This problem refers to the assessment results a homeowner receives from an energy audit of their home, which identifies deficiencies and areas for improvement in their homes energy consumption. For example, if these assessed and/or simulated results differ significantly from the owner's utility bills, the confidence in any retrofit suggestions and associated savings proposed by a tool or auditor might be very low. In other instances, where a mismatch is not directly identified, a home owner might draw wrong conclusions and invest in less profitable scenarios, and subsequently portray energy efficiency measurements as not working to a broader public, as shown in numerous blogs and comments provided online.

Residential energy audits today have various issues, which in turn can lead to poor retrofit decisions. These problems range from inefficient and inaccurate auditing practices and tools, differing opinions and perceptions from auditors, and auditors that are not properly trained (DOE, 2011). Current methods in home energy audits lead to failures such as lower-than-expected savings, no savings, or even higher energy use (Shapiro, 2011). In a recent study conducted by Ian Shapiro, 300 home energy audits of residential homes were evaluated and 10 common problems associated with the audits were identified. These problems are as follows in Table 1:

Tab. 1 10 Common Problems of Energy Auditing (Shapiro, 2011)

Audit Problem	% of Homes
Missed Improvements	*80*
Weak Improvement Scope	*77*
Improvement Life Too Long or Not Provided	*73*
No Life-Cycle Costing	*73*
Poor Improvement Selection	*63*
Low (or Missing) Installed Costs	*60*
Poor Building Description	*60*
Inadequate Billing Analysis	*57*
Overestimated Savings	*53*
Inadequate Review	*30*

The biggest problem identified in this study was missed improvements, the largest contributor to failed audits and retrofitting. Shapiro went on to speculate that this problem is the result of insufficient budgets and time spent performing the audits, lack of training, and owner directives to not evaluate specific improvements. There are a set of common tools and practices used in residential audits that target different areas of energy efficiency in the home. An auditor may choose to use one practice and/or tool, or a combination of practices and tools that may inaccurately target or that cannot assess the areas where their

home is most energy inefficient, and similarly an auditor may not have the means, access, or training to use certain audit tools and practices that will identify where the home is most inefficient in energy use. If a variety of tools and audit practices are not used when performing a home energy audit, crucial indicators of inefficiency may be overlooked.

Conducting a home energy audit can not only be time consuming and expensive, but there are many other factors, which make it a difficult process for those individuals involved and ultimately can affect the accuracy of the process and results. Every home is different and involves different energy consumption influence parameters to be considered. These parameters can increase or decrease the difficulty of each assessment. In a report prepared for the Energy Trust of Oregon (EAI & CSG, 2009), interviews were conducted with several field technicians after they had completed energy audits. They were asked to describe the factors that influenced the time and difficulty they faced while performing the energy audit. The results are presented in the Table 2 and the feedback is not tool specific:

Tab. 2 Factors Affecting Audit Difficulty and Time (EAI & CSG, 2009)

Easier and Faster	More Difficult and Time Consuming
Small house size	Large house size
Simple house geometry	Complicated house geometry Different eave lengths
Single story	Multiple stories
Conditioned basements	Combined basement and crawl spaces
Little or no remodeling	Multiple remodels
Similar windows throughout	Different window types throughout
No shading on windows	
All ducts in conditioned space	Ducted heating system Supply duct in ceilings Unusual duct blasting results
Two-person auditing team	
	Rain (difficult to record notes)
	Appliances located in attic/crawl spaces Difficult to locate appliance and mechanical equipment information Older appliances and mechanical systems with little information
Homeowner is less talkative	Homeowner is more talkative

With difficulty being experienced by auditors as well as the prevalence of problematic assessment tools and practices, this leads to a lack of reliability in retrofitting and its promise of energy and monetary savings in return. The time and money spent on auditing homes also serves as a hindrance towards retrofitting, with many homeowners not wanting to invest in a process that ultimately could lead to no earned value. Therefore, in order to solve these problems, one has to ask and address the questions of the energy

assessment practices and tools being currently used. Which are most effective, and how can they be improved upon to greater benefit residential retrofitting goals and its stakeholders? Homeowners should be saving money and lowering their energy consumption. They look at their high energy bills and want to lower them, but do not know what to do first to achieve this with so many methods to select from, many of which being identified as unreliable. Reassurance and refinement in residential energy assessments is a must.

3 Background

3.1 Common Home Energy Audit Procedure

Typically, the procedure followed when one conducts an energy audit involves the homeowner reaching out to an auditor to assess their home's energy performance. The auditor then asks the homeowner to gather information about their home regarding occupant use, existing problems, home characteristics, and in some cases, annual utility bills. The auditor will use this information in assessing the home using various physical or virtual energy assessment tools and practices. Some of the most common in-field tools used by auditors are Blower Door Tests, Thermal Imaging, and PerFlurocarbon Tracer (PFT) Air Filtration Measurement (DOE, 2011). These tools are used to detect air leaks, measure pressure differences, as well as to detect heat loss throughout a home.

The three main groups of parameters that are to be measured during an energy audit are those involving the heat exchange through the building envelope, which includes the floors, walls, ceilings, and windows and doors; parameters regarding the internal heat from occupant activities, lighting, appliances, and appliances; and parameters dealing with the energy supply for thermal comfort and building services which include HVAC systems and hot water (Chen, 2010). Two key parameters that should also be assessed during an energy audit are infiltration and ventilation. Infiltration, an influence parameter of the building envelope system deals with uncontrolled air leakage through the building envelope. It affects the air exchange rates in a space, and through related heat gains and losses it directly influences heating and cooling requirements. On the other hand, the required amount of ventilation (controlled/conditioned air-exchange) that a space needs to achieve indoor air quality also impacts the heating and cooling demands in a home.

In a typical energy audit, the auditor will initially conduct an interior and exterior home inspection assessing the home for different characteristics, which may impact its energy performance, such as the type and location of windows, orientation of the home, lighting, appliances, etc. The Blower Door Test is usually the first active test performed on the house, and while it is running, an infrared camera will typically be used simultaneously to scan for air leaks and poor insulation in the walls by taking thermal images. Other tests that may be conducted at the auditor's discretion could be a PFT test or a Duct Blaster test among others on site, as well as computer based energy modeling tools that can be used off-site and work in conjunction with each other to assess a home.

With the provided assessment results from an auditor, the homeowner uses the information to decide what to retrofit in their home in order to achieve projected savings and increased energy efficiency. This process is presented in the following model in Figure 2:

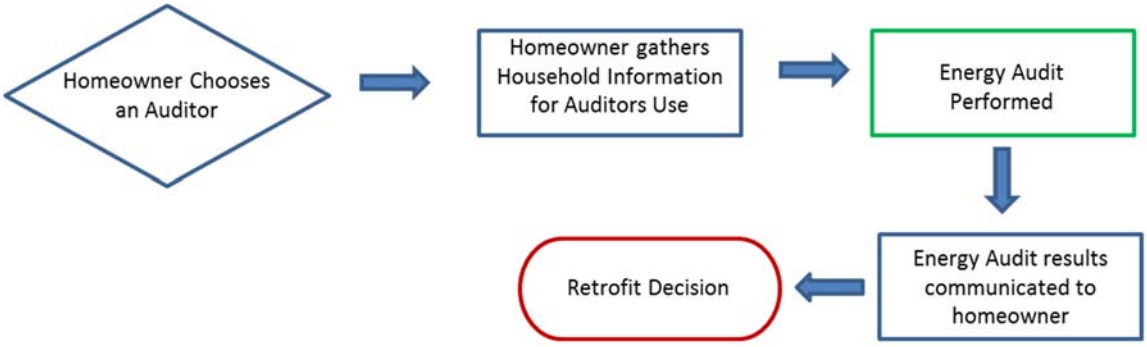

Fig. 2 Top-level Model of an Audit Procedure

An energy audit is conducted on a home with little knowledge of what the main issues are with energy performance in the home, its characteristics, influence parameters, and some knowledge about the cost and consumption of energy to the homeowner. The auditor assesses a home based on the limited information provided to them to try and find out what the energy performance deficiencies are with limited time, resources, and budget, and then communicates this to the homeowner, who will use that information to decide whether or not to retrofit certain elements of their home.

3.2 Common Energy Audit Tools and Practices

The following sections, 3.2.1 – 3.2.3, describe common energy auditing tools as well as practices used in the energy auditing industry. This includes experimental audit tools, simulation (modeling) tools, and load monitoring.

3.2.1 Experimental Audit Tools

Current popular home energy audit practices include the use of experimental assessment tools such as the Blower Door Test, Thermography, and PerFluorocarbon tracer (PFT) Air Filtration Measurement as mentioned previously. These three tools are those prevalently used in the auditing industry by many professionals. Blower Door Tests are used in energy audits in order to measure how air tight the home is and to also identify any locations of air leaks throughout the home. This is achieved by measuring the pressure difference from the interior and exterior of the home through the use of a calibrated fan that puts the house under positive or negative pressure by blowing air in or out of the house through a sealed exterior door way. Figure 3 further illustrates how the tool operates:

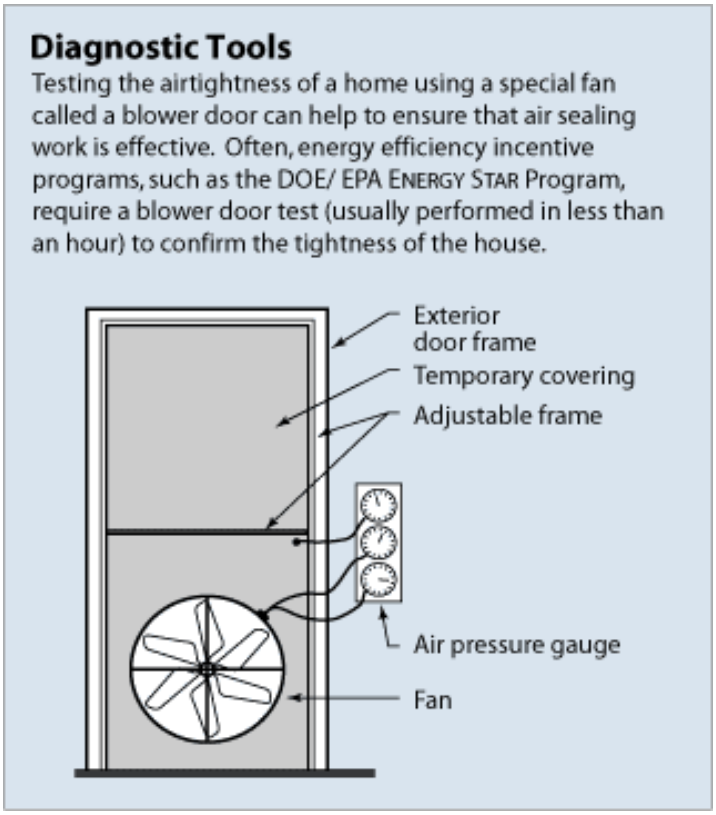

Fig. 3 Energy Efficiency & Renewable Energy (DOE, 2011)

Similarly, the PFT test also measures air tightness of a building except it measures air filtration over an extended period of time, identifying long-term problems associated with energy loss in the home. Thermography uses thermal imaging to assess a home's envelope surface temperatures. This process is used specifically to identify and detect areas where heat loss is occurring and also assesses how effective the insulation is in the home. The cost to perform energy audits varies as it depends on a number of factors including the tools and practices used, the size of the dwelling, and the overall time spent in conducting the audit. In some areas funding is available to support energy audits through government and local energy programs.

3.2.2 Simulation (Modeling) Audit Tools

Several simulation models have been developed and are currently in use that aim to assess an entire home's energy usage and also provide recommendations for retrofit improvements in a more or less accurate and uniform way. These tools range from web based calculators to non-intrusive load monitoring.

3.2.2.1 Web Based Calculators and Energy Modeling Tools

Web based audit tools and simulators have become more prevalent today incorporating simpler interfaces requiring less expertise to allow for a wider audience and use. These tools are intended to help with the decision making process when it comes to improving a home's energy efficiency. Two important aspects that these calculators must take into account when providing assessments for retrofit decision-making are

the homes physical characteristics and occupant use. Capturing this information within these tools can be complex and the accuracy is often unreliable.

A recent study analyzing the accuracy of the web based tool Home Energy Saver (HES) investigated how well this tool can predict the measured energy use of occupied homes given accurate and reasonable inputs, or what they referred to as "intrinsic accuracy". The following questions were considered for the study (Parker, Mills, Rainer, Bourassa, & Homan, 2012):

- What is the intended use of the accuracy assessment?
- How is accuracy defined?
- What level of precision and accuracy is required for the assessment at hand?
- How inclusive is the assessment?
- How are the home characteristics and "ground truth" energy use defined and applied?
- What types of errors are sought, and how are they to be interpreted?
- Can multiple tools be properly compared to one another?
- How can inaccuracies not associated with the software be isolated?

Considering the inclusivity of a tool is an important aspect to consider, which was brought up during this study. Climate and building types can vary vastly, and because of this they can have a great impact on how accurately a tool can produce results. This is something that can be overlooked by web based tools as they become more simplified and widely used around the country. Combining the use of web based calculators is another very important consideration because applying similar inputs into dissimilar tools can produce bias in the results and also limit the opportunity for greater depth in assessments (Parker et al., 2012).

Recently, SENTECH, Inc. conducted a study for the U.S. Department of Energy, which assessed several web based audit calculators available today in order to analyze how accurate they are in evaluating a home's performance regardless of the climate, architectural style, fuel source and building systems of and in the home (SENTECH, 2010). SENTECH evaluated REM/Rate, BEACON Home Energy Advisor, EnergyInsights, Home Energy Tune-uP, EnergyGauge, TREAT, the National Energy Audit Tool (NEAT), Home Energy Saver Professional (HESPro), and RealHomeAnalyzer. The evaluation concluded that not one of the tools alone could capture what is identified to be important to a national home performance assessment. The features considered important to a national home performance are low cost, universal availability, ease of use with reasonable input requirements, conformance to a universally accepted accuracy standard, and the ability to generate improvement recommendations and associated costs. Web based calculator audit tools are criticized for being too generalized and simple, often leading to inaccurate assessments due to excluded information valuable to performing a thorough audit, ultimately leading to missed improvements as well as inaccurate results. These tools also vary in the amount of inputs needed to assess a home contributing to unreliable results. An example of this being the ENERGY STAR Home Advisor audit assessment tool, and Appalachian Power's (AEP) online audit tool. Both aim to assess a home's energy performance, provide recommendations for improvements and savings estimates, but both vary vastly in the amount of information needed to provide this feedback to the homeowner. The ENERGY STAR tool only requires four pieces of general information, while AEP goes into great depth about features and occupants of one's home. Even with a more thorough audit calculation tool than ENERGY STAR, many of the questions asked by AEP are still generalized in scope and require no real energy use data to assess the home's performance and shortcomings.

In conclusion, the study investigating the accuracy of the HES tool found that with more inputs and with comprehensive and operational data used to create predictions, the HES tool could make predictions within 1% of actual energy use for large samples of homes, and within 25% for individual homes. It was also concluded that the more simplistic and less input requiring web based tools were unable to produce unbiased predictions and at times contained large errors (Parker et al., 2012). A conclusion directly contradicting the need for a more simplistic and less input intensive interface as reported to be among the important aspects to have in a national home performance assessment.

3.2.3 Nonintrusive Load Monitoring

Nonintrusive Load Monitoring (NILM) is a strategy used to analyze the energy consumption of individual appliances in a home. It is a more cost effective approach than individual appliance load monitoring tools. A study has been conducted (Matthews, Soibelman, Goldman, & Berges, 2010) using this method to measure how it can be of benefit and enhance current electricity audit methods in the home. The study aimed to provide auditors with useful information and indicators of energy use in order to prioritize their assessments by cutting the time and cost spent performing an audit while increasing the accuracy of their assessments. The results showed promise for this method to be developed into a more refined support tool for energy assessments.

3.3 Utility Use Data Analysis in Energy Auditing

Many tools are available that assess a home's energy efficiency in a variety of ways that collectively give a broad home performance report. Utility bill analysis is a standard procedure for several professional home energy audits that combine the analysis with other audit tools to evaluate savings that can be achieved. Utility bills however, are not utilized in a way that allows for identifying specific areas of inefficiency and to also disambiguate the utility data and how energy is being used throughout the home. Developing these solutions and applying them to support auditors in prioritizing energy deficiencies for the client is an area of research that is in high need. Developing a predictor tool for energy efficiencies using energy usage data could change the way energy audits are conducted and cut down on the time and money spent conducting assessments.

3.4 Measuring Thermal Loss

Using various heat loss equations to estimate energy flows and consumption, as well as a respective saving potential is another method used for energy assessments. For example, by knowing the U-Values of the homes materials, the area of the homes surfaces and a given temperature differential between the interior and exterior of the home, the amount of energy lost through the envelope in the home over a period of time (heat transmission losses Q_T) can be assessed. This respective equation for this particular energy flow is:

$$Q_T = U \times A \times \Delta T$$

In addition to this equation, various other heat flows occurring in a space must be assessed to capture the total balance of heat losses and gains. This includes heat gains such as from occupants, solar heat gains, heating equipment, appliances and other electric equipment, lighting, and many other factors specific to a particular home and its characteristics.

A recent study was conducted (Chen, 2010) in which an energy audit was performed on a building using this formula, among others, to estimate savings and identify where energy consumption could be reduced.

The major finding was that there was major heat loss from transmission and ventilation, while the main energy consumption was through heating. The recommendations were to adjust ventilation settings and also to replace windows. This approach is very useful in order to gauge where the major areas of energy loss are occurring in the home, although the results remain relatively ambiguous in identifying various possible underlying energy use problems.

Another study conducted in 2010 (Ruggles, Morgenstern, Meyer, Wierzba, & Himmelreich, 2011) performed audits on 145 homes in Colorado Springs and compared their heating fuel usage of the homes to the building thermal performance category each belonged to for that climate. This comparison was used to predict the heating energy required to the quality of the thermal envelope and to also identify anomalous energy usage caused by unusual occupant behavior.

3.5 A New Approach

In conclusion to the report prepared for the Energy Trust of Oregon which involved interviewing several audit field technicians and the difficulties they faced, recommendations for improving audit tools for increased accuracy and results were presented. These recommendations were to:

- Develop energy modeling tools that are more accurate and require less time to input
- Have models better predict and report actual energy usage
- Use standard normalized assumptions for base loads and plug loads from typical usage patterns (somewhat contradictory to the prior recommendation)
- Produce recommendations for energy improvements based on specific guidelines (to be determined) and be able to model savings of the upgrades.

(EAI & CSG, 2009)

These recommendations are all areas, which if developed, could increase accuracy of auditing and reduce, and/or eliminate many of the common problems Shapiro identified as associated with auditing. A new solution and approach to refining home energy assessments needs to be investigated for development. Developing an audit support tool and or practices that best addresses the recommendations reported to Energy Trust of Oregon while also taking into account considerations for inaccuracies as identified in the HES study (Parker et al., 2012), and that also improves upon current assessment practices and tools being used could be a step in the right direction to achieving this goal. Investigating what is available, what works, and possible solutions for improvements is the first step and avenue for future research.

4 Research Goal(s)

The purpose of this study was to investigate current energy assessment tools and practices prevalently being used today, with a main focus on Montgomery County Virginia (VA) located in Southwest VA, in order to identify ways in which audits can be improved and become more effective. The literature analysis has identified a need for better energy assessment tools and practices to improve accuracy of performed energy audits and the results to be better communicated to homeowners and retrofitters. There are an abundance of available tools and practices that are used for home energy audits, and many others being developed, but very few have proven to provide utmost confidence and favor in their accuracy.

Conducting this study provided a review of the best energy assessment practices applied in Montgomery County VA and also identified what possible modifications, strategies, investigations, and improvements could be applied to improve performance for the local region. By doing this, it was the ultimate goal to provide a direction for further research and development of the solutions investigated in order to benefit retrofitting potential, assist energy auditors in assessments, and to give homeowners renewed confidence in energy assessments and its rewards.

5 Research Objectives

This study involved four main objectives in order to achieve the proposed research goal. It combined the use of hands-on investigation of assessments, processes and procedures, semi-structured interviews, and experimental modeling studies of audit tools and practices all taking place within the local region of Montgomery County, VA. The objectives and associated methodologies are summarized in Table 3:

Tab. 3 Research Objectives and Methodologies

	Objectives	Methodology
1	*Identify key issues and shortcomings, in current energy audit practices and establish need for refinement.*	*Literature analysis, semi-structured interviewing and shadowing of energy audits conducted with local audit professionals.*
2	*Identify issues with various energy audit tools, software, and practices being used by local energy auditors and companies.*	*Conduct semi-structured interviews with local energy audit programs and energy auditors.*
3	*Identify how various audit tools and practices can be used and or combined to better assess a home's energy efficiency.*	*Several modeling studies involving the investigation and application of various audit tools and practices related to energy influence parameters.*
4	*Propose strategies/solution(s) to refine home energy assessment processes in relation to specific influence parameters for Southwest Virginia.*	*Use modeling studies analysis to show relationship and correlation with the potential benefits to stakeholders and successful retrofits using developed strategies/solution(s).*

5.1 OBJECTIVE 1

Identify key issues and shortcomings, in current energy audit practices and establish need for refinement.

This first objective was important in order to gain a greater understanding of what prevalent strategies are being used to conduct energy assessments, and how audit professionals carry out their processes as well as what their opinions are of them. This provided the foreground and roadmap for investigating possible solutions and implementation of new and different strategies to assist with energy assessments. This was achieved through literature analysis of audit practices, tools and past surveys performed of the energy assessment industry, informal semi-structured interviewing, and shadowing of energy audit professionals during energy audits of residential homes located in Montgomery County, VA. Process maps of audits for each shadowed company were created and validated by the shadowed auditors for accuracy.

5.2 OBJECTIVE 2

Identify issues with various energy audit tools and practices being used by local energy auditors and companies.

This objective further investigated the results from the semi-structured interviews with local energy audit programs and auditors. Interviews were conducted in order to find out more about their processes, tools and practices used, as well as the auditors' perceived difficulties and strengths conducting energy audits. Semi-structured interviews are more flexible than formal structured interviews as while they allowed for certain topic areas and questions to be the main focus and guide of the interview process, straying away from specific topics and questions that are planned was acceptable if the conversation lead that way. This interview style allowed for a more open conversation about energy audits and similarly, more candid responses about their experiences, negative or positive, related to energy audits. The local energy audit companies that were contacted regarding interviews are all companies located in Montgomery County, VA, or in a surrounding county. Core findings as a result of the interviews and shadowing were sent to all participants for validation.

5.3 OBJECTIVE 3

Identify how various audit tools and practices can be used and or combined to better assess a home's energy efficiency.

A series of modeling studies provided the methodology to address objective 3. It involved the investigation and application of some of the simulation tools addressed during the semi-structured interviews with different energy audit companies in the local area, in conjunction with local anonymous home audit details and data provided by a local block grant institution and local energy auditing companies. Different simulation tools and practices were used to assess different energy influence parameters in each home based on the data provided. The energy modeling tools that were used during this experiment included SIMPLE, HESPro, TREAT, REM/Rate, NEAT, and EPS Score to compare inputs as well as assessment results. EPS Score, the modeling tool of choice for the local region due to government program requirements, was the main basis for comparisons to assess how well it performs against other tools and its applicability for energy assessments and the local region. Experimentation with consumption monitors and smart meters were also utilized on a local Blacksburg home's gas water heater in order to investigate the assessment method and its possible application to energy audit practices. Possible integration and development of this monitoring experiment into energy auditing routines will be for future research. The goal of this experiment was to reveal insights into the effectiveness of each tool for our region, new strategies, and/or opportunities to implement support processes to refine energy audit assessments while also providing a way for increased accuracy and confidence in their operations and results.

5.4 OBJECTIVE 4

Propose of strategies/solution(s) to refine home energy assessment processes in relation to specific influence parameters for Southwest Virginia

The final objective involved using the results from the modeling study and to propose the development of possible new solutions, improvements, and strategies to performing more effective energy assessments in Southwest Virginia. The importance of this objective was to reveal the potential benefits to the involved

stakeholders of energy assessments and to reveal opportunities for further research and development of the investigated processes, possibly on a larger, national scale.

6 Research Methodologies

This research study was undertaken with a series of tasks which corresponded to each objective discussed. Each task had a different, or multiple methodologies applied to it in order to complete the task. These methodologies are further explained as followed:

6.1 Literature Analysis

Literature analysis is the first methodology to be used during this study. This methodology is necessary to develop a research focus and to compile a background of the subject. Strategies to be employed included database searches for journals, articles, books, and studies that relate to the subject matter. Creating a search term file that documents and keeps track of prior searches and keywords used helped to organize the information searched for and found towards creating a defined research focus and background.

A study undertaken to research what factors influence how new programs and innovations are sustained within organizations used literature analysis as the main method for data collection. The research team reviewed literature to gain a current understating on the subject matter, and then identified recommendations and areas where future research would be helpful (Stirman et al., 2012). In a journal article about issues with benchmarking human reliability analysis (HRA) methods, literature review, or analysis, was also the main methodology used to conduct the research. The purpose for using this methodology for their study was to review literature that was relevant to their research focus, benchmarking of HRA methods, with the goal of identifying issues that need to be addressed as well as lessons learned (Boring, Hendrickson, Forester, Tran, & Lois, 2010).

Similarly, for this research, literature analysis was used to identify issues with energy audit tools and practices to establish a need for refinement and further research.

6.2 Shadowing

Shadowing is an observational technique, which collects qualitative data. It entails following and observing a subject performing particular tasks and/or their day to day activities in order to gather data for research. It also involves note-taking, informal questions and answers, as well as in depth informal observation. Informal observation, as defined by Colin Robson's book Real World Research, is an observational approach that is less structured, allowing the observer considerable freedom in what information they choose to gather from informants and how they wish to proceed with it.

Rebecca Gill explains in an exploration of shadowing and its implications, that the method helps the researcher to gain a sense of what actually happens rather than what should happen (Gill, 2011). In an article by Elizabeth Quinlan discussing the dimensions of conspicuous invisibility, a term she uses for shadowing, she argues that shadowing is a useful data collection technique, specifically towards institutional ethnography, which is an exploration of people's social relations that structure their everyday lives. Shadowing is a technique used for classic management studies and also organizational change research. It is also used to help increase efficiency and productivity (Quinlan, 2011), similar to the goal of this study. Quinlan also discussed the importance of taking into account a major effect that can alter shadowing results,

the Hawthorne effect, which "is inevitable in all observational data collection techniques; that is, by virtue of being observed what is being observed changes" and in shadowing, disruption of the normal flow of activities is the Hawthorne effect most commonly experienced. Because of this, keeping the right distance, ensuring participants are comfortable with the observer's presence, and being careful with questioning are important things to consider when using this data collection method in order to disrupt the process as little as possible to collect the most useful data.

This methodology was used to shadow energy auditors on a series of audits conducted on local homes in Southwest VA. Shadowing further helped to create a background for this research as well as narrowing the research focus.

6.3 SEMI-STRUCTURED INTERVIEWS

A series of interviews took place as part of this research study. The style of interviewing that was used for this research was semi-structured. A semi-structured interview involves having predetermined questions and topics, although the interviewer has no formal structure or outline for asking the questions. Other unplanned questions may be asked if the conversation leads in a direction that deems it appropriate.

In a study involving practice-close research conducted by nurses doing qualitative research examining health in families of young children with special needs, semi-structured interviewing is a technique often employed to collect data. Ethical approval is needed before this type of research can be used. The interview guide for the questions asked by the nurses began with, "Tell me about…" which was intended to solicit descriptive responses from the interviewees. Fostering an atmosphere of active participation was an important note pointed out in the study in order to have a successful interview. Five stages were outlined for semi-structured interviews used by the nurses. These included stage one, introductions and introducing the research topic; stage two, beginning interview questions with a factual focus; stage three, shifting into more in-depth questions that may solicit emotional responses; stage four, moving back into more factual, less emotional questions; and the final stage, five, ending the interview, possibly chatting casually for a bit, and expressing gratitude to the participant for their time (Baumbusch, 2010). Lesley Lowes and Paul Gill state in a journal article about participants' experiences of being interviewed about emotive topics that, "providing a non-judgmental and confidential environment, where participants can talk about their experiences in an open and unhurried manner with someone who is genuinely interested in what they have to say, can be of mutual benefit to researchers and participants" (Lowes & Paul, 2006).

This particular style of interviewing was used in an effort to gain more insight and honest responses from interviewees from the unrestricted nature of the interview process and conversation. This was communicated to the interviewee before the interview began, letting them know of the nature of the conversation and the freedom to stray from specific questions and topics as appropriate. Institutional Review Board (IRB) approval of questions for this study was obtained before interviews began to ensure all questions were ethical.

6.4 MODELING STUDIES

A series of modeling studies was the final methodology applied to this research study. This methodology involves an in depth study of a particular subject while introducing something new or change testing a hypothesis. A modeling study has some comparable elements to case studies, which are used in a wide array of industries such as business, medicine, engineering, psychology, and many more. Harvard Business

School and Law School both routinely use the case study method to train their students in both continuing education and or advanced research (Francis, 1999). Mark Francis defines a case study in a report about the development of the case study method for landscape architecture as followed:

> *"A case study is a well-documented and systematic examination of the process, decision-making and outcomes of a project that is undertaken for the purpose of informing future practice, policy, theory and/or education" (Francis, 1999).*

While there are several potential benefits to case studies, it is very important to also consider the limitations when undertaking a case study. One limitation in particular that is important to consider for this research, is that case studies can be easy dismissed by those who do not like the messages they contain (Hodkinson & Hodkinson, 2001). This may be for reasons such as a sample that was too small, or case study conditions that are unlike anywhere else, and also biased researchers. For this research, the goal was to implement a modeling study, using energy modeling tools with a small sample size all located within the same region. Another goal was to provide a foundation for further research in other locations and possibly on a national scale using a similar approach. All of which in regards to sample size, location, and future research goals, have been communicated to begin with in an effort to eliminate any dismissals of the modeling studies that may arise.

For this study, seven modeling objects were investigated as a set of seven home's energy audits and relevant data were made available by a local block-grant recipient, a nonprofit housing organization. The audits were analyzed in detail in regards to physical features, usage patterns, and energy use from the provided data. Different energy audit simulation tools were then applied to each home's audit data and the results were then assessed for effectiveness and accuracy. The results developed during this phase were utilized to identify possible shortcomings and issues, and/or new strategies for implementation and combination of assessment tools and practices that allow for improving the energy assessment and savings predictions.

7 Energy Auditing Practices

This chapter covers the outcome of the shadowing process and conducted interviews with local energy auditors. The results produced by both the shadowing and interviews were then synthesized to produce the core findings for the energy auditing practices for the local region which are discussed in section 7.3. The core findings were validated by participants of the shadowing and interview investigations.

A total of four companies, which conduct primarily energy auditing, or some select energy auditing services, were found to be located in or in neighboring counties to Montgomery County and identified as potential participants for this study. Of this four, two are located in Montgomery County VA, one is located in Roanoke County, VA, and the last company is located in Floyd County, VA. Three of the energy auditing companies were contacted out of the four companies to be shadowed and interviewed for this study. The three companies that participated were the two (Company A and Company C) based out of Montgomery County, VA, and the company based out of Floyd County VA (Company B). These companies were chosen due to the locations where they primarily operate and conduct audits , as well as the different perspectives they could provide based on their size and the services they perform. The processes performed while auditing and inspecting a home were documented, and the auditors shadowed were also interviewed. Results of the investigations were communicated to all participants for validation. The following sections give a detailed account of these events while also giving insight into their current opinions, concerns, and perceptions of their own processes as well as the energy auditing industry as a whole.

7.1 Result of the Shadowing

Each local energy auditing company that agreed to be a part of the study and partake in an interview were first shadowed on a typical energy audit that took place in Montgomery County, VA, or the immediate surrounding area. This was performed before the interview in order to contribute to creating a background for the research by observing what local auditors experience on a typical audit. All processes discussed in the following sections were validated for each company by the auditors who participated in the shadowing for both, completeness and accuracy. There were instances where some key steps were excluded prior to validation, such as the post-retrofit test-out phase, which was not observed during shadowing. This was included in the process maps after validation was received from the auditors who noted this step be included in the process.

7.1.1 Company A

When shadowing Company A on energy audits there were either two auditors conducting the audit or just one auditor on site. This different approach within the same company was selected to observe how multiple auditors at the same site affected the overall assessment process in terms of aiding or hindering each other's work. When two auditor conducted the audit, the time it took to collect all the critical data reduced slightly, depending on the size of the home. It was also a more efficient process of collecting data when two auditors were present as this allowed for a division of responsibility and more attention and time was given to assigned areas of the home to each auditor. The typical audit routine for Company A is as follows in Figure 4. The legend located above the figure explains what each symbol shape represents in the maps.

Process Map Icon Legend:

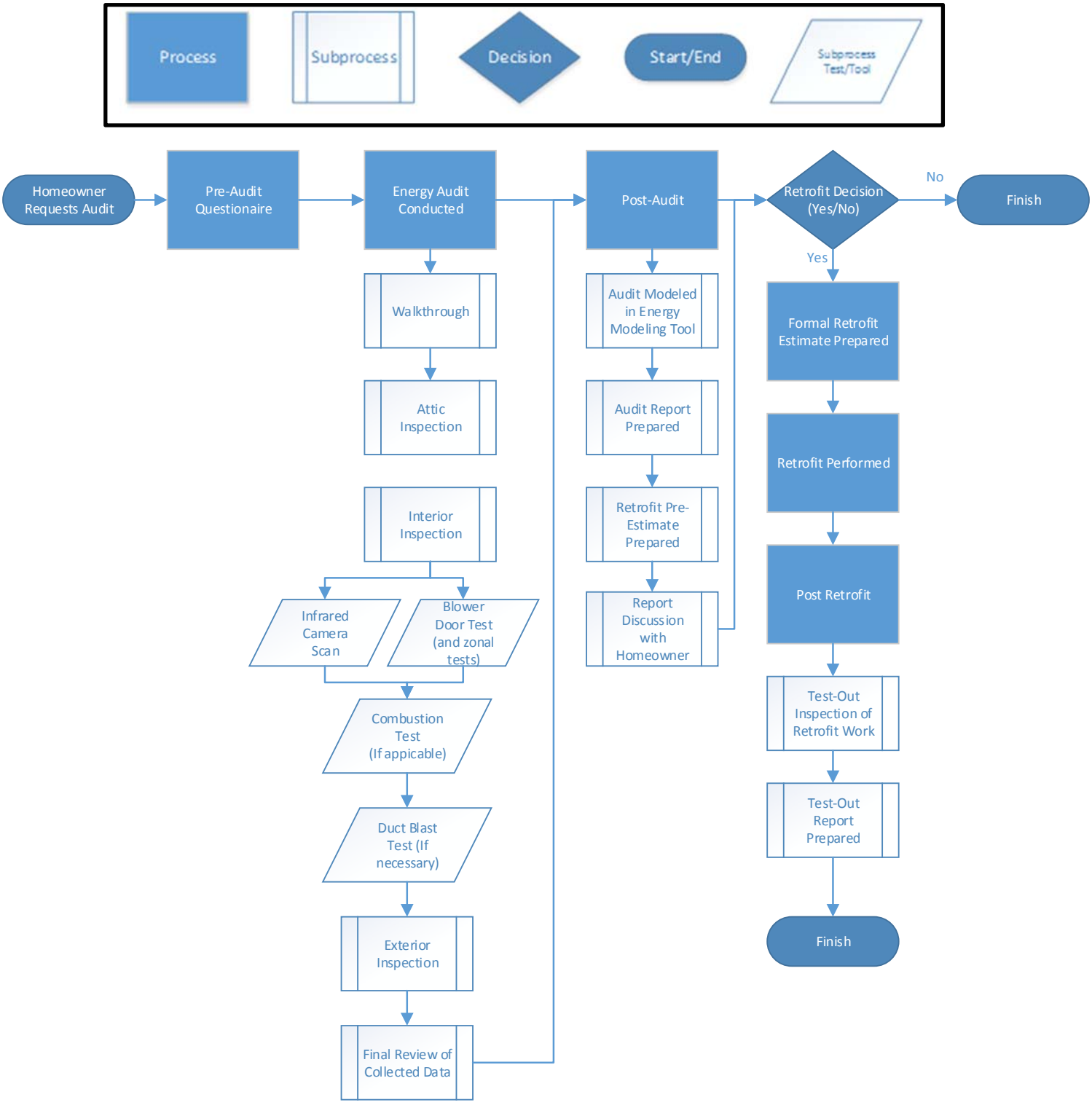

Fig. 4 Company A's Typical Audit Process of Primary Tasks and Tests Performed

The pre-audit questionnaire given to the homeowner before the energy audit by Company A is conducted is a one page document, which asks questions about their house's characteristics, their concerns, and goals for seeking an energy audit on their home. The questions cover various aspects such as:

- How Long Have You Lived in the Home
- Year Built
- Square Footage
- Number of Occupants
- Number of Bedrooms
- Type of Home
- Additions
- Number of Stories
- Type of Heating System
- Type of Fuel(s) Used
- Combustion Appliances
- Basement/Crawl Concerns
- Full Attic (Finished? Access?)
- Attic Concerns
- Window Conditions
- Door Conditions
- Primary Motivation for Getting a Home Energy Audit
- Goals and Objectives for Audit
- Three Primary Areas of Concern

The retrieved responses assist the auditor in preparing for the energy audit and provides them with necessary information to identify what tools they will need. It also enables them to pay specific attention to what the homeowner indicated they are most concerned about and what they are trying to achieve from the audit.

The typical tools used during their audit process consist of a Blower Door, Infrared Camera, Fan Flow, and Moisture Meter. Duct Blaster Tests are sometimes performed if the homeowner has specific concerns with their ducts or would like retrofit work performed on their ducts. Similarly, Combustion Testing is only performed if the home has combustion appliances.

Once the audit is complete and all data has been collected, the data is then entered into an energy modeling tool and a report is generated to review with the homeowner. Results and retrofit options, as well as a pre-estimate for potential retrofit work, are discussed during this time and a decision whether or not to retrofit their home is reached. If the homeowner decides to retrofit their home, they then prepare a formal estimate for the retrofit work outlining the cost of work that will be undertaken. Post retrofit, a test-out will take place inspecting all the retrofit work completed, and following that process a test-out report is then prepared for the homeowner which explains pre/post diagnostic test results.

7.1.2 Company B

Company B is more focused towards performing home inspections rather than energy assessments. However, they previously performed energy assessments as a large part of their work, which has some influence on the process and tools used to inspect a home. Their process is represented in Figure 5:

Process Map Icon Legend:

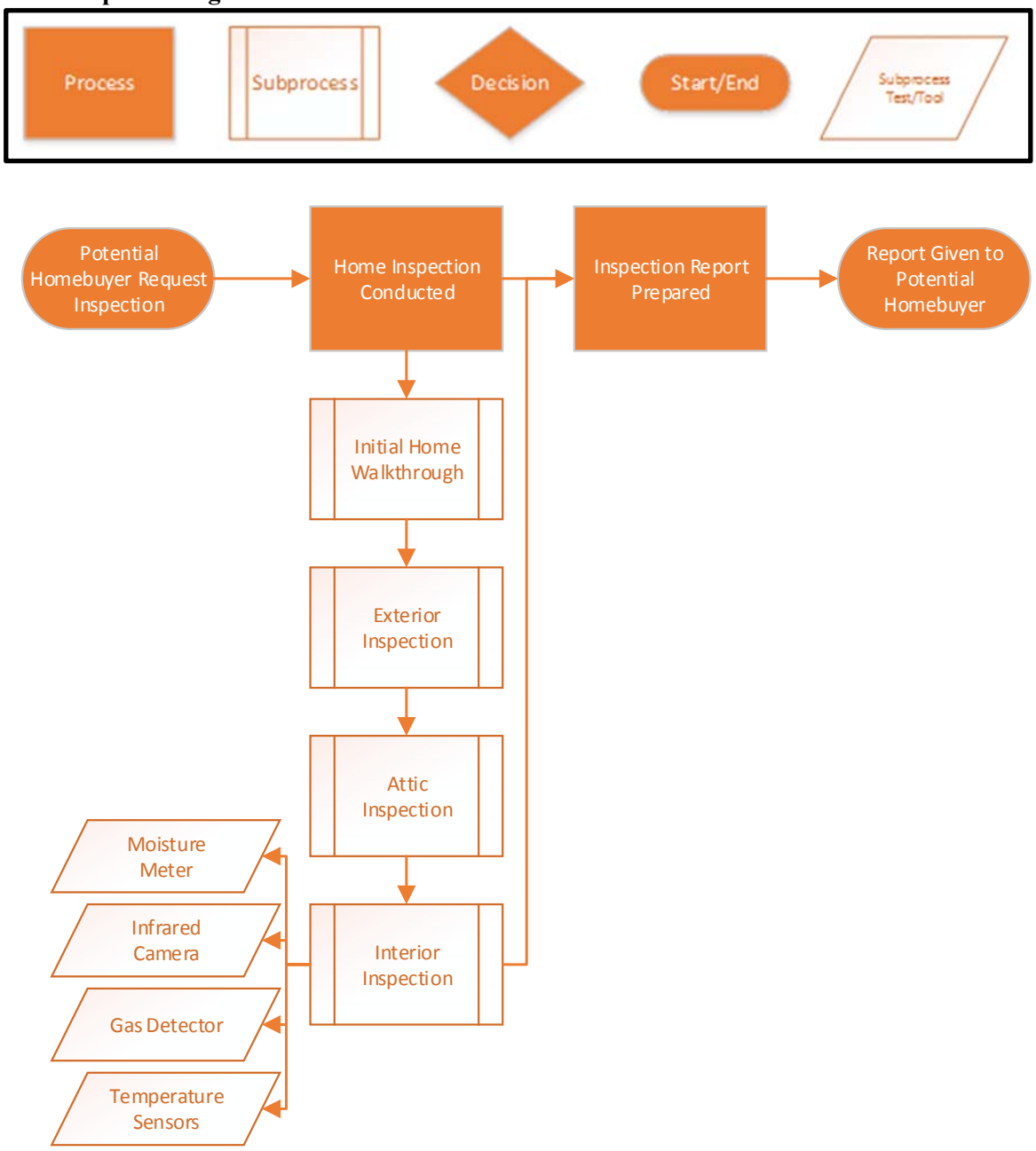

Fig. 5 Company B's Typical Home Inspection Process of Primary Tasks and Tests

A potential homebuyer requests a detailed inspection to be performed on the home in order to detect potential problems with the house such as moisture damage, appliance inefficiencies, missing insulation, dangerous hazards, air leaks, etc. Many of the problems are, or similar to those remedied by a retrofit post-energy audit.

A moisture meter, infrared camera, gas detector, and temperature sensors are the tools used by Company B during a home inspection. The infrared camera was utilized to detect water damage and intrusion on walls and ceilings rather than to detect air leaks as typically performed during an energy audit. The moisture

meter was also used to detect any moisture damage present throughout a home. A gas detector was used around gas appliances to detect possible gas leaks, while temperature sensors were used to check for consistency with the ductwork and possible disconnections.

When the inspection was complete, the inspector prepares a detailed report of all findings and then delivers the report to the potential homebuyer. The inspector has no say or knowledge of what the homebuyer decides to do with the inspection report once complete.

7.1.3 Company C

Company C was the final company to be shadowed during their energy auditing process. Company C consisted of a two auditor team, who conducted the audit together splitting tasks much like Company A's auditor team. Their typical auditing process as observed during the shadowing process is represented in Figure 6:

Process Map Icon Legend:

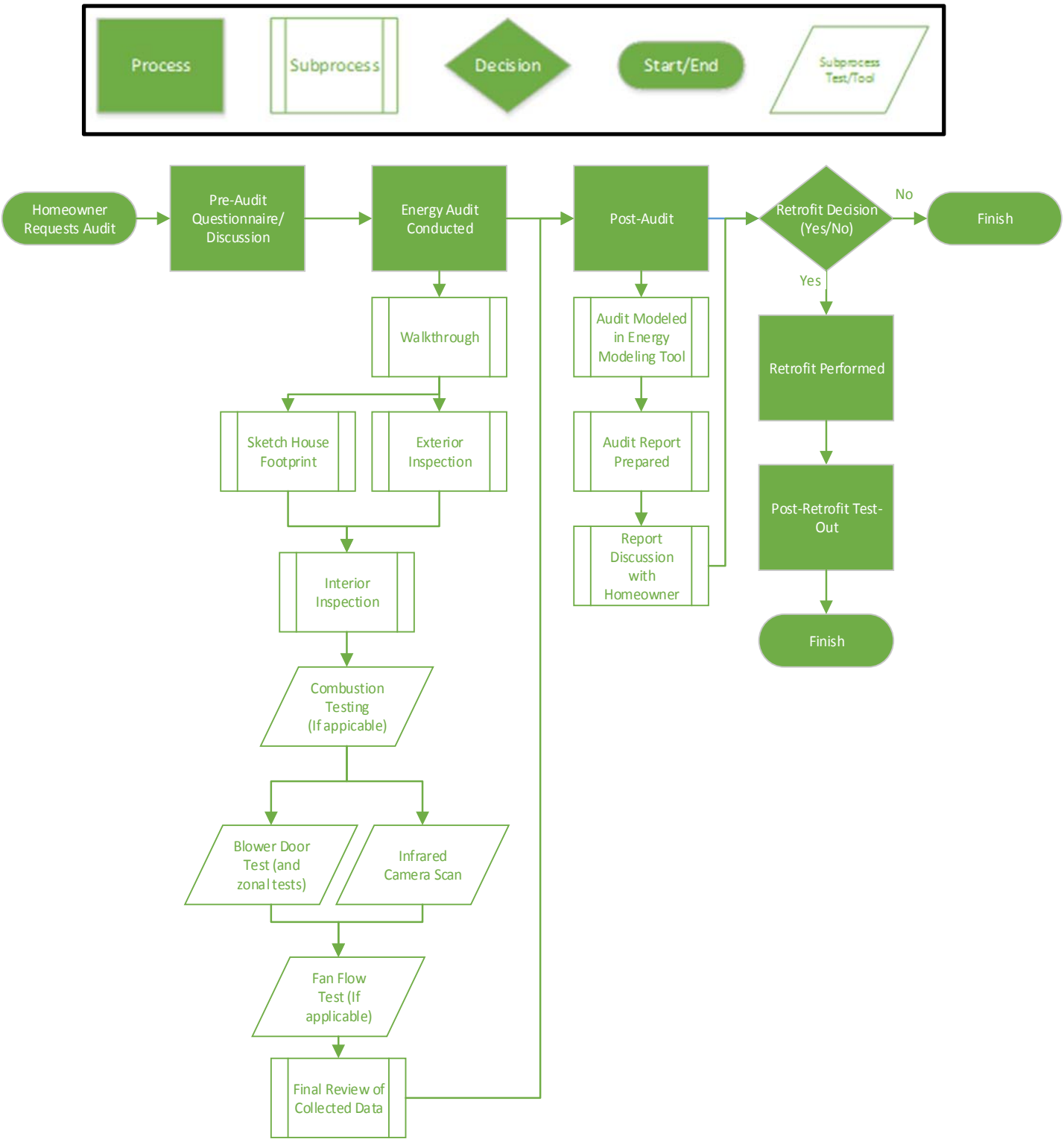

Fig. 6 Company C's Typical Audit Process of Primary Tasks and Tests Performed

Once a homeowner requests an energy audit, the auditors go to the home to inspect the house and perform several energy diagnostics tests. Company C's process is very similar to that of Company A. The same tools are used, or different variations of the same tools are used to perform tests. The tools and tests performed by Company C include a Blower Door Test, Infrared Camera, Combustible Gas Leak Detector, Combustion and Efficiency Analyzer, Fan Air Flow Check. Temperature and Relative Humidity Readings, and present Carbon Monoxide levels in the home were checked.

Results were then analyzed, modeled, and reported to the homeowner who would then make a decision to eventually retrofit their home based on the recommendations presented to them by Company C.

7.2 Result of The Conducted Interviews

Once the shadowing was completed and the processes were observed and documented, questions were asked to energy auditors in the form of a semi- structured interview at a later date. These questions addressed their subjective views, opinions, difficulties, and strengths while performing audits, as well as their company processes, their local energy auditing community, and the energy auditing industry in general. A total of four energy auditors were interviewed and one company owner was also interviewed. Interviews were conducted privately in one on one sessions and lasted between 30 minutes to one hour. The interview question guideline can be found in the Appendix A As the format for the interview sessions were semi-structured, some questions that may have been asked in addition to those on the guideline are not included on the guideline as this structure allowed for deviation should the conversation lead that way as appropriate. Common perceptions gathered from all the interviews and shadowing are summarized and discussed further in section 7.3.

7.2.1 Company A Interview Response Summary

Two auditors (Auditor 1 and 2) were interviewed from Company A as well as the company owner. Their question/conversation responses are summarized as follows:

Auditor 1 Interview Summary:

- Has been an energy auditor for one a half years
- Primarily conducts energy audits in Montgomery County, VA, and occasionally in Roanoke County, VA
- Is a Building Performance Institute (BPI) Certified Professional
- In regards to the training course for his certification, he believes it provides a good foundation for the work he performs. However, there was a lot of information covered in a short period of time and he would have forgotten 95% of the course information if he did not continue on as an energy auditor
    - No required prerequisites made the course more difficult
    - A background in building science would have been beneficial
- The typical homes audited are mainly built between 1960-1970, but this changes from neighborhood to neighborhood where they may find some older or newer homes
- Typical tools used when conducting an energy audit includes a blower door, moisture monitoring, infrared camera, duct blaster, and combustion testing

- Believes that using a duct blaster takes a long time compared to the minimal benefits it produces (no longer required to use it on audits as part of local block grant institution requirements
- Infrared camera is specifically helpful in illustrating air leaks to the homeowner

- Difficulties faced while conducting and energy audit on a home are related to features such as:
  - Architecturally unique homes, which add a lot of time to data collection and sketching up the home layouts
  - Sprawling houses with large duct systems
- Difficulties faced makes developing work scopes much more difficult and time consuming because of the specialty of the homes
- Some common problems seen when auditing homes are related to natural draft water heater, old appliances, insulation voids, and the slope of the grade around a home which can create moisture problems
- Has been using EPS score for one and a half years and is not confident in its results
  - Rarely matches up with homeowner annual utility bills
  - De-values certain areas of the home in terms of savings and sometimes over-values certain aspects
  - Savings estimates are not accurate
  - However, he believes it is a good tool for ballpark numbers on savings for certain aspects, but not accurate enough to give definite estimates
  - Good report for homeowners to understand
- If he could improve upon anything in his audit process it would be related to time and reducing the time to collect data and create a report while also making it aesthetically pleasing and easy for the homeowner to understand
- Believes the most significant problems the homes he audits that have the potential to produce the most savings is increasing attic insulation and air sealing
  - Basement and wall insulation are secondary priorities
- Thinks that homeowners typically need to be educated on attic sealing to know about the benefits – half of the time
  - Some homeowners can become emotional during the auditing process sometimes due to skepticism based on past experiences and broken promises
  - Sometimes they are a lost cause
- If he could have access to any tool or product to help with his process it would be:
  - Sealant for ducts that when blown into the ducts it locates the holes and seals them, but right now the cost outweighs the benefits
  - Interested in the idea of Air Crete – spray on insulation, but it has received some negative reviews based on lack of flexibility
- Believes the blower door adds significant value for internal purposes
  - Having a value to assess improvements made post-retrofit
- Believes the "low-hanging fruit" energy problems in homes are related to weather-stripping, general upkeep and durability of a home
  - These items generally rarely produce push-back from the homeowner
- Compared to other states, he doesn't believe that Virginia offers enough incentives towards getting an energy audit or performing retrofit work

  - Believes that homeowners think that incentives offered by programs sometimes come with ulterior motives – why are they giving me money to perform an audit on my home?
- In regards to the auditor and retrofitter relationship, he believes that there are problems associated with communicating recommendation and experiences them on a regular basis
  - It is a constant process to try and address
  - Working on building better relationships to reduce problems that could occur due to poor communication
- In his opinion, he believes the auditing industries weakest links to be associated with time consuming processes related to data collection, preparing reports, and meetings with clients
  - Would like a way to fast track identifying what is most important to prepare a report and scope while allowing for the versatility in the homes they audit
  - A "cookie cutter" approach is hard to implement because the homes they audit vary greatly

Auditor 2 Interview Summary

- Has been an energy auditor for approximately one year
- Primarily performs audits in Montgomery County, VA, and also occasionally performs audits in surrounding areas such as Pulaski, Giles, and Roanoke
- Is a BPI Certified Professional
  - The training helped to strengthen his awareness of energy issues
  - There was a broad spectrum of topics covered during the course and was a difficult to balance while working at the same time
- The tools typically used on an energy audit include a blower door, zonal diagnostics, duct blaster test, visual inspections and an infrared camera
- The difficulties he faces while conducting energy audits on home related to the variation in the types of homes located in the area
  - Broad range of ages, although the majority were built in the 50s and 60s
  - Older homes add to the difficulty, but has also found that some of the new home are also just as difficult
- Believes the most common problems he sees in homes that he audits are related to air sealing and insulation voids
  - Water heating upgrades is becoming more common
  - But problems always vary from home to home
- Has confidence in the results produced by EPS score considering the amount of inputs it requires, which is minimal
  - Thinks there is a lot more information that could be included as inputs for the software as some things are not accounted for in the tool
  - Noticed that remarkably, the EPS annual utility usage estimates can come very close to the customers actual annual utility usage
- If he could improve upon anything in his audit process it would be to reduce the time to collect data, calculating house volumes and other figures related to the house characteristics without blueprints, and reducing the amount of equipment needed in the field
- If there could be a tool developed to help with his energy auditing process, it would be a sensory tool focused on identify air leaks

- Would also like to have access to a tool that test efficiency of systems and how they perform
- Believes the blower door test adds a lot of value to his process and believes that his analysis and recommendations would change without it
- Does not believe the duct blaster test has much value
- Would describe his typical clients as a combination of energy enthusiasts, interested in saving money and energy, looking for incentive rebates, and have homes that need weatherization work done
- Thinks that there at times can be a lot of convincing needed to create homeowner buy-in when going over reports and recommendation which needs to be improved upon
- Compared to other states, he does not believe that Virginia offers enough incentives to homeowners to seek an energy assessment and retrofit work for their home
    - Thinks that the more incentives that are available, the more aware and educated homeowners will become
- In his opinion the auditing industry's weakest links are related to expensive processes, the lack of and need for more and better incentives, and time consuming processes

Company A Owner Interview Summary:

- Company A has been performing audits since 2007 – about five years
- Owner has no certifications but believes having the company's auditors have them adds value to the company because it adds credibility
    - Believes one can have the knowledge without the certification (used self as an example)
- Believes the majority of their clients right now are energy efficiency enthusiasts
- Believes their main obstacle while conducting audits is getting all the information wanted while still making it cost effective – the more information wanted, the more time it takes to conduct the audit
- Is not confident in EPS score results based on conversations with the company's auditors
    - Some of the inputs subjective
    - Input requirements are not consistent
- Believes the biggest challenge the company faces in general to be getting people to sign up for an audit
    - Not sure what why this is or what the route of the problem is
    - Believes this to be the general populous attitude
    - Clients skeptical of energy auditing
    - Payoff concerns by clients
- Would like to explore/incorporate consumption load monitoring more somehow – interested in the idea but knows it is not feasible
- Doesn't believe Virginia offers enough incentives
- Not sure how the local block grant institution has impacted their business – whether they have hurt or helped
    - Initial relationship problems in regards to procuring clients but has since improved
    - Funding incentives to get an audit has definitely helped
    - Concerned with how the local block grant institution is marketing – shortage of incoming clients
- Considers getting client interest to be the auditing industries biggest problem

- Feels that if State and major utilities were on board it would help the situation
- Believes that communicating the benefits and payoffs to clients is a big issue also

7.2.2 Company B Interview Response Summary

The home inspector from Company B was unfortunately not available for an interview follow-up after being shadowed. This was due to not being able to schedule an interview time within the time frame of this study.

7.2.3 Company C Interview Response Summary

Two auditors (Auditor 3 and 4) were interviewed from Company C. Their question/conversation responses are summarized as follows:

Auditor 3 Interview Summary:

- Has been an energy auditor for about 5 years
- Performs audits primarily in the New River Valley area in Virginia, including Montgomery County. Also performs some audits further out in Roanoke, Floyd, and even out of state at times.
- Holds several certifications:
  - BPI Certified Professional – Heating Specialist
  - Certified Home Energy Rater/Auditor (RESNET) – Certified Energy Manager
  - LEED Green Associate
- Believes that the difficulty involved with achieving a certification depends heavily on which certification is desired
- Opinions of certifications are that they are much like a college degree and they provide a stamp of approval and credibility
- BPI certification have opened a lot of doors for him in the industry
- Some typical tools used on while conducting an audit include the blower door, infrared camera, combustion testing, carbon monoxide leak detectors and personal monitors, bolometer, and energy modeling
- Believes his most important tool is his mind and knowledge of energy auditing and building science, other tools are secondary and serve as validation tools most times for what he already suspected as a problem
  - Can detect 70% of the problems in a home by observation
- Most of the difficulties he faces while conducting an energy audit are related to addressing comfort issues in the home
- Likes working in a team while conducting an audit because it helps prevent overlooking crucial information and data in the field
- Has difficulty with EPS score due to over prediction of results that can commonly occur – can lead to homeowner dissatisfaction
- Believes the common problems and significant issues found in the homes he audits are related to air sealing, insulation, and combustion issues with gas water heaters
  - A combination of the right tools and knowing what to look for is how he best addresses these issues
- Believes there is the value of energy modeling tools, and understands their limitations
  - Knows they cannot be 100% accurate, but even so, it's always better to conduct an energy modeling assessment on a home

- He believes it has been a learning process to try an identify what significantly effects the results of an energy modeling assessment and determining what is the most critical data to have
    - Try not to get caught up in the tiniest details
    - Practices using modeling tools on his own home and compares it to actual bills to check for accuracy and where potential errors are occurring
- If he could improve upon any during his own auditing process it would be communication between the client, mainly after the energy audit has been conducting
    - Communicating in an effective manner what is most critical for the client to correct as well as the consequences and benefits, much like a doctor does with a patient
- Believes that reducing systems loads for heating and cooling is important to consider before making any significant changes to systems in the home
    - Uses the Manual J – Heating and Cooling Load Calculations
- Believes that keeping track of the new technologies in the energy auditing industry is difficult, having a resource to help with that is beneficial
- Would like to see a full-fledged energy tracking tool developed, much like energy consumption monitoring
    - It is difficult to get the most accuracy without knowing how occupants behave in their homes
    - This tool could track any changes (such as having guest in the evening) in the home and communicate how to adjust or accommodate to those changes in order to manage the energy use appropriately
- Believes that the blower door test is much like a scale so the homeowner can see where they stand in terms of air leakage
    - Can be difficult to communicate the results of a blower door test to clients at times because terms such as CFM is not common knowledge
- He does not believe there is a typical client of those who he has performed energy audits for
    - Believes every person and building is different which can make the process difficult, but difficult in a good way because the variation brings a good challenge and learning experience
    - However, many clients are looking to save money on bills and improve comfort as a norm
- Believes incentives for energy auditing and retrofitting are important and are always a good thing to have more of
- Believes there is always risk associated with the retrofit recommendations and the retrofit work performed in terms of miscommunication with energy auditor and retrofitter
    - Murphy's Law - "Anything that can go wrong, will go wrong"
    - There is no guarantee that the results will be as expected from a retrofit
- In his opinion, the weakest link in the energy auditing industry is communication with the client and "making it count"
    - Doesn't like the term "green" because he feels it has become too broad and the meaning is unclear
    - Thinks there is a lot of "fluff" in the industry, which if removed could greatly benefit the industry

Auditor 4 Interview Summary:

- Has been an energy auditor for one and half years
- Primarily conducts energy audits in Montgomery County, Virginia, also conducts audits in surround counties and cities such as Floyd, Roanoke, Radford, and sometimes much further out
- Is a BPI Certified Professional – Residential Building Envelope Whole House Air Leakage Control Installer Specialist
    - Believes that his certifications help add credibility which is important to some clients while others may not be concerned
    - Has helped get work as well as given him access to use certain tools he could not without the certifications
- Believes the that the level of difficulty to achieve certain certifications depends on the type of certification
- The typical tools used while conducting an energy audit includes a blower door, infrared camera, combustion tests, carbon monoxide leak detectors and personal monitors, laser rangefinder, duct blaster, cordless drill, flashlights, bolometer, and digital camera
    - The digital camera is one of the most important tools to carry because it leverages help that can later on come from colleagues in the office who may have more experience or insight when analyzing data
    - Believes that some of the tools used are more critical for raw data, while others are more to simply show and communicate more effectively to the homeowner (i.e. infrared camera photos showing the contrast in colors)
- Believes the most common problems he comes across in homes he audits are related to air sealing, which is usually the least known problem by homeowners
- He is not confident in EPS scores results, but however believes it is good for providing the "big picture"
    - Believes it is too simplified and limited in the required inputs
    - It makes too many assumptions because of how is was designed – to be simple
    - Lacks in prioritizing cost effective measures
- When using energy modeling tools some of the strategies used to input data include using Google earth, taking pictures at the site to estimate window areas, and also creates spreadsheets to help with calculations and prioritizing recommendations
- Some tools and practices he believes would be of great benefit to his process include
    - Volatile organic compound monitor to help with indoor air quality assessments
    - Power metering to monitor energy consumption
    - Digital refrigerant to calculate actual efficiencies, which is more critical for older appliance models or misrepresented systems
- If he could improve upon his audit process it would be in reducing time consuming processes
    - Discussed it would be nice to have a voice recognition tool in the field to assist with data collection
- The typical client he interacts with that seeks an audit are most concerned with a combination of saving money and improving comfort
- Thinks that Virginia lacks enough incentives for energy assessments and retrofitting compared to other areas in the US and even in Europe, where he believes energy conservation in encouraged by many incentives

- Believes there is risk associated with communication retrofit results to retrofitters and it is critical to make recommendations as clear as possible to avoid problems or undesired results
    - Working on making instruction more specific for the retrofitters and clearer communication between the two parties
- In his opinion, the energy auditing industry's weakest links are:
    - Assumptions made due to a lack of information and data
    - Prioritizing
    - Pay-off estimates

7.3 Core Findings of Energy Auditing Practices

From the data collected from both the interviews and shadowing conducted with local energy audit professionals, common perceptions were derived and analyzed further to identify the main strengths and struggles faced in the local energy auditing community. Some general similarities gathered include the certifications held by each auditor interviewed, in which all of the auditors hold at least one certification. This certification is the BPI Certified Professional certification, with the exception of the company owner interviewed who does not hold any certifications. All of the auditors interviewed have been conducting energy audits for between one and two years with the exception of one auditor who has been conducting energy audits for five years, and the company owner who does not conduct energy audits, but has been in operating his business for approximately five years. The auditors interviewed conduct audits primarily in the New River Valley in Virginia which includes the counties of Montgomery, Floyd, Pulaski, Giles, and the city of Radford. They also occasionally conduct audits further out in Roanoke County, and sometimes out of state. The typical homes they audit were built between the years 1950-1970, but they have audited some older and newer homes also. The homes they audit also vary in the characteristics and architectural properties and this is very common. Typical tools/practices used by the auditors include a variety of diagnostic tests such as the blower door, infrared camera, and combusting testing. Their typical clients that seek energy audits are predominantly looking to increase their comfort inside their homes and save on energy bills, while many are also energy enthusiasts. The most common energy related problems they seem to face are related to air sealing and insulation. There was discussion regarding the awareness of risk associated with retrofit recommendations and the actual retrofit work performed/results, the route of the problem discussed as being mis-communication and instructions that are not specific enough. It was a general consensus that their clients (homeowners) often need to be "convinced" in order to create buy-in for the recommendations they give post audit, an issue the company owner identified as what he believes to be one of the energy auditing industries biggest issues. Many of these general similarities revealed through shadowing and interviewing are discussed further and relate to some specific difficulties and strengths faced by the auditors, which will be discussed in sections 7.3.1 and 7.3.2.

7.3.1 Common Strengths

Diagnostic Tools/Tests

Many common tools and tests performed were observed in the field as well as mentioned in the interviews by each auditor, and there was general favor in their value for different reasons. It was discussed how certain tools are more critical for collecting raw data, while others more for communicating and presenting information to the homeowner post audit, sometimes even during an audit, as observed during shadowing. The blower door test and infrared camera are two tools used prevalently in the field by all the auditors as

observed during shadowing. These tools were of most interest to the homeowner, and also the most know by the homeowner, where many times the homeowner asked when those tools and tests would be performed, and intrigued with the processes when they were. Viewing the contrast in colors presented on the infrared camera as the blower door was running was easy for the auditor to translate the meaning to the homeowner of what they saw related to the condition of their home and this served as a visual aid of sorts in the field where curiosity arose, and also in the reports presenting data collected and analyzed.

Internal benefits of the tools were also discussed. The data of the blower door serves a purpose much like that of a scale, as one auditor described it. It provides values which they can use to compare a house's pre and post retrofit state to evaluate improvements. Other tools and tests used for diagnostics such as combustion testing, efficiency tests, and carbon monoxide detectors provide a lot of raw data not only for energy assessments, but also for health and safety inspections. A tool mentioned by only one auditor in an interview but seen on every audit shadowed, was the digital camera. This was used to collect an abundance of photos of the home as well as appliances. These photos were used as data in the office to analyze and provide retrofit recommendations. The auditor that discussed this tool in the interview described the camera to act much like that of a pen and paper, but in a more efficient and accurate way.

Certifications

As previously mentioned at the beginning of this section, all of the auditors interviewed are BPI Certified Professionals, with some auditors holding multiple other certifications related to energy auditing and building performance. It was a general consensus between all auditors, as well as the company owner, that their certifications add significant value not only to their personal knowledge, but also towards obtaining business and resources. The BPI certification was discussed as an intense course with a lot of information delivered in a short period of time that may not have been absorbed if it were not for them continuing on practicing in the professions as energy auditors. Despite this, there was general favor that the certification training helped to strengthen awareness and knowledge of energy auditing and the associated building science. All believed that their certifications provided themselves, as well as the companies they work for, with credibility, helping them to attain work where the certifications were of particular importance to clients looking for it as a credential. The certifications also provide access to use certain tools they were restricted from without it which allows them to expand the scope of work they can perform. The company owner mentioned that while he believes an individual can have all the knowledge the certification offers in training, without it, the credibility is missing.

Team Work

When shadowing auditors on local audits, they were observed individually conducting an audit, as well as in auditing teams which was comprised of two auditors. It was discussed by all the auditors how they favored working together in the field, rather than individually. This was because it reduced the time it would take collect data in the field by dividing responsibilities, and this also allowed for more knowledge and insight in the field while collecting data. This combination allowed for more attention to be applied to areas in the home being inspected due to the reduced time constraints, as well as allowing for a reduction in possible overlooked data that could have been omitted if they did not have a team member there to converse with and prioritize the scope of work. While observing the auditors in the field, it was also apparent how

much more efficient their time was spent and divided while conducting and audit on a home versus conducting an audit individually.

7.3.2 Common Struggles

Diversity in the Local Housing Stock

Although a majority of the homes audited by the interviewed auditors were built between the 1950s and the 1970s, this does not mean that there is one typical style of home they encounter. All the auditors discussed how they face a wide variety of types of homes; some old, some new, some very architecturally unique, while others less unique. This adds a considerable amount of difficulty to their processes out in the field and back in the office.

The variation of homes they audit adds a lot of time spent collecting data in the field and analyzing the data in the office. The auditors need to know what tools to use and bring which is derived from the work scope developed for the home. This disparity in the type of homes they encounter make it difficult to use the exact same process for each home, although there are many of the same tools and processes implemented each time on an audit, what and how they address the home with these tools and processes can be much different. Not having architectural plans to assist with calculating volumes and creating floor plan layouts is another difficulty that relates to the diversity of homes they encounter and the extra time needed to collect that information.

Although this adds difficulty to the auditor's processes, one auditor mentioned how this difficulty is not always a bad one to have. It was discussed how the added challenge is a good learning experience and helps the development of an auditor in a positive manner.

Time

Time consuming processes such as collecting data in the field while on an audit, analyzing data, and communicating with the homeowner was a popular subject that arose in many different ways relating to different issues. For example, a lot of time is consumed when auditing homes due to the variation in homes they audit as discussed in the previous section; it is also effected by the tests and tools used in the field, some more critical than others for perhaps presenting recommendations to the homeowner, but maybe not so much when inputting data into an analysis, or vice versa. Many of the auditors discussed this as what they believe to be the auditing industries weakest link because it is affected by so many different aspects of energy auditing and cannot simply be addressed by one solution.

It is apparent that energy auditors are looking for faster ways to complete audits and it seems to be a constant struggle they face. The time constraints they face can lead to rushing and missing critical data. This can lead to assumptions and poor recommendations as discussed by one of the auditors. As one auditor mentioned, his main obstacle is getting all the data he wanted from an audit while still making it cost effective, because the more information that is wanted, the more time it will take to collect and process it. Time management is an area that could use a lot of attention and investigation in relation to energy auditing.

Lack of Incentives

All the auditors and the company owner expressed how the lack of incentives provided by the state of Virginia to have an energy audit and retrofit work performed on one's home is a limitation to their work and clients received. They believe that Virginia lacks compared to other states and other countries who

offer more and better incentives to homeowners. It was discussed how incentives not only can encourage energy conservation, but it also bring more business to the energy auditors companies. The local block grant institution, which the auditors currently work with, offers incentives to homeowners to seek an energy audit and retrofit work. Incentives can be an asset towards generating new business but it was discussed how even so, some homeowners are still skeptical towards incentives. This skepticism is speculated to arise from past bad experiences, disappointment in expected pay-offs, and the fear of ulterior motives.

Communication with Homeowners and Report Formats

The need to "convince" homeowners of the benefits of the recommendations was a common struggle that came up in all of the interviews, due to some homeowner skepticism and also due to communication barriers. This is also related to how the audit reports are presented to the homeowner. Finding ways to improve the effectiveness of how information is communicated to the homeowner is an important issue. This includes aspects such as the terminology used that may not be common knowledge, visual presentation of data, and pay-off estimates and benefits. How a homeowner responds to the information presented to them by an energy auditor may be completely different for another homeowner and adapting to this a difficult process is a challenge they are faced with.

EPS Score and Energy Modeling

The interviews revealed a general consensus for unreliability in the energy modeling tool EPS score's results. One auditor however did mention that considering the amount of inputs required (which is not many) the results were remarkably close to actual utility data he had compared it to, thus giving him confidence in the results produced by EPS score. For the other auditors and company owner interviewed, their views were quite the contrary.

It was discussed that there was a lack in confidence in the results produced by EPS score because of the simplicity and generalized nature of the tool which over-valued certain savings estimates, produced problems due to inconsistent input requirements, and contained subjective and generalized inputs. One auditor described that the difficulty faced with EPS score is due to over predicting results which leads to homeowner dissatisfaction, and also noted that it is difficult to get the most accurate results without knowing how occupants interact in their homes and use their energy, which EPS score completely excludes. Despite these dissatisfactions with the EPS score, there were some benefits identified for the tool, which includes providing a good report format for homeowners to easily understand, and also its value in providing the "big picture" and ballpark estimates.

One interviewed energy auditor discussed how he knows that EPS score and other energy modeling tools cannot be 100% accurate, but regardless it is always better to utilize them when conducting and energy assessment. He believes that learning the different tools and identifying the inputs and data that have the most significant effect on the results in order to increase accuracy is a learning process, which takes time and practice, something himself and his colleagues are always working to improve upon.

8 Energy Modeling Tools Literature Analysis

Before investigating various energy modeling tools in a series of modeling studies, a review of literature on different tools selected for the modeling studies was conducted. A specific focus was placed on investigating the background of EPS Score, the modeling tool used prevalently by energy auditors in Montgomery County, VA as part of local program incentive requirements, and also a focus was placed on occupant behaviors role in energy modeling tools.

8.1 EPS 2008 Pilot Background

For the EPS 2008 Pilot report, an in depth comparison of four energy modeling tools were conducted in order to identify a platform for the EPS score modeling tool. EPS score is used prevalently in Montgomery Country, VA in conjunction with local block grant institution requirements to use the software. SIMPLE was the modeling software ultimately chosen as a basis for EPS score, outperforming HES-Mid, HES-Full, and REM/Rate, the three other analyzed energy modeling software packages.

Inspired by the European Union directive to implement energy certificates in all member states (and specifically the example of United Kingdom's Energy Performance Certificate), the goal of the EPS 2008 Pilot "was to find an effective, accurate, and cost effective method and set of tools to calculate and report on a home's energy performance" (EAI & CSG, 2009). EPS score was developed to be an asset based rating and excluded all occupant behavior that could influence an assessment. REM/Rate was shortlisted to be evaluated due to it being a very widely known and used tool in the US as well as being a Home Energy Rating System (HERS) accredited software; SIMPLE was also shortlisted because of the few and less technical inputs it required; and HES was evaluated based on the accuracy reported for the tool as well as its function as an online modeling tool designed specifically for homeowners. The two levels of HES analyzed were HES-Mid, and HES-Full (most complete level). The tools characteristics are summarized in Figure 7:

Tool	Format	Expertise	Specificity	Inputs
REM/Rate	Disk	Technical	Detailed	100
SIMPLE	Spreadsheet	Semi-technical	General	32
HES-Mid	Online	Nontechnical	General	24
HES-Full	Online	Semi-technical	Detailed	185

Fig. 7 Characteristics of Selected Modeling Software for EPS 2008 Pilot, used with permission of Energy Trust of Oregon (EAI & CSG, 2009)

Each software was measured for accuracy by comparing the software predictions to actual utility use data for each home assessed in the sample of 190 home located in Portland and Bend, Oregon. The resulting EPS score software was developed as a calculation tool of energy consumption based upon the assumptions of normalized occupant behavior. The results revealed that SIMPLE produced the most accurate predictions and showed the most promise for becoming the basis for the EPS score, which it eventually became. SIMPLE had a mean absolute percent error of 25.1%, HES-Full resulted in a 33.4% error, REM/Rate resulted in a 43.7% error, and finally HES-Mid resulted in a 96.6% error. Figure 8 shows a comparison of each software's accuracy for total energy consumption of the 190 sample of homes. The lower and flatter the line appears the more accurate the tool predicts the total energy consumption.

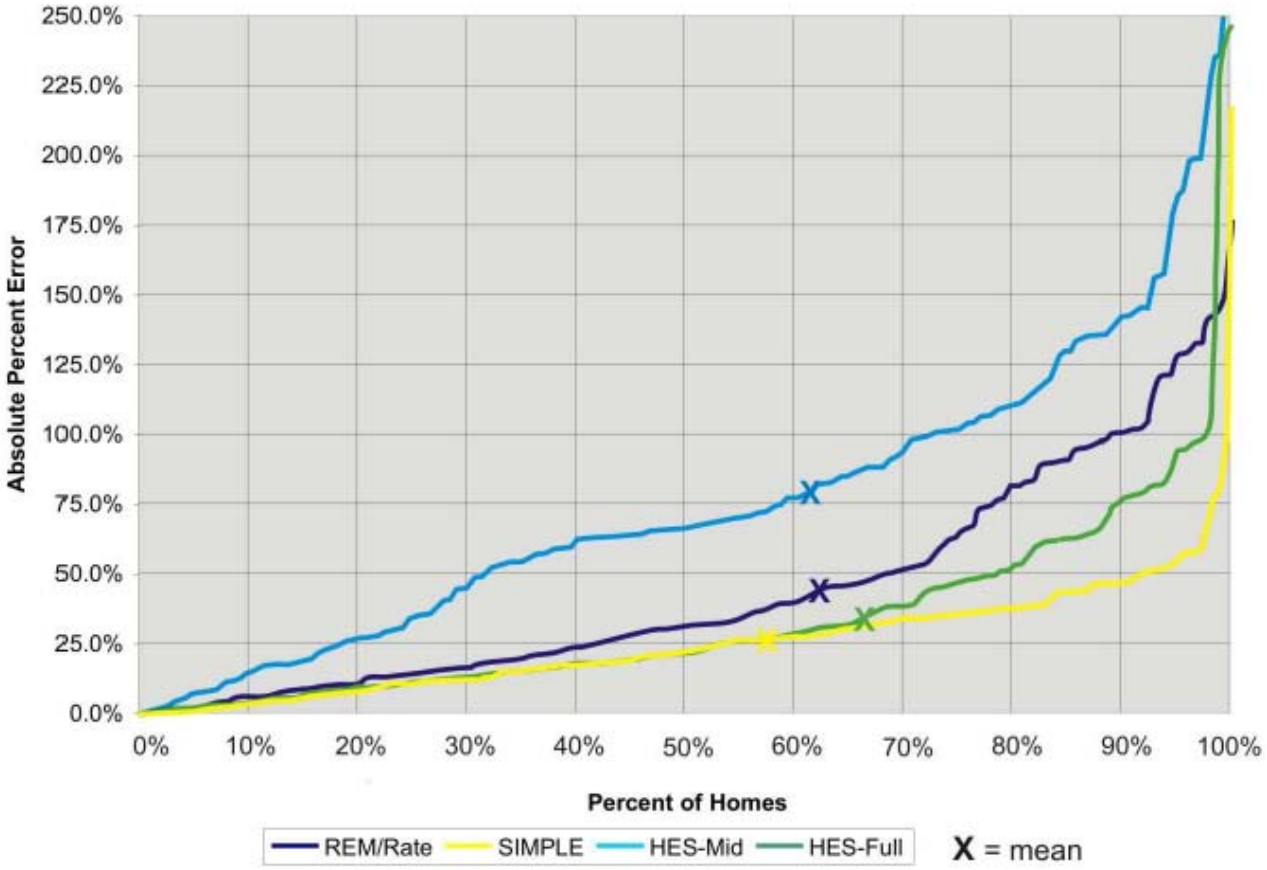

Fig. 8 Comparison of Software Tools Prediction of Total Energy (MBtu) for 190 Home Sampled, used with permission of Energy Trust of Oregon (EAI & CSG, 2009)

In conclusion to this study, EPS certified software programs are required to be able to predict energy use within 25%$ for 70% of homes and within 50% for 90% in comparison to actual data in order to produce credible levels of accuracy. None of the software's evaluated were able to meet this requirement, although SIMPLE came the closest, thus making it the current basis for EPS score. It is the hope that SIMPLE will continue to be improved upon to meet this requirement.

8.2 Occupant Behavior Influences on Energy Modeling Tools

A study which investigated the impact of the uncertainties associated with occupant behavior on the results produced by energy modeling tools explored this topic on an elementary school (Clevenger & Haymaker, 2006). The elementary school used for this study was investigated under typical conditions in which the behaviors of the occupants and the associated variations experienced with lighting, equipment, people, hot water, and heating and cooling were taken into account for the energy assessment. Results revealed that the energy used by the elementary school was sensitive to occupant behavior inputs in both cold and warm climates simulated to the same degree as normalized energy use by approximately +65% / -40%. This deviation tended to increase predicted energy use estimates. The results also showed that the occupant behavior parameters that most impacted the results were equipment load, ventilation rate, infiltration, and occupant schedule. In conclusion to this study, it was discussed that occupant behavior is a significant source of uncertainty in energy modeling predictions. By incorporating occupant behavior influence into their assessments, predictions increased by more than 150%, and a variation caused by one single parameter significantly impacted the results.

Another recent study conducted focused on the homeowner perspectives on decision making in responses to home energy audits similarly investigated the impacts of occupant behavior influence parameters on energy modeling (Ingle et al., 2012). The study combined industry opinions from individuals such as energy auditors, with those of homeowners. Among the objectives investigated for this study, was the importance of household energy behaviors to asset based energy modeling in relation to accurately representing homeowner energy use as well as providing upgrade recommendations. Of the homeowners interviewed for this study, the majority of the motivations documented as to why they decided to seek an energy audit for their homes were due to reducing energy costs (26% of interviewees), improving energy efficiency (23%), and general curiosity (23%), similar to the motivations of homeowners in Montgomery County, VA. The homeowners from the study were less motivated by EPS scores asset based results because they were interested in improving living conditions and making upgrades to their home. However, almost all of the homeowners claimed interest in EPS score if they were buying a home. The auditors interviewed for the study stated that EPS score has potential as a tool to compare against other homes, i.e. home inspections, with one auditor specifically saying, “I think it’s great but potential homebuyers are not our customers”.

The study conducted by Ingle et al. analyzed self-reported occupancy vs. EPS and HES asset assumed occupancy as shown in Figure 9. It was found that by adding behaviors to the asset models, large differences in asset modeled results occurred as depicted in Figure 10:

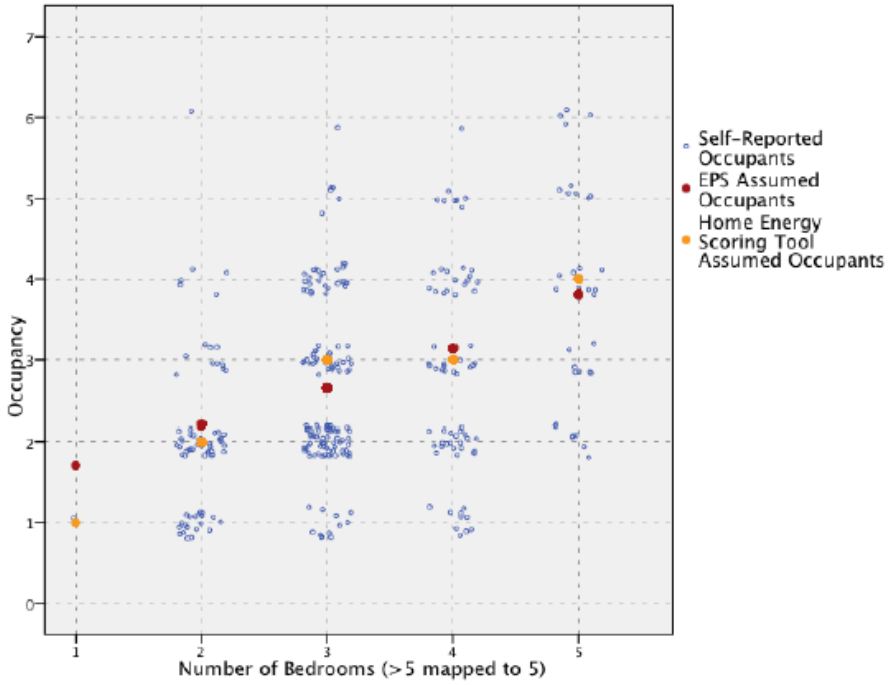

Fig. 9 Self- Reported Occupancy Inputs vs. EPS and HES Assumed Occupant Inputs (Ingle et al., 2012)

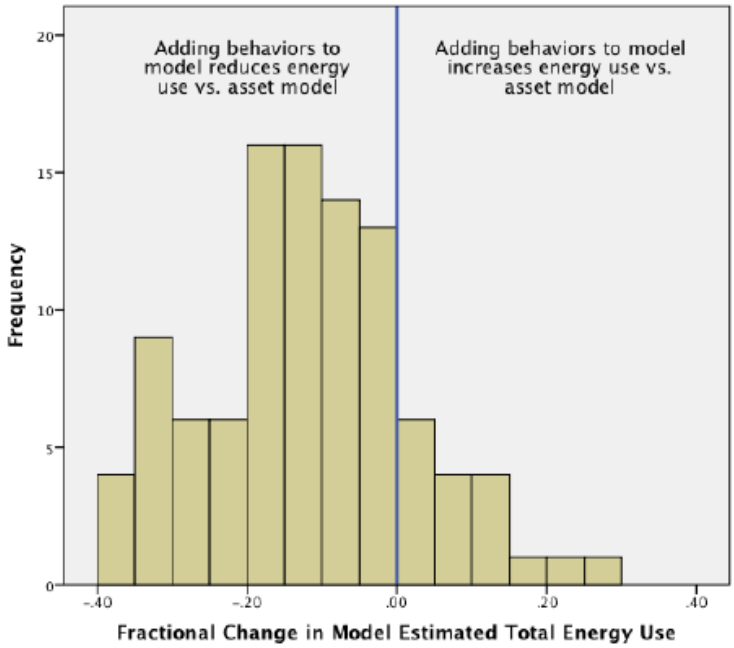

Fig. 10 Adding Behaviors to Asset Modeling Tools Impact on Results (Ingle et al., 2012)

The study concluded that by adding behavior factors, accuracy increases in matching with observed utility billing data and that asset based tools may not align with existing homeowner interests and opinions.

In a report prepared for the DOE by Pacific National Laboratory (Lancaster et al., 2012), actual versus predicted savings from retrofit decision were investigated in Portland Oregon where behavioral patterns in relationship to the results were among one of the main aspects also investigated. The goal of the study was to identify common traits and factors that appear to influence the success of a home energy retrofit in achieving significant realized savings. 18 households participated in the study and there were several occupancy and behavioral changes identifies that influenced the results which are as follows:

1. Added household members which led to increased heating patterns and energy consumption not accounted for in savings estimates
2. Changes in household occupancy, which can make savings appear or disappear in data regardless of changes made to the home
3. How occupants inhabit their homes can change in ways predicable or not
4. "Thermostat Battles" between household members seeking different temperatures in the home for thermal comfort
5. Active management of the home's thermal environment – i.e. opening and closing blinds, lighting, domestic hot water
6. Habits and rational calculation, such as cooking patterns, cleanliness standards, socialization, etc., were noted as being undoubtedly important to both energy consumption and conservation, but not discussed much when it came to energy analysis

The study concluded with some key points:

- Current energy modeling tools and practices are not designed to detect behavioral habits and patterns, although interviews can
- Household are not monolithic in their energy consumption or conservation
- A diversity of savings levels can be realized by households installing similar measures
- Actual savings and predicted savings levels may be quite different
- Occupancy, thermal control practices, and habits all seem to contribute to consumption and conservation in ways that are not actively addressed by retrofit program activities
- Households that practice active behaviors to control energy costs in addition to pursuing upgrades may achieve higher savings and levels of satisfaction with the upgrades
- At least some of the causes of deviations from expectations are attributable to the dynamics of consumption which are strongly affected by the dynamics of everyday life and households evolve even over short periods of time, sometimes substantially, contrary to the default assumption

9 Energy Modeling Tools

Several energy modeling tool inputs were analyzed in this chapter, as well as the modeling results they each produced. EPS score, the modeling tool as required for the local region was the main basis of comparison to evaluate how other tools perform against it, specifically in the modeling studies. Inputs were assessed for how well they addressed an established set of general energy influence parameters in order to complete a simplified energy assessment. Inputs were also analyzed for the ratio of the minimum required inputs to optional inputs, as well as the ratio of asset based inputs to occupant behavior based inputs in order to investigate how this can affect assessment results. Finally, modeling studies involving seven anonymous actual Montgomery County, VA home's energy assessment details were used to compare energy modeling tool results among the several tools. The results from the modeling studies were then analyzed to reveal outliers, limitations, strengths, and concerns for using these tools on the Southwest VA housing stock, and also how, or if, these matters relate to local auditor strengths and struggles.

9.1 Energy Modeling Tool Inputs

For this study, EPS score was compared against other energy modeling tools to evaluate for how well it can assess energy consumption parameters in homes located the Southwest VA region. EPS score is used prevalently by Montgomery County, VA auditors as part of local block grant institution requirements. As discussed in the EPS Pilot report background section 8.1, SIMPLE, although close to the requirements of a credible EPS score software program, did not meet the requirements. However, it is currently the software model platform for EPS score. In addition to this, the pilot study was conducted in Portland and Bend, Oregon, a climate much different to that of Montgomery County, VA. In an impact analysis study conducted by Tolga Durak, a concise set of general energy influence parameters was developed, which ought to be considered to complete a simplified energy consumption assessment. These influence parameters are listed in Table 4:

Tab. 4 Minimum Energy Influence Parameters for Energy Assessments (Durak, 2011)

	Energy Influence Parameter
1	Year Built
2	Total Square Footage
3	Footprint Area
4	Volume
5	Perimeter Length
6	Form Factor
7	Shape of the House
8	Interior Ceiling Height
9	Number of Stories
10	Number of Rooms
11	Number & Size of Windows
12	Number of Occupants
13	Ages of Occupants
14	Building Thermal Envelope
15	Space Usage Characteristics
16	Infiltration
17	Ventilation
18	Zip Code
19	System Characteristics
20	Occupancy Patterns

These set of influence parameters are not just specific to the research location of Blacksburg, VA, due to this, baseline parameter calculations to be used in conjunction with the influence parameters were calculated which are specific to Blacksburg, VA. It was determined that all of the 20 parameters identified have an impact on the energy consumption domains of space heating and cooling. Additionally, the number of occupants, ages of the occupants have an impact on domestic hot water energy consumption and interior lighting. Similarly occupancy patterns also have an impact on domestic hot water energy consumption as well as appliances and electronics energy consumption. These influence parameters are not included as part of the EPS score analysis as they are not asset based parameters, even though for this area, they are included in the minimum set of influence parameters required to produce a simplified energy assessment.

Before each of the modeling study homes were entered into the different energy modeling tools, an in depth input analysis was conducted for each tool to investigate which influence parameters are covered in each and also to identify any limitations that may be present.

9.1.1 Energy Modeling Tool Inputs Comparison

An inventory of the inputs for five energy modeling tools were taken in order to quantify the amount of information needed to be input into each tool. These were then grouped in to optional and minimum categories. The optional category is comprised of inputs that were not required in order to produce assessment results for the tool and could be bypassed. The minimum category is comprised of inputs that were required in order to attain assessment results and could not be bypassed.

Quantifying the inputs was not based on the exact number of blank fields that needed to be completed for each tool, but rather by the type of information/influence parameter each input addressed. For example,

rather than counting each type of window information needed into an individual input such as each window size or window area, this was instead grouped into one input, number and size of windows. This was done for the purpose of minimizing the inventory and also to make it more comparable. See the Appendix, Table 7, for a more detailed breakdown of the comparison. The summary of the input comparison is represented in Figure 11:

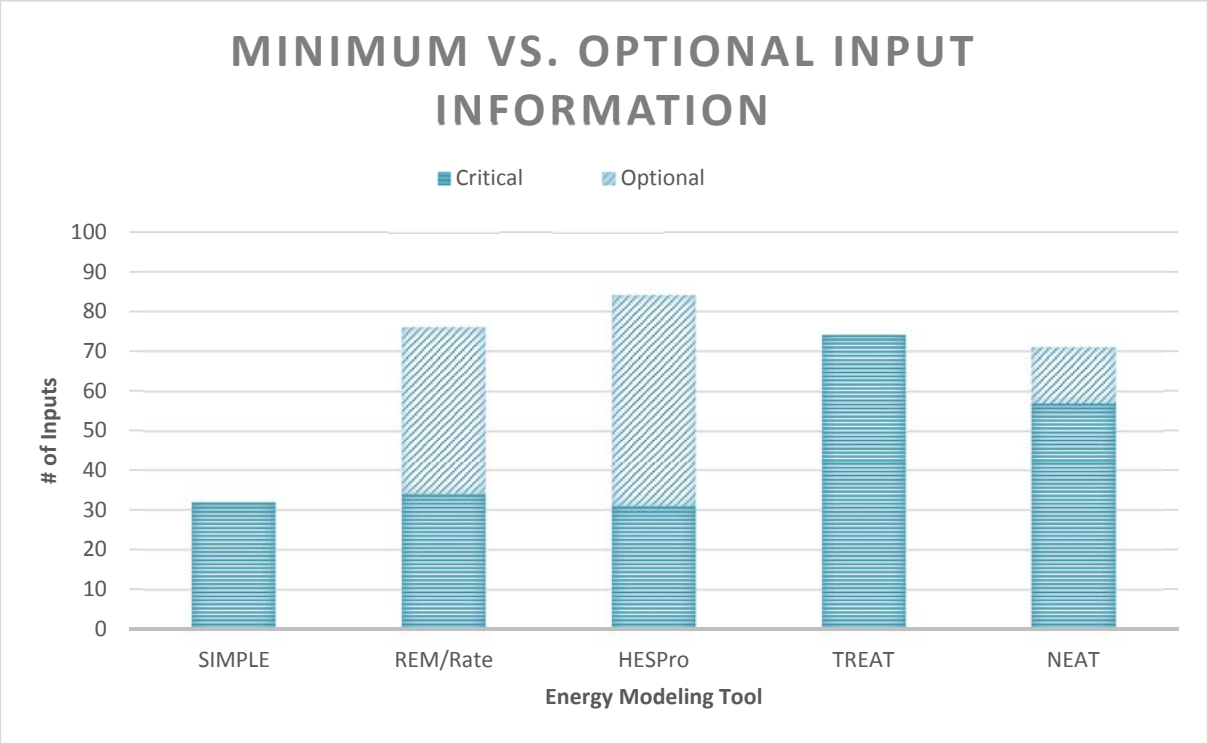

Fig. 11 Minimum vs. Optional Input Information for Various Energy Modeling Programs (approx.)

The graph in Figure 11 shows that there is a great variation in the amount of optional and minimum required inputs incorporated into the six modeling tools evaluated. The closest tools in overall inputs are REM/Rate and HESPro, while they are also both very similar in the amount of minimum inputs required to SIMPLE. TREAT and SIMPLE are the only tool that require all minimum inputs, while NEAT is not too far behind, with very few optional inputs compared to REM/Rate and HESPro. This input comparison revealed the disparity in not only the total inputs required to produce energy assessment results, but also for inputs not required to produce results for each tool, one possible reason to why results produced by each for a home energy assessment could vary.

Each tool was then evaluated for how well they address the minimum energy influence parameters identified by Durak. This is represented in Figure 12. If some inputs related to one of the energy influence categories are included in the tools, it was concluded that it addressed the parameter in some depth, whether great or little.

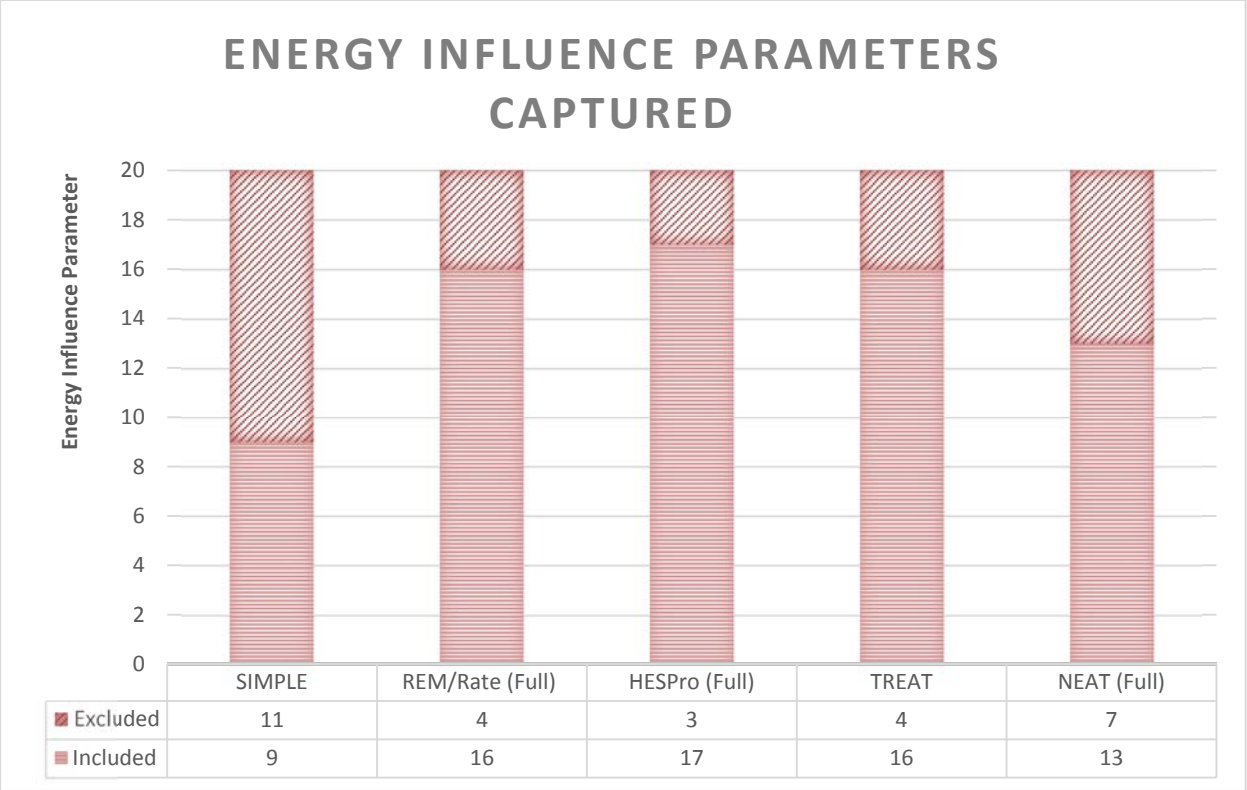

Fig. 12 Durak Energy Influence Parameters Captured in Various Energy Modeling Tools (approx.)

SIMPLE includes the least of the identified energy influence parameters, while REM/Rate (full), HESPro (full), and TREAT covered the majority of the energy influence parameters making them apparently the most appropriate to conduct a home energy assessment. HESPro (full) and REM/Rate (full) are only among the top three in this analysis if the full set of inputs for each are used in an energy assessment.

A common consensus from interviews with auditors and professionals in Montgomery County, VA, which was discussed in section 7.3.1, was the lack of reliability with EPS score. One main aggressor to this issue is that the tool being very simplified and completely asset based. SIMPLE, the software platform for EPS, contains very few occupant behavior inputs, although, these inputs were removed from the software when incorporated into the EPS tool. Similar to SIMPLE, the five modeling tools analyzed for this study also contain some occupant behavior inputs although very few compared to the total inputs of each which is represented in Figure 13:

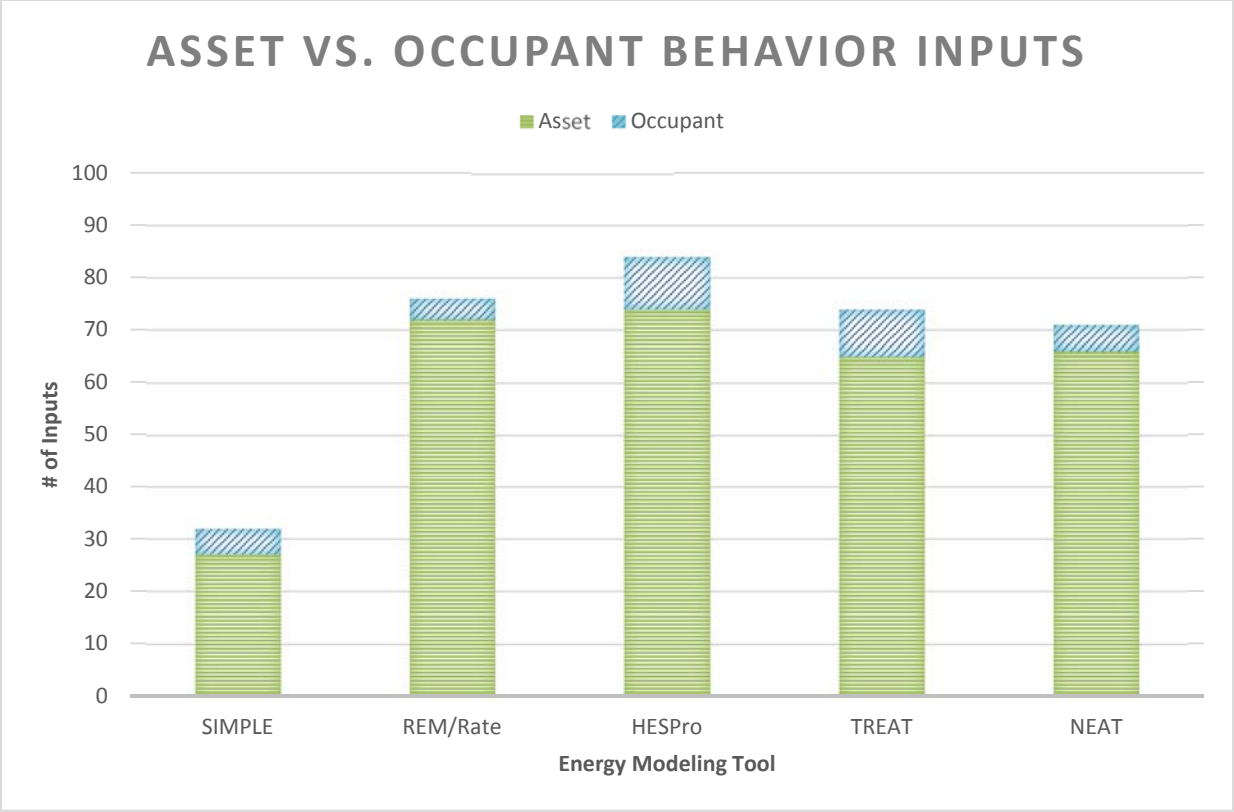

Fig. 13 Asset Based Inputs vs. Occupant Behavior Input Information for Various Energy Modeling Programs (approx.)

As addressed by Durak, occupancy patterns are an important consideration when assessing a home's energy consumption in the Blacksburg area, but this is important in any climate. Due to EPS scores omission of occupant behavior influence parameters, EPS score cannot tell the homeowner how well their home is operating based upon their own specific behaviors, but rather based on the characteristics and contents of the home as a separate entity. Based upon conversation with the energy auditor professionals in Montgomery County, VA, typical clients in the area are seeking home energy audits because they would like to know how their house performs, increase thermal comfort, and also seeking to reduce their utility bill expenses. All of these aspects depend heavily on how the occupants inhabit their homes on a daily basis. Without assessing how occupants interact in their homes, it makes it very difficult to accurately assess how occupants can save on utilities, address thermal comfort, and know how their home performs according to the way they live. As concluded from the studies discussed in section 8.2, incorporating occupant use behavior into an energy assessment can significantly increase accuracy.

9.2 MODELING STUDIES

For this study, seven Montgomery County, VA homes were modeled in four energy modeling tools, SIMPLE, HESPro, REM/Rate, and TREAT, to create a series of modeling studies. The simplified (or minimum) inputs settings, if applicable, were used for all the modeling studies. The results produced by each tool was compared to each other, as well as to the EPS score results produced for each home which

were modeled by local energy auditors. These modeling studies were conducted in order to identify similarities, differences, outliers, concerns, strengths, and applicability of the modeling tools to the Montgomery County, VA housing stock, as well as how they compare in performance to EPS score, the required tool for this region. The protocol, results, analysis, and findings for these modeling studies are discussed in this section.

9.2.1 Protocol

For the energy modeling study portion of this study, seven homes were chosen with some similar features of the typical housing stock located in Montgomery County, VA, the main category for this group being built before 1980. Five energy modeling programs were used for these modeling studies, EPS score, SIMPLE, HESPro, REM/Rate, and TREAT. The information used to enter each home's details into each system originated from past EPS audit data conducted by auditing companies located in Montgomery County, Virginia. As the audit details from the EPS reports were often insufficient information to be entered into the other modeling tools due to the extensive inputs, or varied questions and parameters required, different strategies had to be used in order to get a complete report from each system specific to each house. These strategies included using web based mapping systems such as Google Maps and Earth to get location orientations of the house and other features, or to simply get exterior photos of the house for use in each assessment. Baseline parameter calculations developed Tolga Durak for a Blacksburg VA sample home were also implemented where necessary to calculate features such as wall and fenestration areas, where that information was not available in the EPS reports. The sample home developed by Durak is assumed to represent a common residential construction type in Blacksburg, Virginia, the location of each home used in this energy modeling study. Some of the auditing companies that provided access to EPS reports also supplied a supplement audit report which contained additional information regarding the features of each house, which assisted in entering information into each modeling program. The minimum inputs were only used for each energy modeling tool to attain a more comparable and basic analysis results between all of the tools, and also due to the limitation of audit details and input information supplied by the EPS report audit details. The main objective of this study was to assess what is missed with each tool (including EPS) which could lead to higher accuracy and identify missed improvements; if there is a better tool available for this region and housing stock; which tool is most appropriate for certain consumption domains; and to potentially evaluate which are best for predictions and for assessments, and which tools would work best for the auditors in this region if combined with their other processes.

9.2.2 Selected Modeling Study Homes

Table 5 gives a basic description of each of the homes used in the energy modeling study listing the vintage, total square footage, location, utility types, and number of occupants if available. The sample of homes were selected to represent the variation in homes local energy auditors encounter, as well as the typical housing stock found in Montgomery County, VA, specifically Blacksburg, the location of each sample home. This sample selection was primarily based off responses from auditors interviewed who described the typical houses they audit, and also based on some census data for Montgomery County VA housing characteristics, specifically for vintage and size.

Tab. 5 Homes Used for Energy Modeling study

House	*Location*	*Vintage*	*Square Feet*	*Number of Occupants*	*Heating*	*Cooling*	*Water Heating*
1	Blacksburg	1960	1700	?	Elec. Heat Pump	Elec. Heat Pump	Electric Storage Tank
2	Blacksburg	1965	3270	?	Baseboard Heating & Fireplace	N/A	Electric Storage Tank
3	Blacksburg	1928	2380	3	Gas Furnace	Room A/C Units	Gas Storage Tank
4	Blacksburg	1975	2452	?	Elec. Heat Pump	Elec. Heat Pump	Electric Storage Tank
5	Blacksburg	1970	1116	3	Elec. Heat Pump	Elec. Heat Pump	Electric Storage Tank
6	Blacksburg	1939	1310	?	Elec. Heat Pump & Gas Furnace	Elec. Heat Pump	Electric Storage Tank
7	Blacksburg	2002	1900	?	Elec. Heat Pump	Elec. Heat Pump	Electric Storage Tank

As represented in Table 5, the number of occupants for each household was not always available from the information provided. This was one of the limitations when entering each home's information into the modeling tools which required this information. Input strategies addresses how this was approached in order to generate assessment results from the modeling tools.

9.2.3 Modeling Tool Input Strategies

As discussed in the protocol, section 9.2.1, there were several instances where information required for an input in the modeling tools were not available and "intelligent guessing" was required to produce assessment results. Strategies used for this investigation, as well as by local auditors, are described in the following sections.

Google Maps and Google Earth

Google Maps and Google Earth was a good tool to use in order to get location orientations of each home, and to also get exterior photos of each home if that information was not available in the given information. This strategy was helpful when the modeling tools asked for information such as the direction faced by doors and windows; location of windows and doors; the amount of windows and doors on each wall. This eliminated the need to guess the input information by having an accurate source and visualization of data.

Supplement Reports

Some auditing companies produce supplement audit reports in addition to EPS reports. These accompanied the EPS reports that were made available for the study and were used in some cases to get additional information that was not available from the EPS reports. Additional information that was provided in these reports included test details (blower door, combustion, etc.); exterior inspection observations; house characteristics and features; and appliance details.

Blacksburg Baseline Parameters

For certain types of input information for the modeling tools, baseline parameter calculations were utilized in order to estimate values. These equations were derived from Durak's baseline calculations for a sample Blacksburg home.

Area of Fenestration was used to estimate the area of window space on each house as this information was not available. 8% minimum and 15% maximum of the floor area was calculated and averaged for the total area of fenestration for each house using the following equations:

Af (min) = (floor area) x 0.5 x 0.08

Af (max) = (floor area) x 0.5 x 0.15

Af (mean) = (Af min + Af max) / 2 = Baseline

Other baseline parameters used include heating and cooling set points, as well as the amount of gallons in a water heater tank which were designated baseline values by Durak for energy modeling a Blacksburg home. Heating and cooling set point baselines are 68°F and 78°F respectively, and for a water heater tank, 60 gallons is the baseline storage capacity. A baseline supply temperature for a hot water heater was also defined by Durak to be 135°F, and a baseline efficiency factor for a water heater tank to be equal to 0.90. Lighting use per day was calculated to equal 2.069 hours per day as a baseline for Blacksburg according to Durak. All of these baseline values were used when actual data was not available to input into the modeling tools.

Local Energy Auditor Strategies

From interviewing local auditors, it revealed that there are some instances where they utilize other tools and strategies similar to those implemented for this investigation. These tools and strategies were used to input information not necessarily for EPS score, but rather other analysis tools used in conjunction with EPS, while collecting audit details for a house, or simply for personal curiosity.

The tools and strategies local auditors mentioned they utilized are as follows:

- Google Sketch up to calculate the area and volume of a house

- Google Maps/Earth to look at orientation and directions of a house
- Utility analysis tools created to analyze utility usage and compare it to regional households based on size and number of occupants (useful in comparing actual usage to homeowner's EPS score for increased accuracy)
- Spreadsheets created in Microsoft Excel to assist with calculations and prioritization of recommendations
- Phone application to get the house orientation during exterior inspections
- Light bulb ROI tool to calculate payback and annual savings for switching from incandescent bulbs to CFL bulbs

Other Input Limitations and Restrictions

Other limitations and restrictions faced while entering each home's information into the modeling tools are summarized as follows. This represents information that was sometimes not available from the given data, or baseline values/calculations were also not available to use. As a result of this, the input data had to be interpolated using external data estimates and averages from sources such as the department of energy or appliance manufactures. If no other sources provided credible information, the default settings were used instead:

- Appliance model information, efficiency ratings, input capacity, etc.
- Locations of appliances
- Additional appliances (i.e. second refrigerator or freezer, secondary heating, etc.)
- No input for window AC units (utilized on one home)
- Roof characteristics (insulation levels, color, etc.)
- Number of occupants and ages
- Occupant behavior patterns (shower use times, laundry patterns, etc.)
- Lighting use intensity and distribution of incandescent and CFL on the interior and exterior of the house
- Plug loads
- Number of baseboard heaters
- Types of windows and variation on each wall (i.e. some with both single and double pane)
- Townhouse settings, specifically for HESPro (mid) – cannot input 0 square feet of windows for right and left walls if placed between two houses
- Percent of space open to floor levels above
- Distribution of conditioned floor area

For this interpolation, EPS audit reports performance ratings (very poor, poor, average, good, and excellent) given for different aspects of the home assisted with evaluating and deciding how to represent the required information in each modeling tools not given. This was especially a useful strategy for estimating insulation levels when not prescribed from the given data.

9.2.4 Energy Modeling study Results and Analysis

9.2.4.1 Energy Modeling Results

Table 6 depicts the assessment results for each house entered into the energy modeling tools. Most tools produced results in kilowatt hours per year (kWh/yr), while some provided therms as the unit for gas utilities, and gallons for propane use. For the purpose of comparison, all results were converted to kWh/yr. The results for annual consumption are as shown in Table 6:

Tab. 6 Energy Modeling Annual Consumption Results for Modeling study Homes

House 1	EPS Score	SIMPLE	HESPro	REM/Rate	TREAT
Heating	4700 kwh/yr	5077 kwh/yr	8926 kwh/yr	6829 kwh/yr	4046 kwh/yr
Cooling	1400 kwh/yr	895 kwh/yr	775 kwh/yr	1495 kwh/yr	473 kwh/yr
Water Heating	3100 kwh/yr	1468 kwh/yr	1759 kwh/yr	5099 kwh/yr	5577 kwh/yr
All Else	6300 kwh/yr	5630 kwh/yr	5562 kwh/yr	5832 kwh/yr	7782 kwh/yr
TOTAL	16000 kwh/yr	13070 kwh/yr	17022 kwh/yr	19255 kwh/yr	17878 kwh/yr
House 2	**EPS Score**	**SIMPLE**	**HESPro**	**REM/Rate**	**TREAT**
Heating	17900 kwh/yr	31125 kwh/yr	12163 kwh/yr	29776 kwh/yr	14450 kwh/yr
Cooling	N/A	N/A	N/A	N/A	N/A
Water Heating	3700 kwh/yr	2256 kwh/yr	2173 kwh/yr	4513 kwh/yr	5452 kwh/yr
All Else	8400 kwh/yr	7370 kwh/yr	5543 kwh/yr	9701 kwh/yr	6438 kwh/yr
TOTAL	30000 kwh/yr	40751 kwh/yr	19879 kwh/yr	43990 kwh/yr	26340 kwh/yr
House 3	**EPS Score**	**SIMPLE**	**HESPro**	**REM/Rate**	**TREAT**
Heating	25200 kwh/yr	21423 kwh/yr	17929 kwh/yr	21755 kwh/yr	25878 kwh/yr
Cooling	N/A	N/A	890 kwh/yr	2608 kwh/yr	N/A
Water Heating	5700 kwh/yr	5480 kwh/yr	4748 kwh/yr	7092 kwh/yr	8616 kwh/yr
All Else	6400 kwh/yr	6767 kwh/yr	6339 kwh/yr	7854 kwh/yr	7885 kwh/yr
TOTAL	37000 kwh/yr	33670 kwh/yr	29906 kwh/yr	39309 kwh/yr	42379 kwh/yr
House 4	**EPS Score**	**SIMPLE**	**HESPro**	**REM/Rate**	**TREAT**
Heating	-40 kwh/yr	6664 kwh/yr	7133 kwh/yr	10257 kwh/yr	6794 kwh/yr
Cooling	1000 kwh/yr	1600 kwh/yr	810 kwh/yr	2139 kwh/yr	1236 kwh/yr
Water Heating	3900 kwh/yr	3157 kwh/yr	2173 kwh/yr	7327 kwh/yr	5151 kwh/yr
All Else	7300 kwh/yr	6810 kwh/yr	5543 kwh/yr	8206 kwh/yr	5957 kwh/yr
TOTAL	12000 kwh/yr	18231 kwh/yr	15659 kwh/yr	27929 kwh/yr	19138 kwh/yr
House 5	**EPS Score**	**SIMPLE**	**HESPro**	**REM/Rate**	**TREAT**
Heating	3600 kwh/yr	4424 kwh/yr	4918 kwh/yr	5480 kwh/yr	5779 kwh/yr
Cooling	1100 kwh/yr	1683 kwh/yr	591 kwh/yr	1377 kwh/yr	431 kwh/yr
Water Heating	2500 kwh/yr	3157 kwh/yr	2173 kwh/yr	5715 kwh/yr	5538 kwh/yr
All Else	5300 kwh/yr	5709 kwh/yr	5543 kwh/yr	4953 kwh/yr	5324 kwh/yr
TOTAL	12000 kwh/yr	14973 kwh/yr	13225 kwh/yr	17525 kwh/yr	17072 kwh/yr

House 6	EPS Score	SIMPLE	HESPro	REM/Rate	TREAT
Heating	6100 kwh/yr	5253 kwh/yr	4500 kwh/yr	22889 kwh/yr	6380 kwh/yr
Cooling	2500 kwh/yr	1429 kwh/yr	688 kwh/yr	1524 kwh/yr	609 kwh/yr
Water Heating	2700 kwh/yr	3157 kwh/yr	2251 kwh/yr	5187 kwh/yr	6786 kwh/yr
All Else	6300 kwh/yr	6625 kwh/yr	5540 kwh/yr	4924 kwh/yr	7708 kwh/yr
TOTAL	18000 kwh/yr	16464 kwh/yr	12979 kwh/yr	34524 kwh/yr	21483 kwh/yr
House 7	**EPS Score**	**SIMPLE**	**HESPro**	**REM/Rate**	**TREAT**
Heating	3700 kwh/yr	3957 kwh/yr	3914 kwh/yr	5774 kwh/yr	7911 kwh/yr
Cooling	2200 kwh/yr	1347 kwh/yr	834 kwh/yr	1671 kwh/yr	1380 kwh/yr
Water Heating	2900 kwh/yr	3157 kwh/yr	2251 kwh/yr	3986 kwh/yr	5162 kwh/yr
All Else	6100 kwh/yr	6417 kwh/yr	5540 kwh/yr	6946 kwh/yr	8910 kwh/yr
TOTAL	15000 kwh/yr	14526 kwh/yr	12539 kwh/yr	18377 kwh/yr	23363 kwh/yr

The following group of bar graphs portrayed in Figures 14 - 20 represent each modeling study home's results for a more visual comparison of results of each modeling tool. Patterns and outliers related to modeling different housing footprint areas, vintages, appliance types, and consumption domains are revealed in the graphs and will be discussed further in subsequent sections.

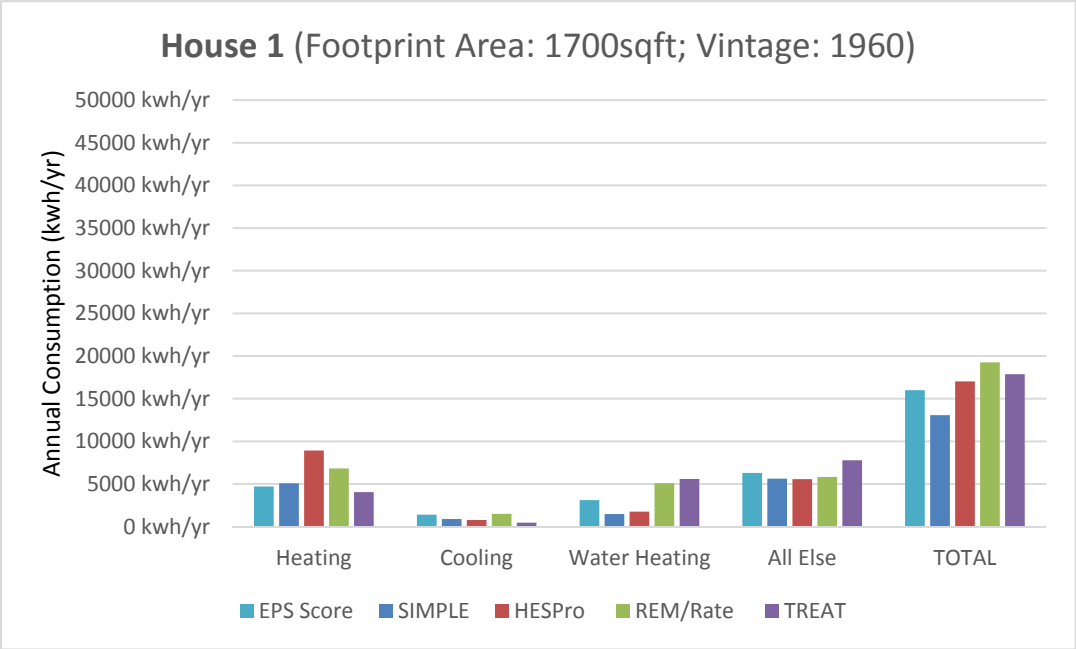

Fig. 14 House 1 Energy Modeling Results

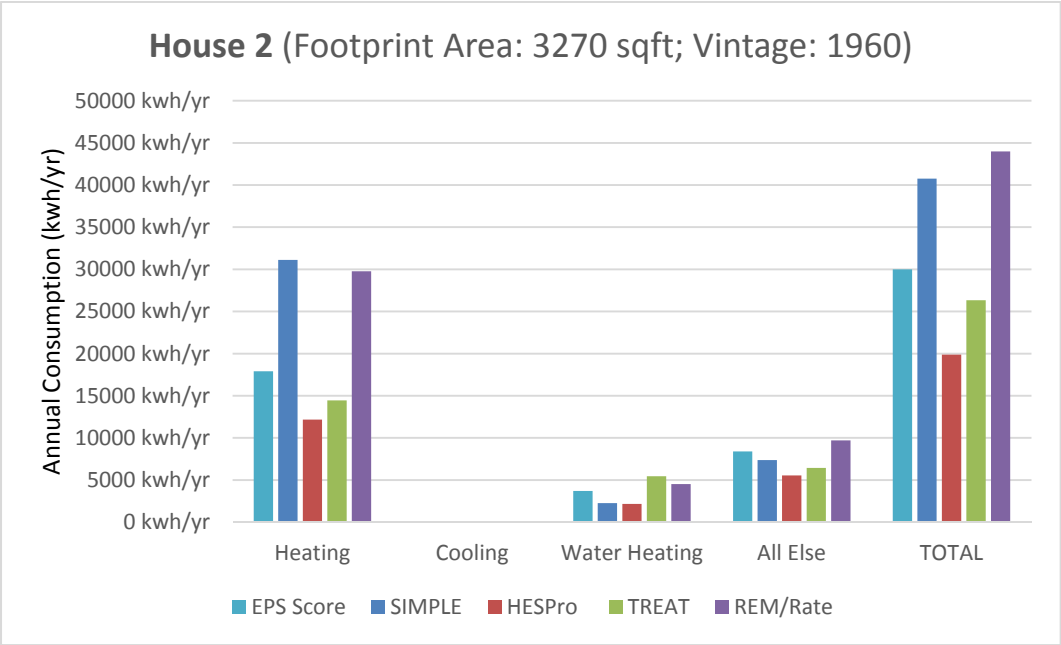

Fig. 15 House 2 Energy Modeling Results

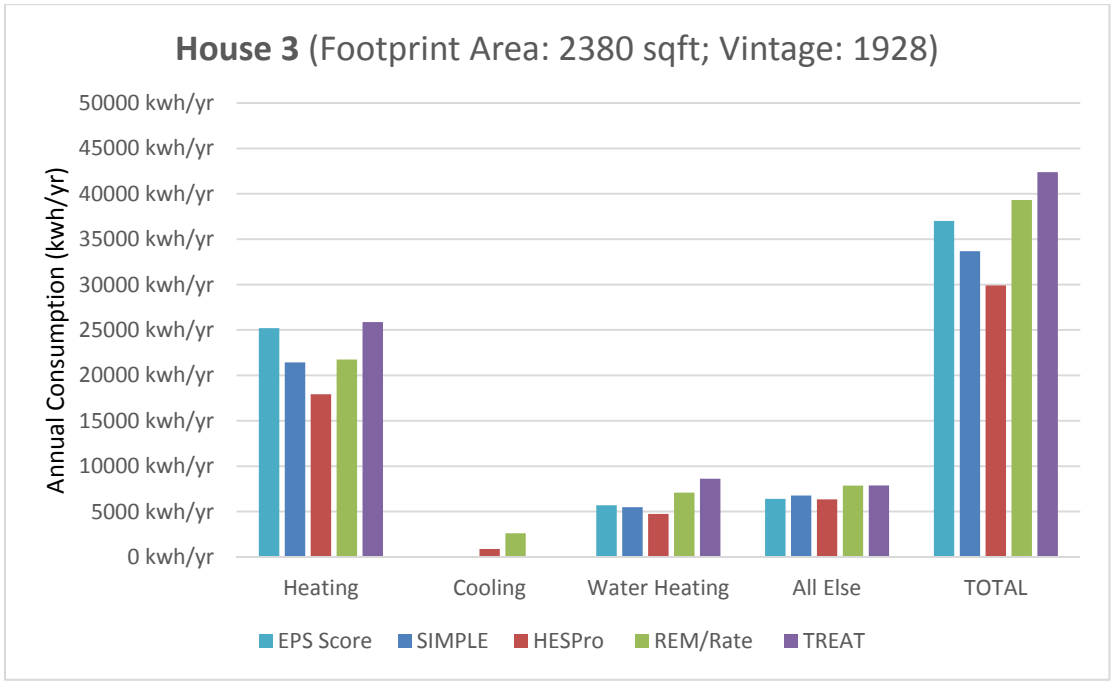

Fig. 16 House 3 Energy Modeling Results

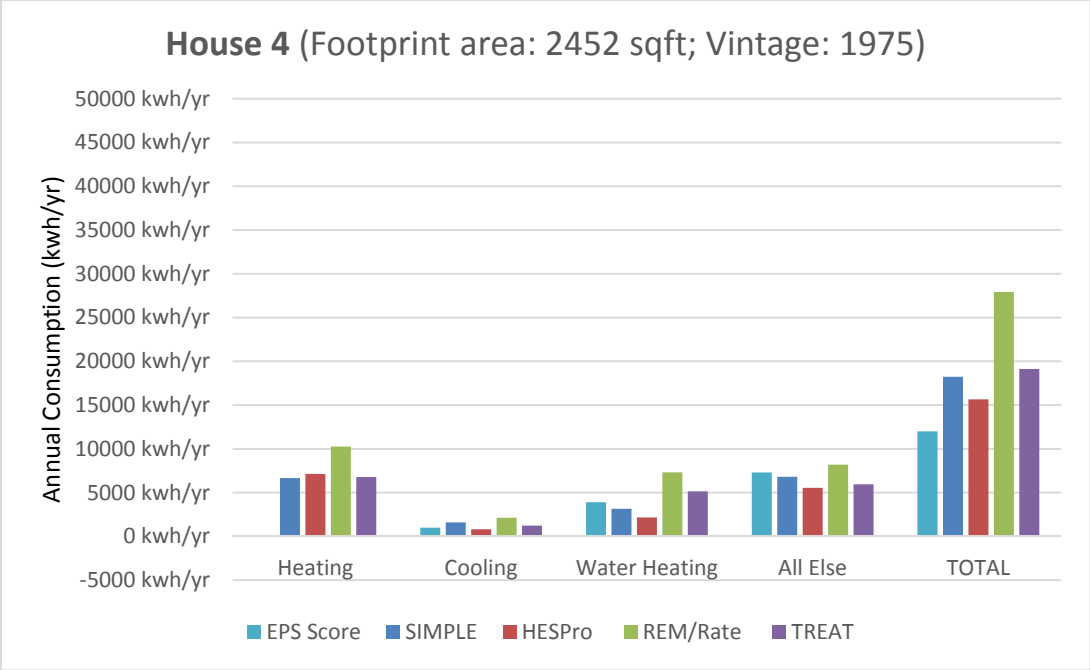

Fig. 17 House 4 Energy Modeling Results

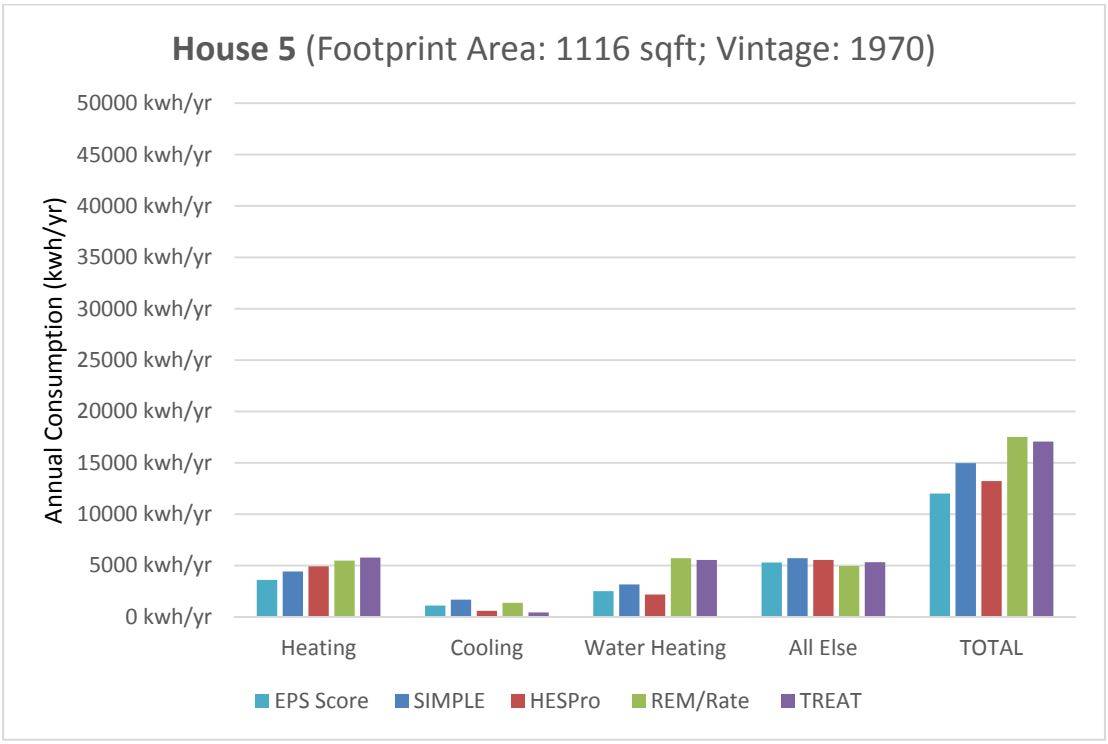

Fig. 18 House 5 Energy Modeling Results

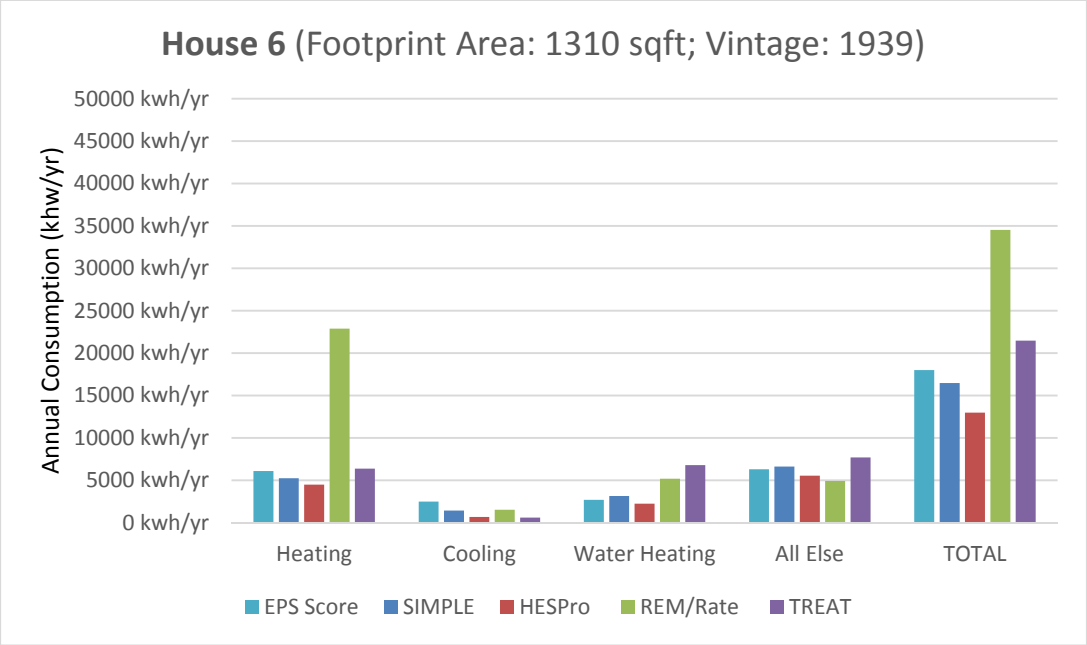

Fig. 19 House 6 Energy Modeling Results

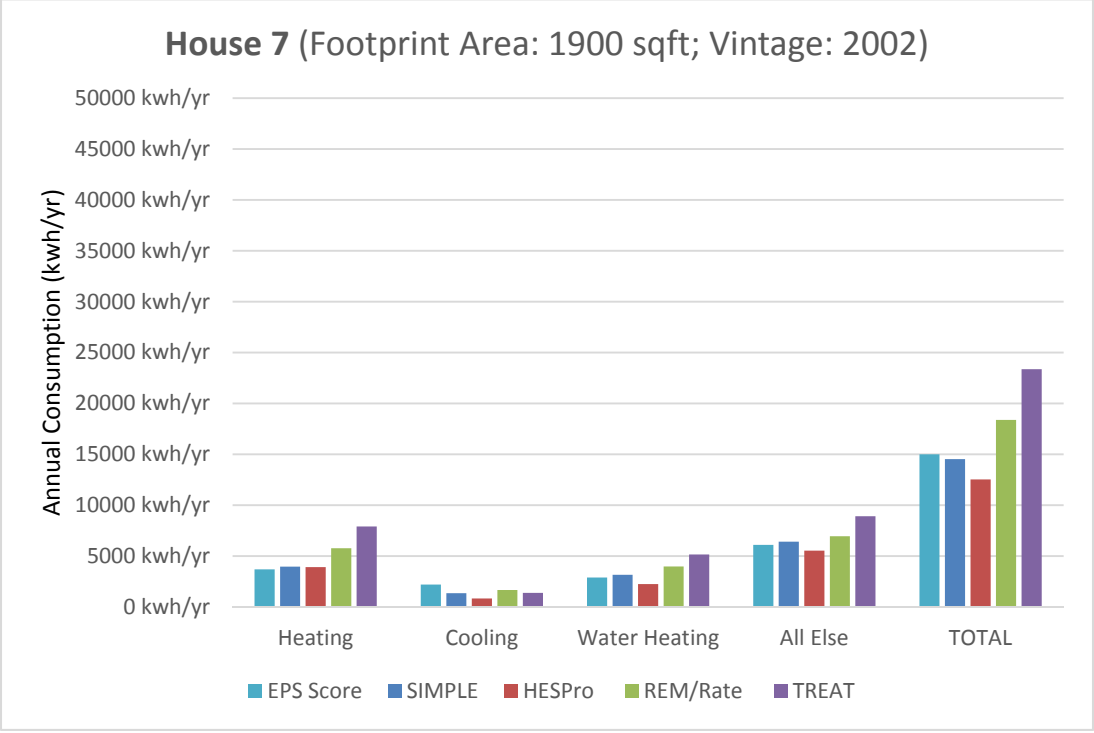

Fig. 20 House 7 Energy Modeling Results

Outliers

There were several outliers identified all related to modeled heating results. These outliers were identified in Houses 2, 4, and 6. Figures 21-23 represent the outliers identified and the possible reasons why these outliers occurred and their effect on the results analysis are discussed following each home's graph presented in the figures.

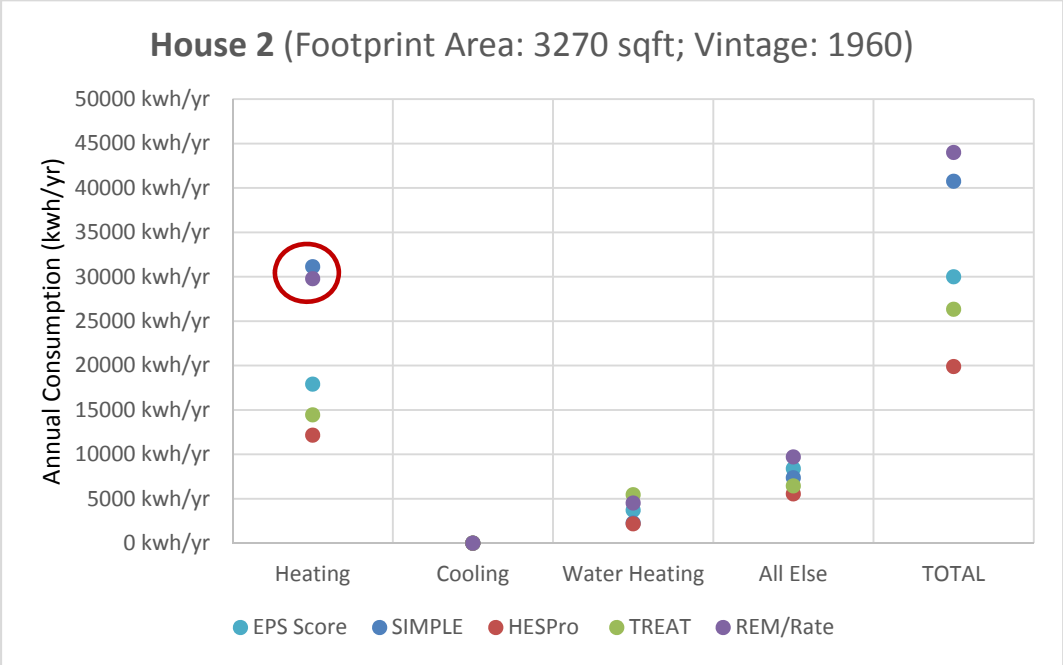

Fig. 21 House 2 Outliers – Outliers Circled in Red

Figure 21 shows House 2 with heating result outliers generated by SIMPLE and REM/Rate. The heating systems utilized in House 2 are baseboard heaters and fireplace heating, with no cooling system. These results were significantly higher than those provided by the other three tools, almost double in the difference. It is suspected that the way SIMPLE and REM/Rate assess baseboard heating as the primary system is considerably different to that of the other tools. SIMPLE and EPS results remained relatively close in all other domains for each home as expected, due to SIMPLE being the basis for EPS, which makes the difference between the two heating results produced for House 2 questionable. One other reason for the large difference in values produced by SIMPLE and TREAT could be due to the heating set-points input into each tool, which can have a large impact on the results produced for baseboard heating systems. These values were interpolated because this information was not available from the given data.

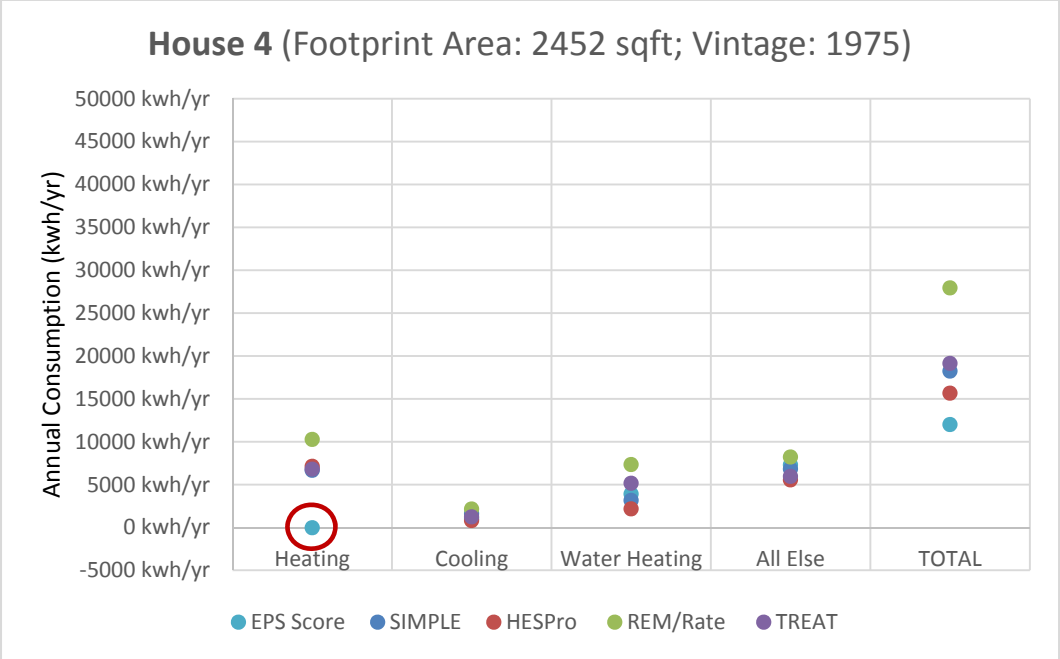

Fig. 22 House 4 Outliers – Outliers Circled in Red

House 4 represented in Figure 22 depicts an outlier produced by EPS score in the heating domain. EPS reported -40 kwh/year for heating in use in House 4. This is most likely the result of an input error by an auditor as this is not a possible result. House 4 uses an electric heat pump as the primary heating system in the house, and all other tools produced results somewhat close in annual usage, and were not negative values.

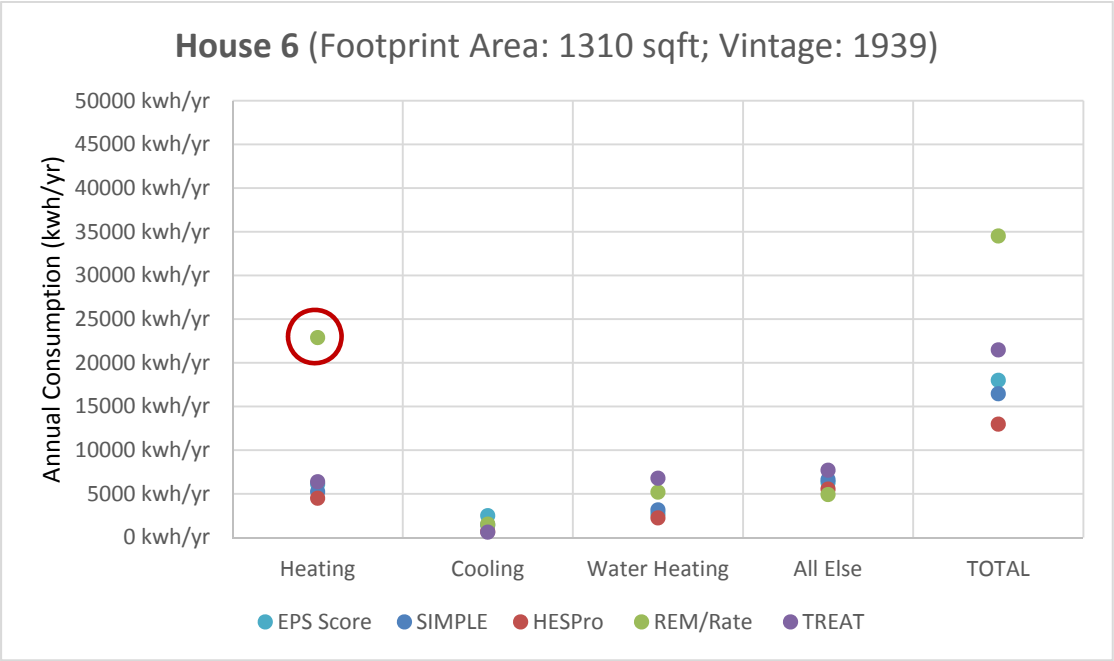

Fig. 23 House 6 Outliers – Outliers Circled in Red

The final significant outlier noticed from all of the results came from House 6 which is represented in Figure 23. The heating result produced by REM/Rate was considerably higher than the other tools results produced for heating. The suspected reason for this outcome is due to REM/Rate inability to appropriately recognize and allocate appropriate load for the two HVAC systems the home uses. House 6 uses two HVAC systems, an electric heat pump as well as a gas furnace.

9.2.4.2 Modeling Results Analysis

Figure 24 shows the four consumption domain results from each modeling tool for all seven homes a part of the energy modeling tool modeling studies. The results shown in the scatter plot graphs gives a good comparison of how well each tool captured a home's information based on how small the range of results are scattered.

Fig. 24 Heating, Cooling, Water Heater, and All Else Results Graphs for Energy Modeling studies

It is apparent by looking at the graphs displayed in Figure 24 that heating is the most volatile domain of results, while cooling, water heating, and all else remained relatively small in the range of results produced for each home. These patterns and other similar correlations and concerns are identified and discussed in this section. EPS results are represented by a red hollow circle outline marker in contrast to the other tools results which are represented by opaque circle markers on the graphs to make comparison clearer.

Heating Results Discussion

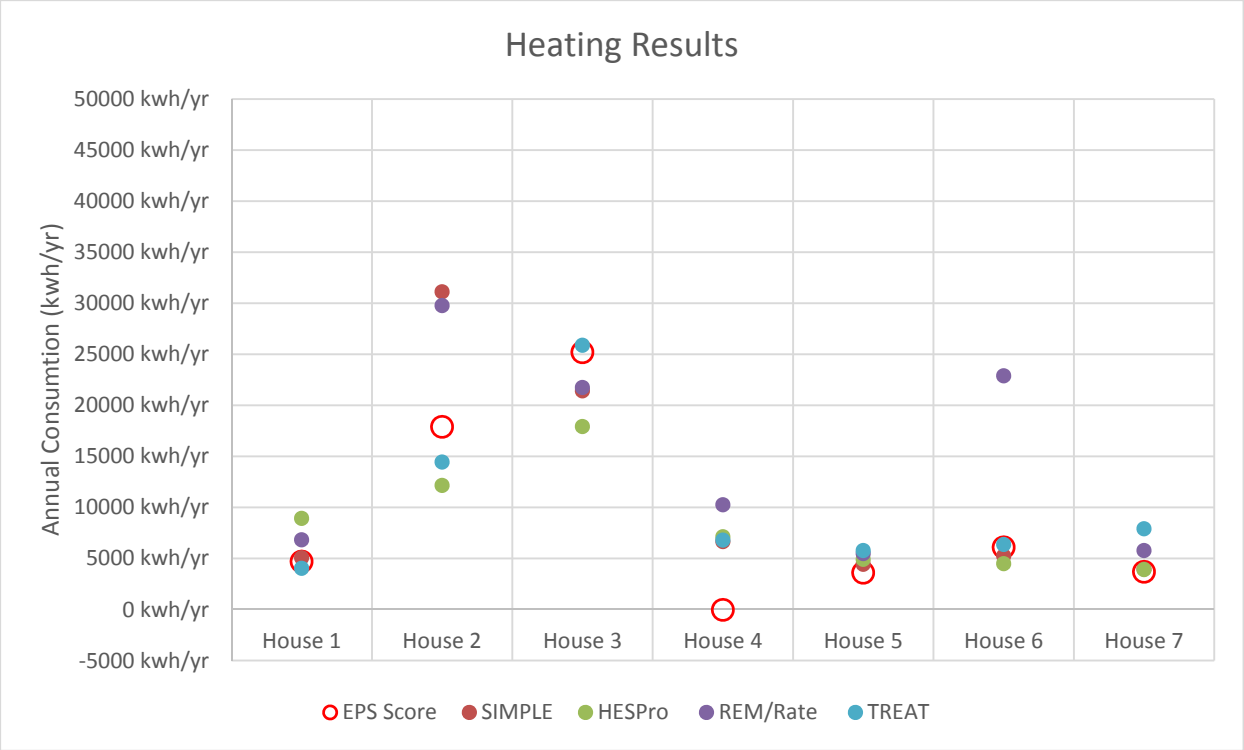

Fig. 25 Heating Energy Modeling Tool Results for all 7 Houses

As noted in the outlier discussion, heating was the source of all the significant outliers generated from the results. With the exclusion of the outlier produced for House 6, House 5 and House 6 were the only homes out of the seven to produce the closest results with the difference of both homes highest and lowest heating results falling below 2200 kwh/year. It can be seen from this sample of modeling studies that heating is a domain where a lot of uncertainty, as well as diversity, can arise in the results produced from tool to tool. Figure 25 shows the heating results for each modeling study home modeled by the tools. REM/Rate and TREAT required the most minimum inputs regarding heating systems in order to complete a simplified energy model of the home, and even so, HESPro, SIMPLE, and EPS all had instances of being on the outskirts of the results pool for a home. Some difficulties and corrected errors that occurred while entering heating input information were due to information such as infiltration rates; estimating actual insulation levels in the homes envelope and keeping them consistent across the different tools where prescribed insulation values restricted consistency; inputting an exact number of baseboard heaters present in a home where that information was unknown; entering correct efficiency levels, input capacities, and load sizes for heating systems where that information was not available; and also restrictions on location choices for heating systems to the interior of the home. Input strategies discussed in the previous section 9.2.3 were utilized to approach these difficulties.

From the results, it also appears that smaller homes produce less volatile results for heating than for larger homes. House 6 is the exception, but if the heating outlier was not taken into account, all homes below 2000 sqft in total size would have produced the lowest range in results for heating. This analysis shows that the modeling tools assess heating in smaller homes at a more reliable level than for large homes which are

perhaps more unique in geometry and characteristics that a simplified energy model cannot capture accurately enough in its analysis.

In summary, heating can be considered a significant domain to account for when assessing a home in this region for the reasons discussed. In Figure 26, which shows the average results modeling results produced for each consumption domain, heating was often times the biggest, or among the biggest, contributors to total energy consumption in the home, in front of the All Else category (comprised of appliances, lighting, and household electronics), and Water Heating.

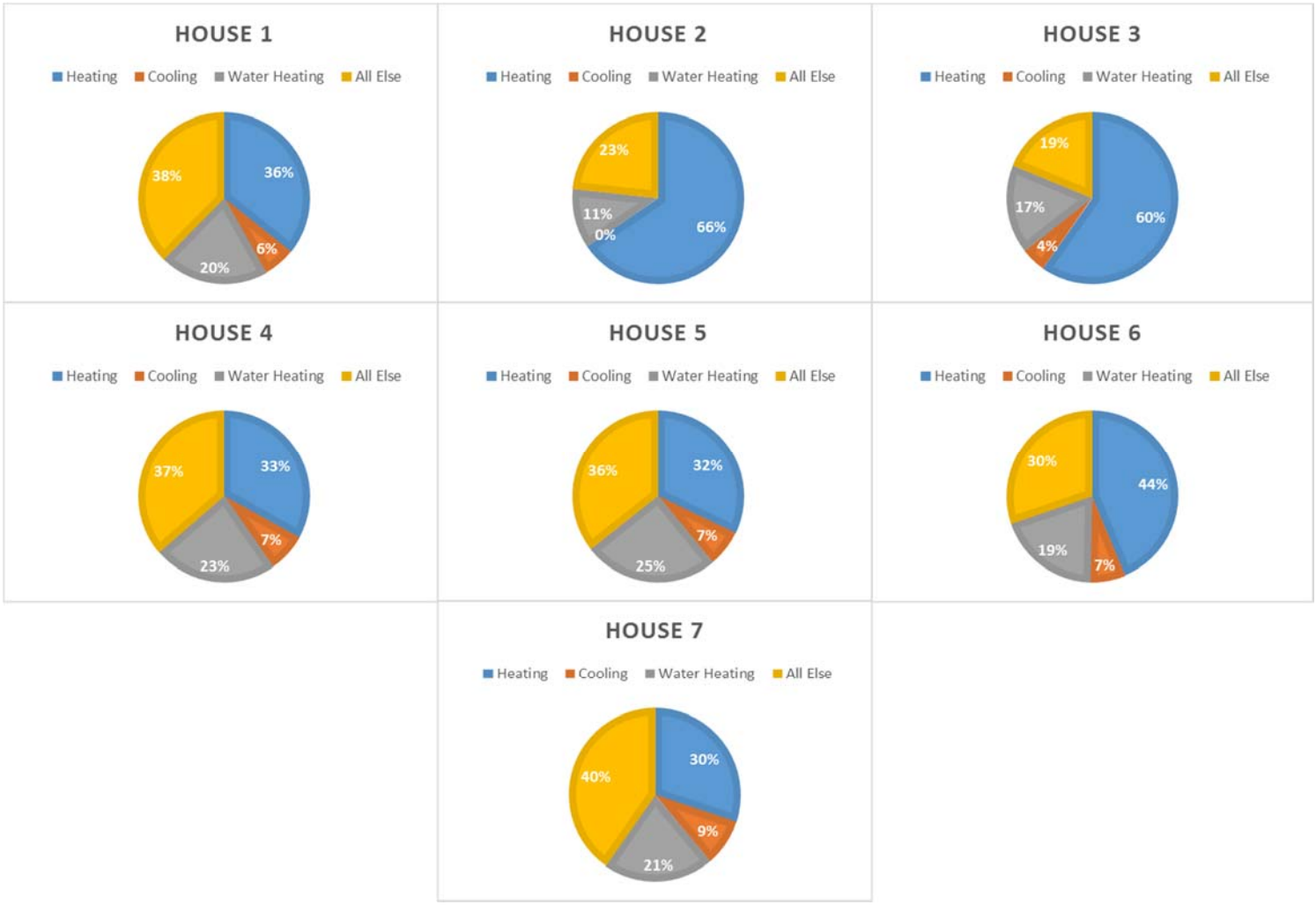

Fig. 26 Average Energy Consumption in Heating, Cooling, Water Heater, and All Else Results Distribution for Each Modeling study House

Cooling Results Discussion

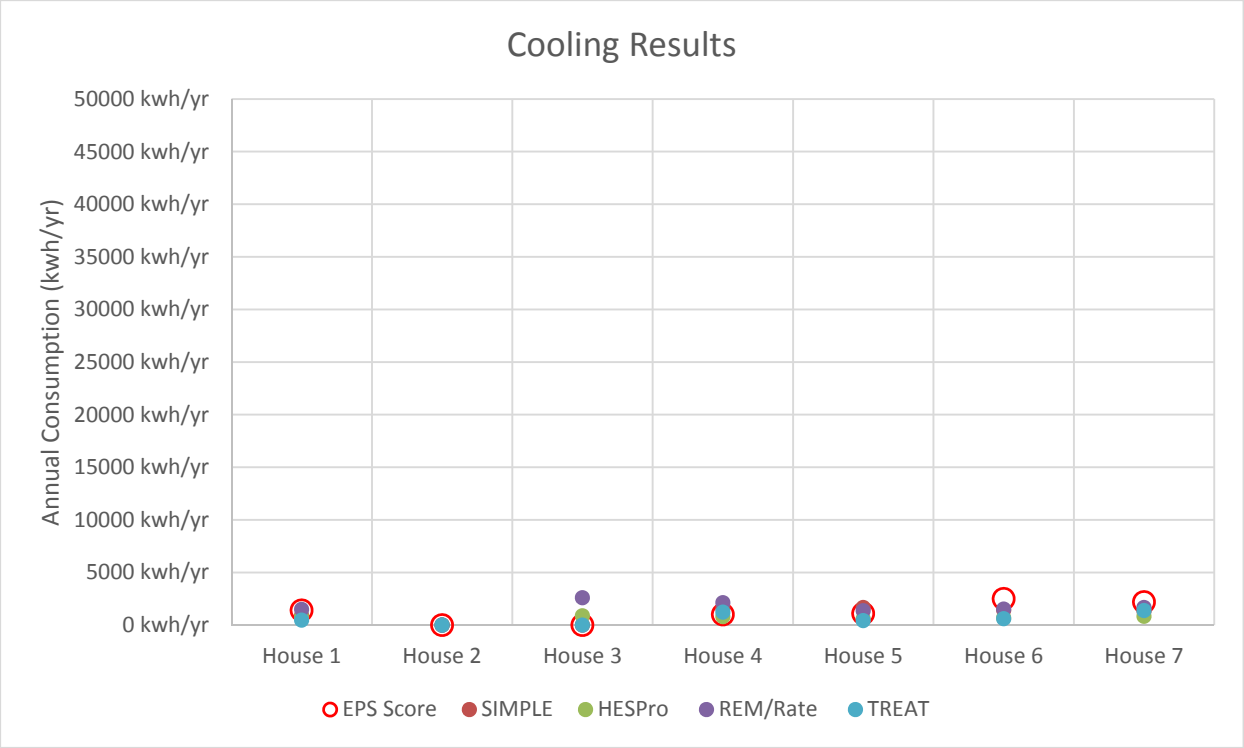

Fig. 27 Heating Energy Modeling Tool Results for all 7 Houses

Cooling results were very close in range for each home as can be seen in the scatter plot graph for the cooling results represented in Figure 27. All the results were relatively low compared to those produced for heating. The reasons for this could be due to several issues such as, the focus on heating attributes inputs over cooling in the modeling tools, and also the Montgomery County, VA climate being primarily heating oriented over cooling.

For all the modeling tools, the number of inputs that focused on heating was greater than for cooling. As seen in the Appendix Table 8, the inventory of heating/cooling inputs are not distributed equally which could inhibit the way cooling is captured and calculated in the modeling tools. Due to the utilization of heat pumps, the HVAC system used by the majority of the sample of the homes (except for House 2 and 6 which utilized no units or room AC units), which can provide both heating and cooling, the load may be distributed more heavily towards heating results, causing this imbalance in inputs, as well as produced results. This probes the investigation into the climate characteristics for Southwest VA, and if this uneven distribution is due to heating demand being higher than for cooling.

The National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center provides climate data for regions around the US. Using this database, Heating Degree Day (HDD) and Cooling Degree Day (CDD) data was accessed in order to better understand the heating and cooling energy demands for Southwest VA. HDD and CDD 2012 and 2011 data from the NOAA database are represented in Figures 28 and 29 showing the distribution of HDD and CDD for the Southwestern Mountain Region of VA. Data from 2012 and 2011 was used because all the homes in the sample for the modeling studies were audited during that time period:

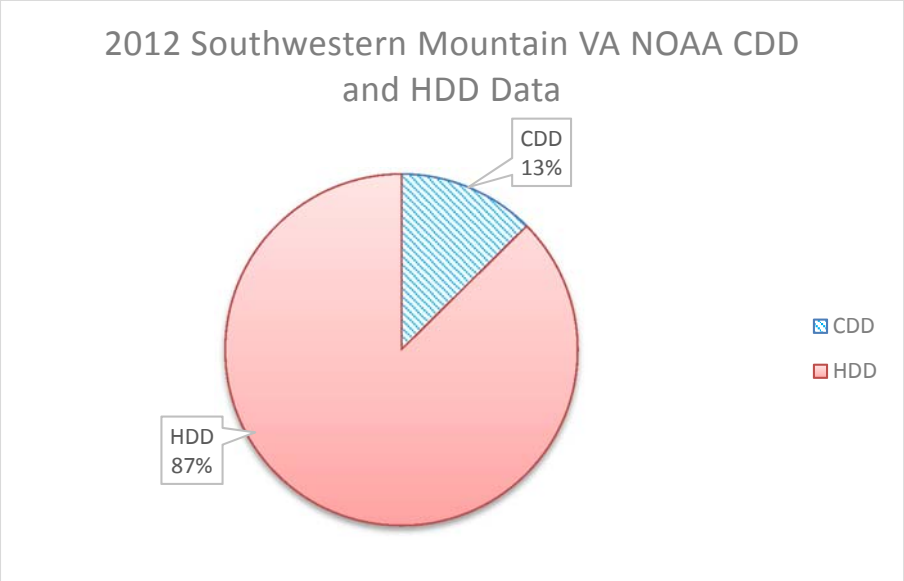

Fig. 28 2012 NOAA HDD and CDD Data Distribution for Southwestern Mountain VA Region

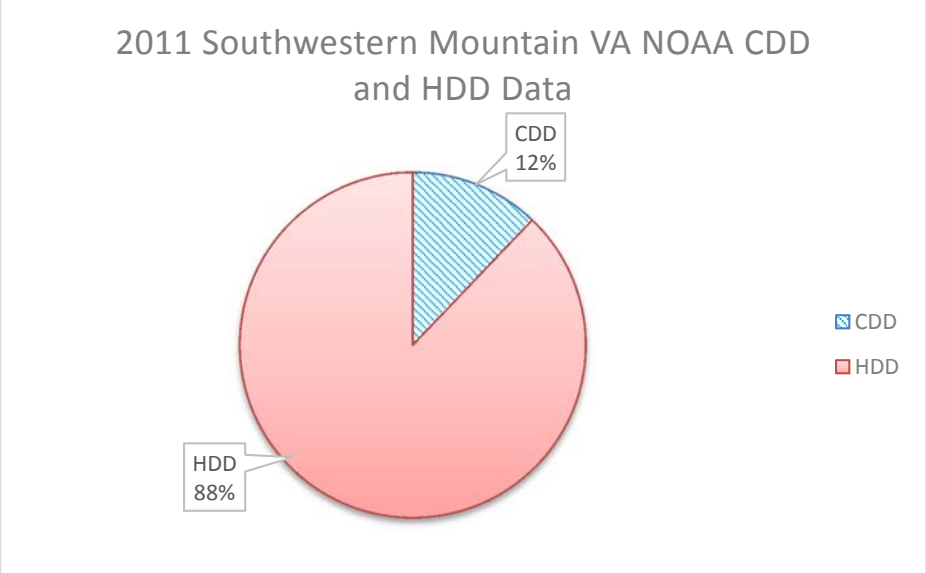

Fig. 29 2011 NOAA HDD and CDD Data Distribution for Southwestern Mountain VA Region

It can be concluded from Figures 28 and 29 that HDD are much more significant than CDD for the Southwest VA regions, eluding to the fact that Southwest VA has a heating dominated climate, which is taken into account by the energy modeling tools. This is obviously the main cause for the low cooling consumption results produced for each home by the modeling tools, which were the lowest reported results out of the four main categories. Each tool asked for the location of the house using the zip code it is located in. By the results produced, the tools were able to capture the climate influence on the homes heating and cooling performance well based on the distribution of less cooling consumption than heating. In conclusion, based on the results of the modeling studies, cooling is an insignificant domain captured by the energy modeling tools because of the climate location (heating dominated) where cooling does not have much

impact on the energy consumption. Recommendations for upgrades, pay-off estimates, and annual usage estimates all related to cooling should not be the most significant priority when conducting and energy assessment based on this analysis for a home located in this region. Heating is the most significant factor to evaluate over cooling when assessing a home's HVAC systems in Southwest VA if the greatest savings in energy and cost are desired by the homeowner.

Water Heating Results Discussion

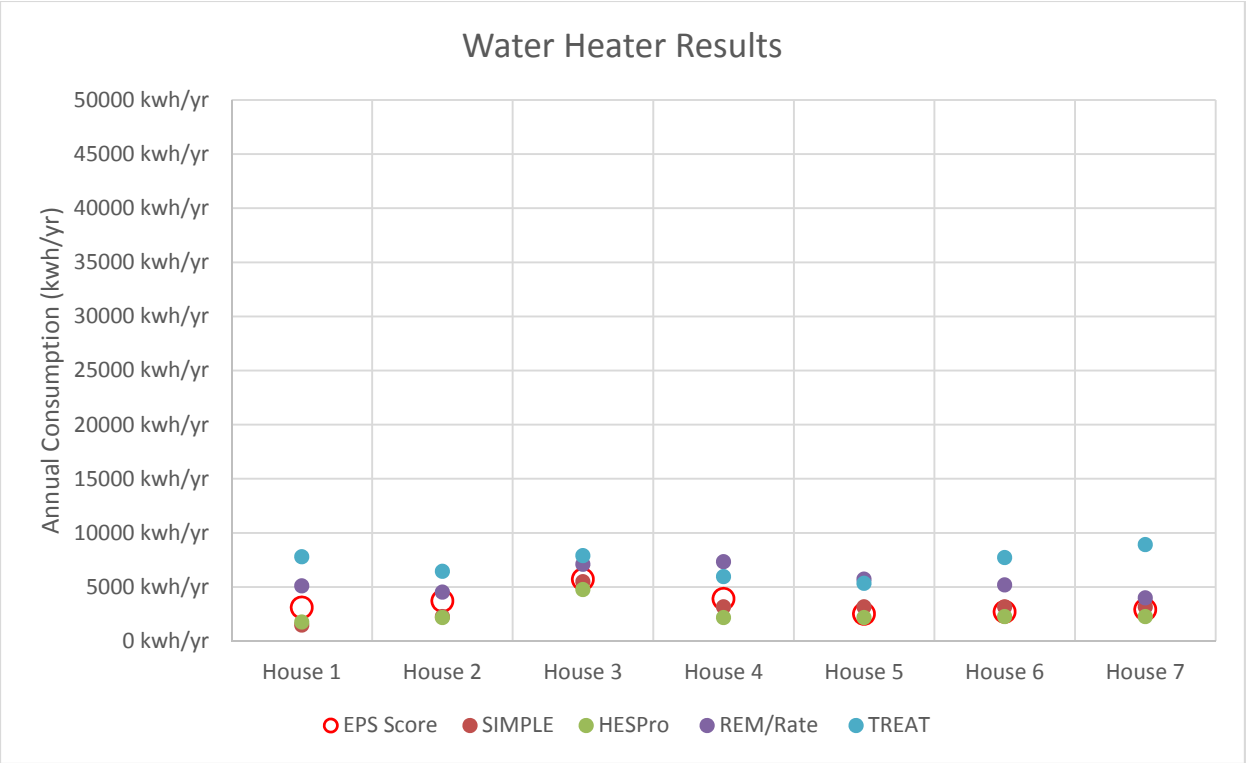

Fig. 30 Water Heating Energy Modeling Tool Results for all 7 Houses

Hot water heating results shown in Figure 30, similar to cooling, were relatively consistent for all homes, House 3 being the exception with larger than average results produced in all the modeling tools except for REM/Rate. Results for water heating annual usage remained very close in value for each home which led to a concern that there were some influences not being captured.

According to Durak, the influences on annual hot water consumption are the year the house was built, the type of heating system used in the house, the number of rooms, zip code, available energy source, and space usage characteristics (Durak, 2011). With the exception of the zip code (the same for all homes), all other influences on the water heater identified by Durak varied for each house as well as each tool. Due to this, it seems apparent that the influences may not be taken into enough, or any, consideration by the modeling tools when computing consumption estimates based on the results produced.

House 3 is the only house in the sample to use natural gas for the water heater fuel, while all others use electric water heaters. The results for House 3 are higher than average for EPS, SIMPLE, HESPro, and TREAT compared to the other homes. These tools appear to capture the difference between the heating efficiencies of gas and electric fuel. When comparing House 7, built in 2002 with a total square footage of

1900, and House 2, built in 1960 with a total square footage of 3270, it is apparent that the year the home was built and the size do not have much, if any, relevance to the results calculated. House 7 and House 2 differ greatly by size as well as age, and also by the number of rooms, but yet the results produced for water heating consumption are very closely matched for each tool. The year a home is built has impact on the consumption for hot water because if the hot water heaters have not been replaced recently, water heaters in older homes are not as efficient as for those in newer homes and consume much more energy. Insulation levels in older homes and the type of building materials are also not as efficient in preventing heat loss than in newer homes which could increase the energy consumed (Durak, 2011). The number of bathrooms and kitchens could similarly increase the demand for hot water which none of the tools required specific information for.

REM/Rate and TREAT also produced the highest results for each home for water heater annual usage. TREAT required the most required inputs regarding water heater characteristics and consistently produced the highest results, except for House 4, in which REM/Rate produced a higher result. SIMPLE, HESPro, and EPS Score produced the lowest results, the tools with the most generalized inputs in contrast to REM/Rate and TREAT, tools with the most detailed inputs.

In summary, the type of fuel used for water heating seems to be captured by the tools, with the exception of REM/Rate; the size of the home, year built, number of rooms do not appear to have a significant, or any, impact on water heating consumption estimates by the tools; and it is unknown how much varying the number of occupants and space usage characteristics (of the tools requiring those inputs) would have an effect on the results as baseline and default values were used where that information was unavailable.

All Else Results Discussion

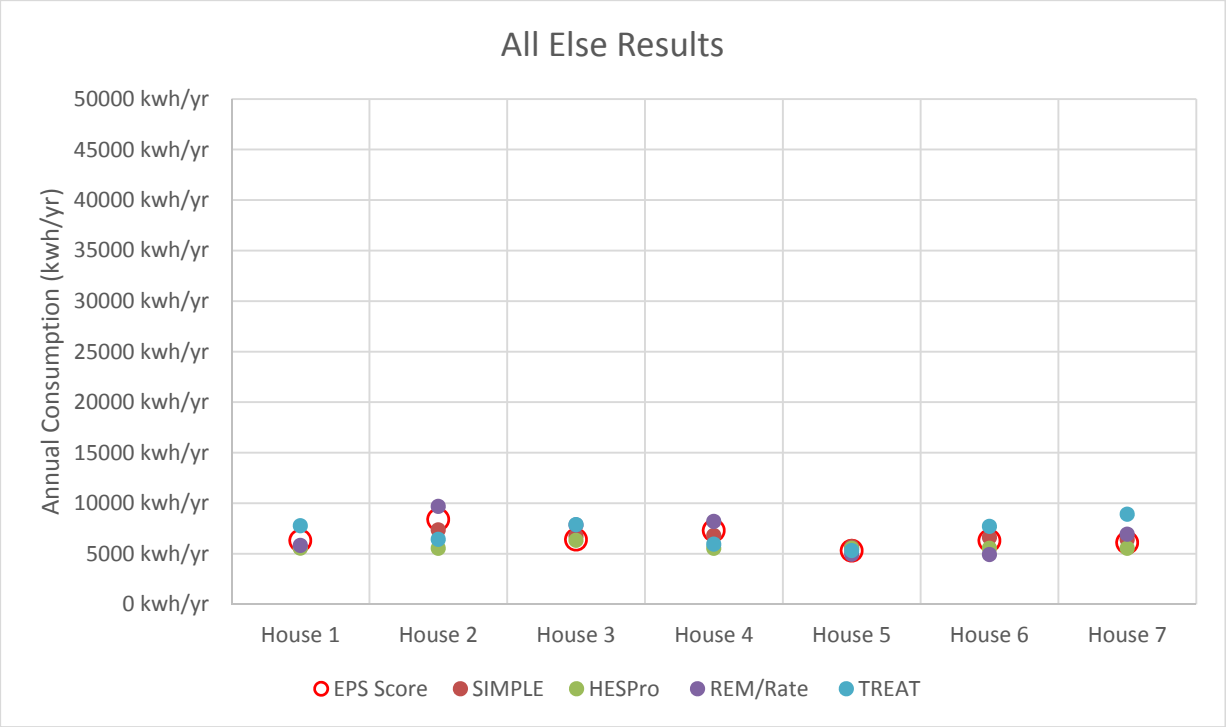

Fig. 31 All Else Energy Modelling Tool Results for all 7 Houses

All Else results include annual consumption estimates for lighting, and small and large appliances such as refrigerators, washers, dryers, cooking equipment, and electronics. Figure 31 depicts all results produced for the 7 homes for this category of All Else. Results varied for this category for each home. The influences on appliances and electronics include the total square footage, number of rooms, year built, and the age of occupant. The influences on lighting include the number and size of glass doors, number of stories, orientation, space usage characteristics, the number and size of windows, local surroundings, and the number and size of skylights (Durak, 2011). As the results showed enough variation from house to house, unlike that for cooling and water heating, it seems that some of the influences are being taken into account for this domain possibly in other such as efficiency levels and Energy Star appliances. Some appliances may have a more significant impact on the consumption results in this domain compared to others.

House 2, the largest of all the homes produced the most varied results in this domain, while in contrast, House 5, the smallest of all the homes produced the least varies results in this domain. This leads to a conclusion that the larger the home, the more difficult it becomes to estimate the consumption of appliances and lighting than for a smaller home. This may be a case when other measures may need to be applied to larger homes in order to reach a more accurate estimate. As this was not consistent for all homes, for example, results produced for House 3, a 2380 sqft home were more consistent than for House 6, a 1310 square foot home. This led to some speculation regarding whether or not certain appliances carried more significance others in certain tools, and which ones carried the significance.

9.3 CORE FINDINGS OF ENERGY MODELING TOOLS

Based on the results produced and inputs analyzed for each of the energy modeling tools, and also from entering data into the tools, some apparent strengths and struggles were identified which could affect results of an assessment. They are summarized as follows.

9.3.1 Modeling Tool Strengths

"The Big Picture"

In the consumption domains of Cooling, Water heating, and All Else which the modeling tools produced results for, for each tool, the range in results for each house were very significant. Although the results produced were not significantly different, accuracy is still an issue that it is unknown. Due to these issues, the tools are assets for providing ball park estimates and "the big picture" so to speak, for these consumption domains. But if accuracy is desired at the highest level, extra steps and investigations could be necessary as it was determined that there is a large absence of occupant behavior influences and the presence of all 20 identified energy influence parameters (Durak, 2011) in each of the tools inputs, which if more were included, accuracy, as well as applicability to the local region and homeowner, could potentially increase.

Capturing Location and Climate Influences

As a result of the consumption rates produced for heating and cooling, the analysis and comparison of those numbers provided some insight into how well the tools account for location. It was found that while heating results fluctuated with some significance for each home, cooling remained relatively stable and consistent for each home, as local climate data is taken into account when assessing a home's audit data. Due to the study location, it was concluded that cooling is an insignificant domain towards an energy assessment of a home in this region.

Smaller and Less Geometrically Unique Homes

From the analysis of the heating energy consumptions, it was concluded that the modeling tools appear to assess a smaller and less geometrically unique home more consistently across all of the tools, specifically in the heating domain. All of the homes with less than 2000 sf produced results with the least difference, excluding outliers. As the average size of a home located in Blacksburg is 1800 sf, this can be applied to a good amount of the housing stock with some assurance that results produced will not be too far off. However for larger and more unique homes, some caution may need to be taken in regards to the reliability in results and recommendations calculated and produced.

9.3.2 Modeling Tool Struggles

Ignored Energy Influence Parameters

Figure 12 depicted the amount of influence parameters out of the 20 identified for a simplified assessment that are captured by each modeling tool used in the modeling studies. It was concluded that not one of the tools incorporated all 20 of the influence parameters in their simulations. TREAT, and the detailed inputs of REM/Rate and HESPro, includes the majority of the 20 influence parameters to some degree. One could assume because of this, these tools would produce the most accurate results. However, this is again difficult to determine without comparing energy modeling results for local home to actual utility data. Even so, the fact that the tools do not include all 20 influence parameters in their assessments is a weakness, where there

is potential for increased accuracy if they were to include analysis of all 20 influences. From analyzing the results produced for Water Heating, and All Else, one could see that the results had minimal differences which could be due to certain energy influences not applied to the assessments, or even certain influence parameters included which carry a heavier weight and impact on the results. Investigation into which influences are most critical to the assessment results could provide more insight towards this and potentially assist auditors in prioritizing the data they collect to ensure the most critical data is captured for the results the tools produce.

Lack of Occupant Behavior Influences

Much like that of the 20 influence parameters, all of the tools include a very small amount of occupant behavior energy influence inputs as represented in Figure 12. It was concluded that the presence of occupant behavior and use patterns can significantly increase the accuracy of an energy assessment because it reveals how the occupants of a home consume energy. The more occupant behavior included, the closer it can align with actual utility bills and allow for more accurate recommendations towards adjusting behaviors to conserve energy as well as possible retrofit recommendations to achieve the same end.

Generalized Inputs

Generalizing inputs, for example, SIMPLE having options for evaluating certain characteristic such as air tightness, and insulation levels with vague value options of average, leaky, very leaky, etc., can limit the accuracy. This was brought up by auditors in the interviews who described EPS score as being over simplified leading to over estimated results. Some tools allowed for more prescriptive inputs when entering data such as insulation levels, or air leakage rates. Once again, it was not determined how much accurate have less generalized inputs affected the results for the home modeled which would have been a good evaluation not only to assess accuracy, but also to determine if the extra time collecting more exact data in the field to use for less generalized modeling tools is worth the extra time and effort many auditors are wary of. Fast tracking the audit process may be acceptable for some energy assessments methods, but may not be best for others where accuracy is desired.

Heating Consumption Estimates

As discussed in section 8.3.4.3, Results Analysis, heating is a consumption domain which is very volatilely captured by all of the modeling tools. Several outliers and a disparity in annual heating consumption estimates were produced in this domain for many of the homes. Investigating what caused the discrepancies revealed for heating could reveal what inputs and influences have the most critical impact on results produced, and comparing to actual utility data would assist in validation

9.3.3 Misuse of EPS Score

In conclusion to the modeling studies and analysis that took place, the use of EPS Score in the local region can be evaluated based on the results produced and the literature analysis conducted. EPS Score was developed to be generalized in the inputs it encompasses and also created to be asset based in order to provide homeowners with a "miles per gallon" rating of their home in regards to energy use, thus the term "energy performance score", or simply, EPS Score. As literate analysis revealed, this miles per gallon rating appears to be much more useful to the real estate industry, rather than the energy auditing industry. Giving a completely asset based rating has its uses and benefits, but it may be being misused in this local region where it is applied to energy audits in which the benefits of an asset based modeling tool may not apply the

same way to an energy audit. EPS score is a good tool to compare a home's energy use to other homes located in close proximity to each other in regards to potentially purchasing a home because it provides usefully information towards making an informed purchase decision. Due to this, EPS Score is a tool which could possibly be more effectively and appropriately utilized for home inspections rather than energy audits.

The accuracy of the results produced by EPS score were difficult to evaluate with the absence of actual utility use data to compare them against, and by observing the results compared to other tools results no large consistent disparities were noticed enough to rank how poorly or well the tool performed in, a task which future research can address.

10 Energy Consumption Monitoring Investigation

From the interview responses gathered, some of the auditors mentioned how a process that allowed for consumption load monitoring could be of benefit to increase accuracy. To address some of this curiosity, as well as to investigate an energy assessment not implemented in this local area, a gas water heater was monitored in a home located in Blacksburg, VA and the energy consumption was calculated, as well as the associated cost based on how the occupants use hot water. The intent of this experiment was to investigate the potential of this method towards benefiting energy assessment accuracy, and the feasibility of the entire process. By specifically monitoring consumption patterns specific to an occupant, the process can help reveal occupancy load, base load, and peak load for a specific home and climate. By calculating the energy required to heat the hot water in the storage tank this process also has the potential to disambiguate utility bills, as well as other potential auditing solutions that could increase accuracy.

10.1 Gas Water Heater Tank Monitoring Experiment

Temperature sensors were placed on a gas water heater appliance in a home located in Blacksburg Virginia in order to monitor the consumption patterns. The house is occupied by two adults, one teenager, and two young children. A total of three temperature sensors were attached to the water heater tank. One sensor was placed was on the hot water outlet pipe, one on the cold water inlet pipe, and one at the gas pipe close to the water heater burner. It was monitored for a month which provided data on how the household consumes hot water and revealed occupant use patterns. Onset HOBO wireless data loggers were used to collect the data which was automatically recorded into HOBOnode Manager. A screen shot of the tool is shown in Figure 32:

Fig. 32 Screenshot of HOBOnode Manager Used to Manage The Gas Water Heater Tank Data

Data was then exported into an excel document in order to analyze it. Figure 33 displays all the data from the three sensors overlapped on one comprehensive graph.

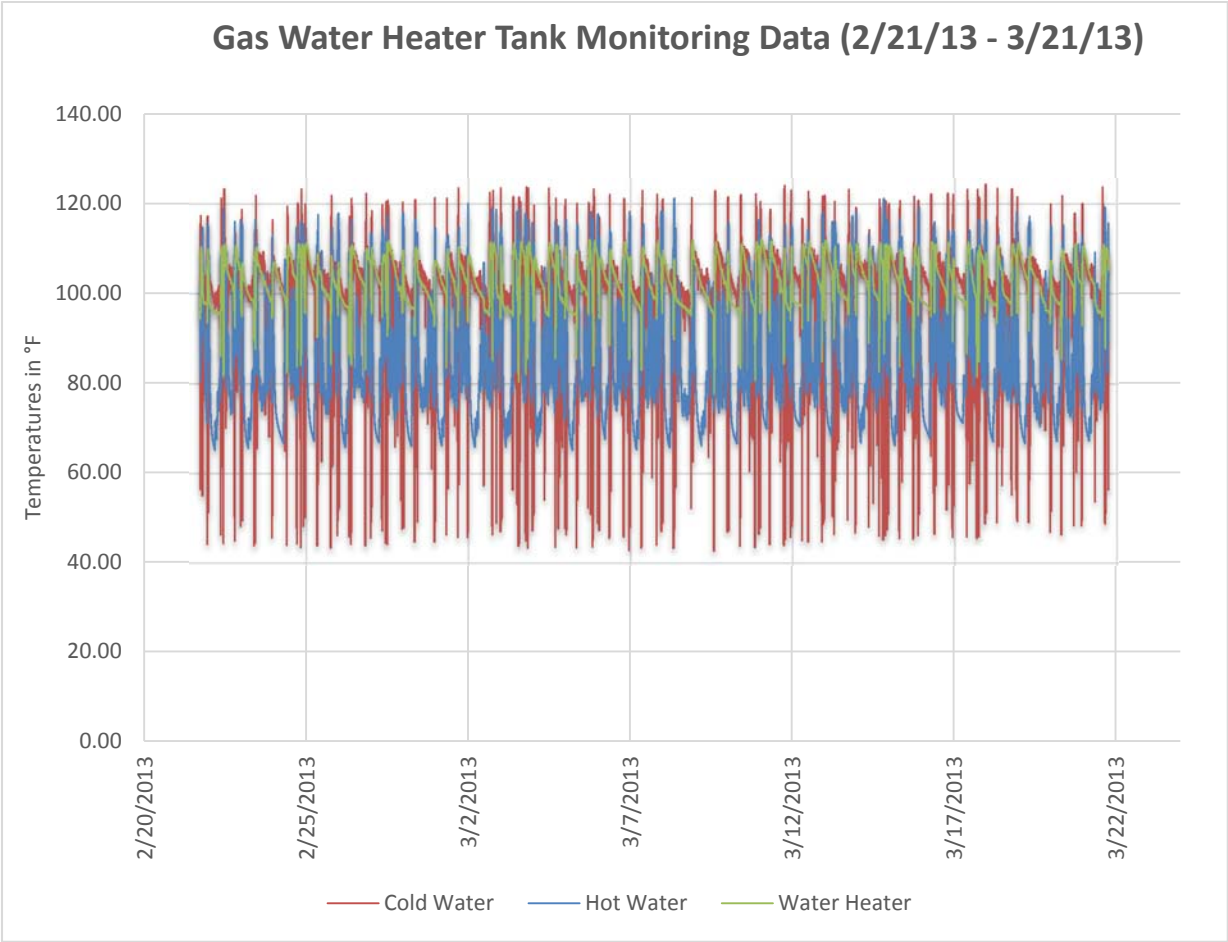

Fig. 33 All Monitoring Data for Blacksburg Home's Gas Water Heater Tank

Separate graphs were created to represent the cold water, hot water and water heater. For each category, the data was separated into 24 hour days to represent the tank activity over the course of a day. Data for different days in each category were overlaid on top of each other to reveal occupant behavior patterns. Examples of this can be seen in Figures 34, 35 and 36.

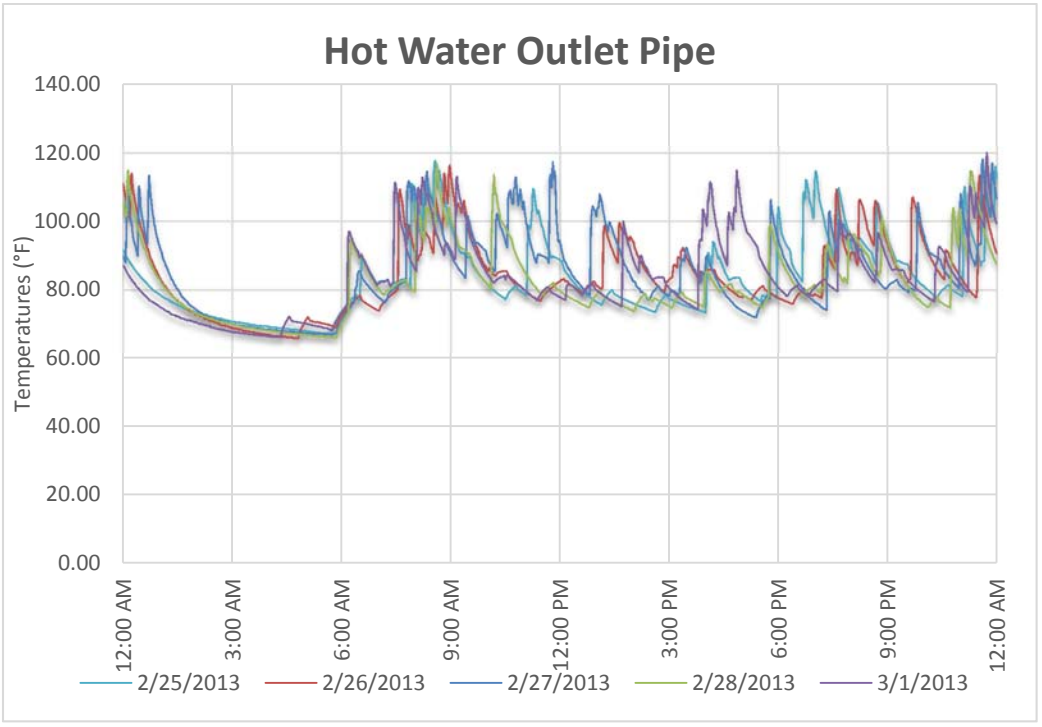

Fig. 34 Hot Water Outlet Pipe Temperature Data (2/25/13 – 3/1/13)

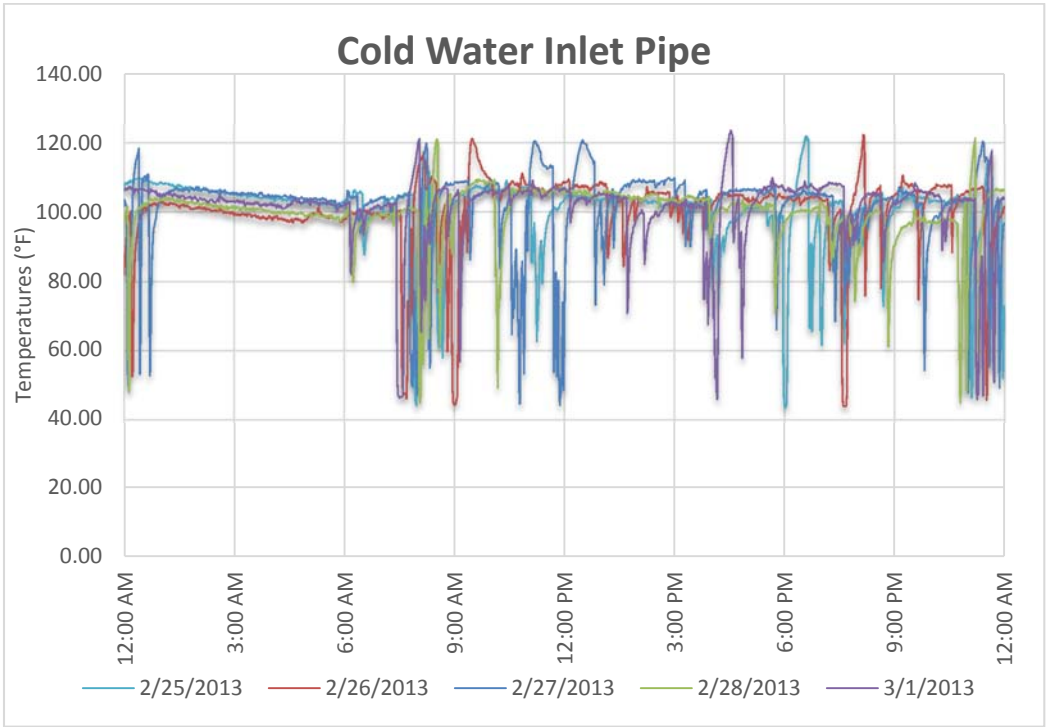

Fig. 35 Cold Water Inlet Pipe Temperature Data (2/25/13 – 3/1/13)

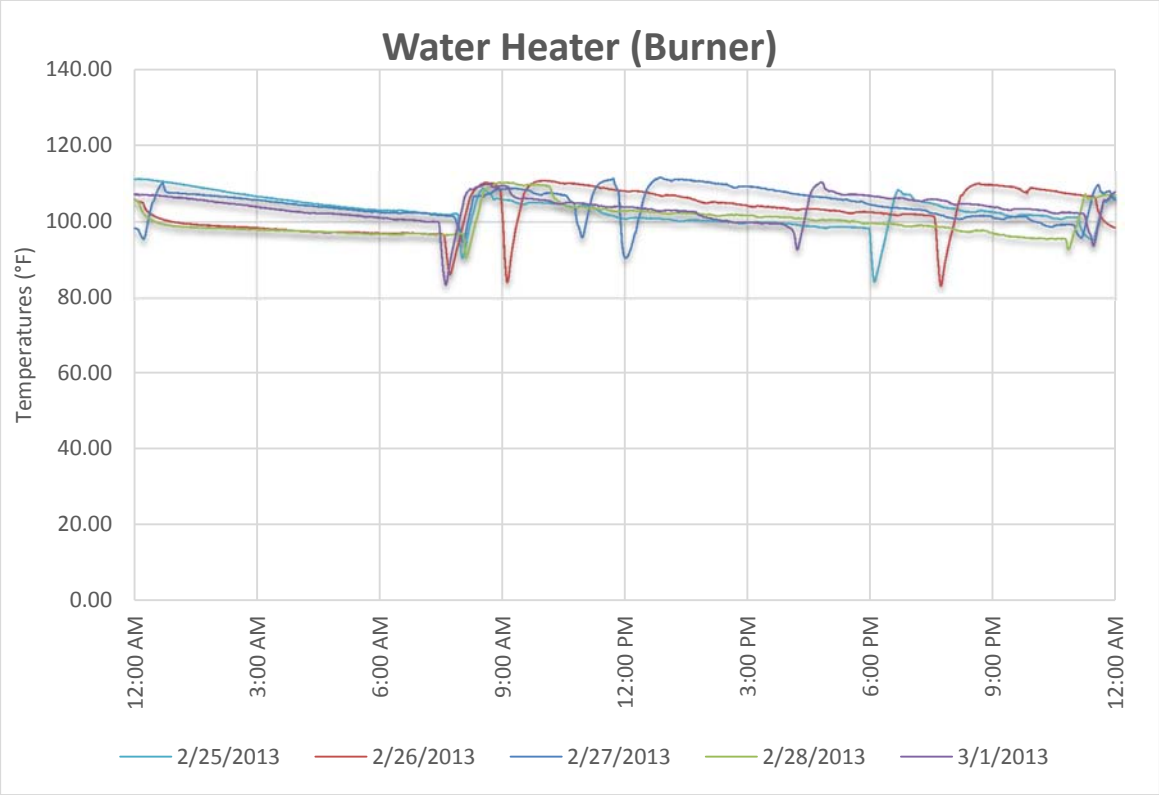

Fig. 36 Water Heater (Burner) Temperature Data (2/25/13 – 3/1/13)

As Figures 34, 35 and 36 show, how the occupants of the home demand hot water is revealed. As hot water is demanded, cold water enters the tank as the temperatures move in opposite directions at the same time. The water heater is perhaps the most revealing data. The sharp dips represent cold water entering the tank at the bottom when hot water is demanded and the gas burner fires to begin heating water in the tank. These spikes occur several times throughout the day and a similar pattern occurs daily. Once in the morning when the occupants begin their day. In the afternoon during the week, hot water is sometimes demanded if an occupant is at home. In the evening when most occupants have returned home during the week. And finally, close to midnight when the dishwasher is started before all occupants go to bed. The set point for the hot water burner is set to about 110 °F as it never goes much above this temperature. When new cold water is introduced, the water heater will trigger and begin heating the water inside the tank. Spikes represented on the water heater graph only occur and the mentioned peak hot water demand times during the day, when most occupants are present in the home.

10.2 Calculating Energy Consumption and Cost

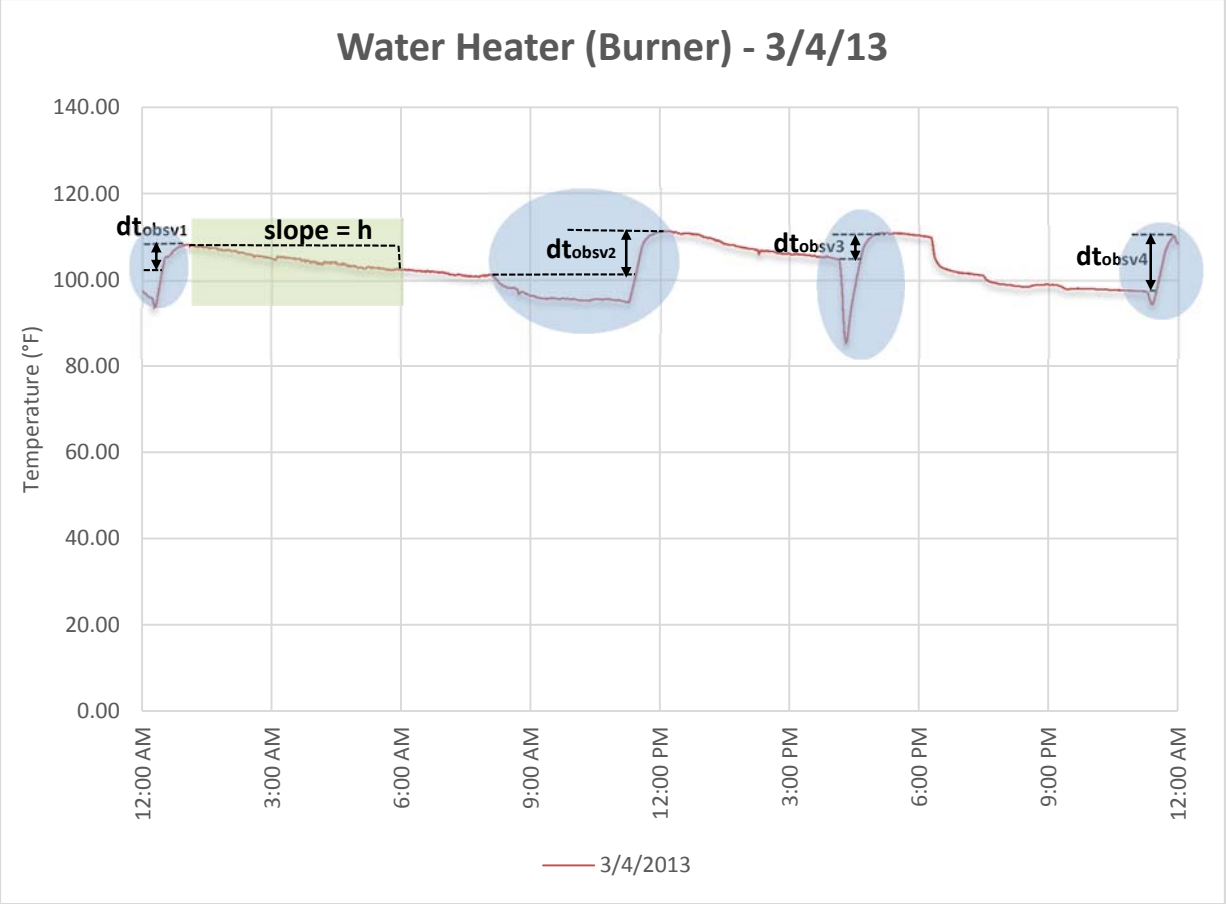

Fig. 37 Water Heater (Burner) Temperature Data (3/4/13)

By analyzing the data represented in Figure 37, the water heater temperatures observed throughout the day on 3/4/13, the energy required to reheat the water in the tank for that day can be calculated. This can also be done to assess the heat loss, or U-value, of the tank and assist in evaluating savings potential all based on actual occupant consumption behavior rather than estimated values used in many energy modeling tools.

For this gas water heater, the energy required to heat water is calculated using the following equation and values:

$$\mathbf{Q = m \cdot c \cdot \Delta T}$$

m = mass of the water (gallons to pounds = 8.33 multiplier)

c = specific heat of water (1.00 BTU/lb·°F)

ΔT = water temperature differential (dt_{CON})

In order to calculate a value for Q (energy to heat water), first ΔT, or dt_{CON}, must be found. This is equal to the total dt observed (dt_{TOT}) during the day minus the dt slope (h) which is experienced at night when the water heater is not in use. This slope is multiplied by 24 hours to represent the temperature differential that would be experienced if the water heater is not used, the static loss. The following equations explain how these values are calculated, refer to figure 20 to visualize where the values are taken from:

$h = \Delta T_{night}/hr = [°F/hr]$

$dt_H = h \cdot 24hrs = [°F/day]$

$dt_{TOT} = \Sigma\, dt_{obsv} = [°F/day]$

$dt_{CON} = dt_{TOT} - dt_H = [°F/day]$

It was found that the energy required to heat the water in the storage tank on March 4th is 4248.30 BTU. The following calculation shows how this value was retrieved:

$h = (108°F - 102°F) / 5hrs = 1.2°F/hr$

$dt_H = 1.2°F/hr \cdot 24hrs = 28.8°F$

$dt_{TOT} = (108°F\text{-}103°F) + (111°F\text{-}99°F) + (111°F\text{-}102°F) + (109°F\text{-}96°F) = 39°F$

$dt_{CON} = 39°F\text{-}28.8°F = 10.2°F/day$

$Q = m \cdot c \cdot \Delta T = (50\ gallons \cdot 8.33lbs/gallon) \cdot (1.00\ BTU/lb \cdot °F) \cdot (10.2°F/day)$

$\underline{Q = 4248.30\ BTU/day}$

An additional step can be taken to calculate a more accurate value for the energy required for the tank to heat the water by dividing Q by the efficiency factor of the tank. For this tank, the efficiency factor is equal to 0.90. The final consumption value for Q would then equal:

$Q = (4248.30\ BTU/day) / 0.90 =$ **$\underline{4720.33\ BTU/day}$**

Using this calculation based on actual consumption data, an estimation of how much money is exhausted on the water heater use each month can be estimated, either by calculating the energy to heat the water for each day and summing the total for the month, or by multiplying the total calculated for one day by the days in a month, all assuming consumption behavior remains the same for the household each day. For this water heater the total cost per month based on use patterns from March 4th is estimated as follows:

1 therm = 100043 BTU/hr

1 CCF = 1.031 therms

(4720.33 BTU/day) / (100043therms / 24hrs) = 1.13 therms

Natural gas cost for Blacksburg = $1.8129 per CCF = $

$1.81/CCF (Blacksburg natural gas cost) \cdot 1.031 = $1.86/therm

$1.86/therm · 1.13 therms = **$2.11/day or $59.04/month or $708.52/year**

The Energy Guide listed on the water heater tank states that based on the national average, natural gas costs $0.5620/therm, and estimated the average annual cost for that model of water heater to be $171. If the annual cost is calculated based on the national average listed on the Energy Guide using the calculated energy to heat the water in the tank based on actual consumption, the annual cost would equal approximately $231.80 rather than $708.52/year using the natural gas cost rate for Blacksburg. $231.80 is 73.77% over the value estimated on the tank which could be due to several reasons, specifically for this case, the use of a national average, as well as the Energy Guide not taking into account the actual consumption patterns of the individuals using the water heater.

10.3 Is Hot Water Consumption Monitoring Worth the Effort?

The time and effort put into conducting this monitoring experiment and energy assessment were considerable. It involved activities such as getting access to the appropriate tools, equipment, and software to conduct the experiment; mounting the sensors and syncing them with the monitoring software; monitoring the data for at least one month to identify clear weekly patterns in consumption that were useful in assuming a typical occupancy use schedule; extracting the data from the software and analyzing the data in created excel spreadsheets; and finally calculating energy consumption and cost estimates. While this assessment technique can lead to a much more accurate energy consumption estimate towards calculating savings and making recommendations, it is not a practical strategy for auditors to implement due to the time and cost involved which when totaled can be considerable. This is particularly true when it involves monitoring a hot water heater in Blacksburg where the results produced from the energy modeling study homes did not reveal any significant or volatile patterns, unlike that for the heating domain. A process such as this one, if developed well, by reducing the time and effort to set-up the monitors and extract data, could be of great benefit to a climate such as the one experienced in Southwest VA when monitoring heating utilities.

10.4 Other Potential Uses for Consumption Monitoring Methods

Although the feasibility of an assessment such as this one conducted on a gas water heater is not the most efficient in its current form, there could be possibilities to develop a process like this into a method that could be of great benefit in terms of improving accuracy with estimates, disambiguating utility bills, possibly assisting in energy assessment report formats by illustrating projected improvements based on current use that is easy for homeowners to interpret, and being an aid to other areas where energy auditors may be flying blind such as revealing occupancy consumption patterns without the need for extensive interviews with homeowners. Investigating this method with other utilities and appliances in one home with the attempt to disambiguate the utility bills in terms of how much each consumption domain actually consumes and costs out of the total billing cycle was an experiment that was at some point planned to be conducted for this study in order to evaluate the accuracy. However, due to the extensive time and resources required this was not feasible within the time frame of this thesis, but it is the hope to conduct this experiment in the future as well as evaluating potential ways it could be developed into a feasible process.

11 Conclusion

Energy auditors and their assessments are a key factor towards successful retrofitting and energy consumption goals. The recommendations they provide to their clients are crucial towards decision making and in many ways can be seen as the center of influence in the retrofitting industry towards improving energy efficiency. As shown previously in the introduction and background sections of this document, there are many barriers and struggles still present that are preventing energy auditing, retrofitting, and household energy savings from reaching their potential. This study investigated and identified ways to address these barriers and struggles specific to Montgomery County, VA in order to provide additional avenues for future research towards improving the energy assessment process implemented in this region as well as their effectiveness in providing accurate and reliable retrofit recommendations to the local population. Core findings revealed an overlap in struggles faced by local auditors' use of energy modeling tools, and issues present with energy modeling tools as investigated in the modeling studies. Time consuming processes also overlapped in many areas and were identified as struggles for the auditors. The following contributions can be identified from this research's core findings.

11.1 Contributions

1. **Identified local energy auditor strengths based on their energy assessment processes**
    i. **Use of diagnostic tools and tests** in their assessments process for data collection as well as communication with clients
    ii. **Certifications** towards energy auditing, which provide them with the credibility sometimes important towards securing clients; provides them with access to resources; enhances their knowledge of energy auditing, building science, other and related subject areas
    iii. **Team work** collecting data in the field where they work more efficiently as opposed to collecting data individually

2. **Identified local energy auditor struggles based on their energy assessment processes**
    i. **Diversity with the local housing stock** adds difficulty to collecting data in a consistent and efficient way
    ii. **Time** consuming process spent collecting and assessing data, creating reports, and communicating with clients
    iii. **Lack of VA incentives** for homeowners to seek energy audit and retrofit work for their homes
    iv. **EPS score and energy modeling tools**, specifically with a lack in reliability with results produced, generalization of inputs, over estimated results, and not knowing the critical data to achieve the best accuracy for the local housing stock

3. **Identified strengths of energy modeling tools and their application to the local housing stock**
    i. **Providing the "big picture"** with the estimates and recommendations provided by results, as opposed to utmost accuracy of detailed recommendations and specific pay-off estimates

ii. **Capturing location and climate influences** in the results where heating is a much more significant consumption domain for this region than cooling which is reflected in the assessments
iii. **Assessing smaller and less geometrically unique homes** where the results produced by each tool were more consistent, specifically for heating consumption

4. **Identified struggles of energy modeling tools and their application to the local housing stock**
   i. **Ignored energy influence parameters** limit the accuracy of the results produced
   ii. **Lack of occupant behavior influence parameters** also limit the accuracy of real consumption results produced to be used for retrofit decision-making
   iii. **Generalized inputs** limit the preciseness of data collected from an audit and also inhibits consistency between different tools
   iv. **Heating consumption** is a volatile domain assessed by the tools

5. **Misuse of EPS Score** in energy auditing and retrofit savings potential assumptions, when it may be possibly more appropriately applied to the real estate industry and used in home inspections.

6. **Future Research –** refer to section 13

12 Research Study Limitations

There were limitations to this study that could have impacted the results, as well as the scope of the study which are identified and summarized as follows:

- **Sample sizes** – of not only the local auditors that participated, but also of the homes investigated in the modeling studies. Considering the size local auditor population, and the distribution of energy auditors to each energy auditing company, it is safe to say that a majority of the local energy auditors were included in this study. There were additional energy auditors and companies in surrounding areas who could have been included but energy auditors that primarily operated in Montgomery County VA were desired as the focus of this study. Ten local homes were also planned to be used for the modeling studies conducted with energy modeling tools. Seven were used for this study with the desire to include three more homes with actual utility use data as an additional analysis step. The utility data was not made available during the time frame of this study, as a result the sample size was reduced to seven. Additionally, if more homes were used for this analysis, it would provide a stronger basis for validating analyses.

- **Audit details for modeling studies houses** – the energy modeling studies were conducted using past EPS report audit details conducted by local energy auditors. This was limited information for some of the modeling tools used that required more input data to produce results. Due to this, some data had to be interpolated. This interpolation may have affected the accuracy of the results produced for the analyses. Having access to more specific audit details and home characteristics could have increased the accuracy in the results produced.

- **Utility use data void** – not having access to actual utility use data for the homes used in the case studied prevented the possibility of evaluating the results for accuracy.

- **The Hawthorne Effect** – in regards to the shadowing that took place for this study, the Hawthorne Effect "is inevitable in all observational data collection techniques; that is, by virtue of being observed what is being observed changes"(Quinlan, 2011). Every effort was made during the shadowing that any normal flow during the auditor's process were not disrupted. But as the Hawthorne Effect describes, when one is being observed, there is always the possibility of changing what is being observed, which is out of the control of the observer.

13 Future Research

As a result and conclusion to this study, future research was identified to continue to investigate this topic and related areas. These research areas include:

- Developing a matrix of tools and practices that are specific to local auditors strengths as well as specific to assessing local homes

- Using actual utility data as a comparison to produced energy modeling results for local homes to further assess their accuracy in specific consumption domains

- Identifying the tools and practices which are most appropriate for predictions vs. assessments

- Investigate what critical data is captured in energy modeling tools. and which effect the results produced, and/or if certain influence parameters have a larger impact than others in their assessments

- Investigate the effects of incorporating more occupant behavior influences in the energy assessment procedures undertaken

- Monitoring the energy consumption of an entire house in an attempt to disambiguate the utility bills as an energy assessment methods, and also possible ways to develop and implement this strategy to energy auditing processes in an efficient and accurate way

- Investigating the implications of generalized vs. detailed inputs in energy modeling tools and the accuracy of the results produced

14 Appendix

Appendix A: Interview Question Guideline

Semi-Structured Interview Guideline

Title of Project: An Effort to Refine Home Energy Assessment Methods in Support of Retrofit Decision Making

Participant: _____ _____
Name **Date**

1. How long have you been a home energy auditor?
2. In what counties in the New River Valley area do you primarily operate?
3. Do you hold any certifications?
4. What tools and methods do you typically use when conducting an energy audit on a home?
    a. Can you explain the strengths and advantages of these processes you face, if any?
5. Can you explain any difficulties you face while conducting an energy audit on a home?
    a. Are they related directly to the type of home?
    b. Are they related to the processes you use (tools/methods)?
6. Are there some particular common energy efficiency related problems/issues you see with homes that you audit?
    a. If so, can you elaborate?
    b. Are there a set of tools/methods you use that you feel best assess these issues?
        i. If yes, what tools and how do they help?
        ii. If no, why not, and what would you use to address these issues?
7. Are you familiar with the Energy Performance Score's (EPS)? If so, do you have confidence in its results?
    a. Why or why not?
8. Are there any energy modeling tool input strategies you use if you have insufficient data?
9. What would you improve upon during your audit process?
10. What would you consider to be the most significant energy issue most commonly identified on energy audits you perform?
    a. Would you say, if remedied, it would produce the most savings?
    b. If not, what do you think would, given a limited retrofit budget?
11. Are there any auditing methods/tools that you know of available today that you believe are of great benefit, but you do not have access to use on your home energy audits?
    a. If so, what are they, and how do you believe they are of benefit?

12. If there were a tool/method that could be developed to assist the home energy audit process in some way, what would you think that would be and how would it help?

13. Cafe2 audits no longer require the use for duct blaster tests on every audit due to recent auditor consensus that it provides low value and minimal information to assessments in relation to the large amount of time and effort needed to conduct that test.
    a. What value to an audit do you believe the blower door test adds?
        i. Do you think it may be just for show to the homeowner (validation that an audit is taking place)? Or gives critical data to assessment results?
    b. What about for the infrared camera?

14. Are there any low-hanging fruit or "sweet spot" energy problems you tend to look for first in a home that are common?
    a. If so, what tools help you best accomplish this goal?

15. In regards to certification training for rating and software such as HERS, BPI, and EPS score, how would you describe their value to your company, and also to you personally?
    a. Was the training process difficult?
    b. Were lessons easily applied in the field?
    c. Is there any support/mentorship available that you utilize?
    d. Preparation for housing variations/types you deal with in areas which you operate?

16. How would you describe your most typical clients for audits?

17. Do believe that Virginia and/or this region effectively offer enough incentives to attract people to perform energy audits on their homes?

18. Can you describe your company's relationship (past and/or present) with cafe2?

19. What is your opinion with the current state of auditor relationships with builders/retrofitters?
    a. Any concerns with liabilities? Cultural gap – US reputation with law suites
    b. Communication?
    c. What type of recommendations do you give? Direct fixes to problems or description of the problems only?

20. In your opinion, what would you consider to be the energy auditing industries weakest link?

Appendix B: IRB Study Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: An Effort to Refine Home Energy Assessment Methods in Support of Retrofit Decision Making

Investigator(s): Teni Ladipo and Dr. Georg Reichard

I. Purpose of this Research/Project

The purpose of this research/project is to investigate current energy assessment tools and methods being used prevalently today (with a main focus on Southwest Virginia) in order to identify ways in which they can be improved and become more effective. For this portion of the research, semi-structured interviews will be conducted with home energy auditors who have conducted home energy audits in the Southwestern Virginia region. The purpose of the interviews is to find out more about the processes, tools, and methods used by auditors for our regional climate, as well as the auditors' perceived difficulties and strengths conducting energy audits.

II. Procedures

The semi-structured interview style will be used to conduct all interviews. Semi-structured interviews involve having questions and topics predetermined by the investigators, although the interviewer has no formal structure or outline for asking the questions, and other unplanned questions may be asked if the conversation leads in a direction that deems it appropriate. The only activity you will be expected to perform is to be the interviewee, the individual the questions are directed towards. The interview will take place at your work place or at an agreed upon location at a convenient time for you. The interview should take between 30 minutes to 1 hour to complete. Notes will be taken by the interviewer during the interview, documenting responses and questions asked. Your name and employer belonged to will not be disclosed to outside sources and they will remain confidential.

III. Risks

You may be asked questions involving personal opinions about practices and processes used during your energy audit routine, which may be associated with employer policies. In order to protect your privacy, complete confidentiality will be applied to each interviewee, and your name and employer will not be disclosed to any outside sources. Interviews will also be conducted in private areas designated by you at your workplace or other agreed upon location.

IV. Benefits

The ultimate goal for this research is to provide a direction for further research and development of investigated solutions to improve energy assessment tools and methods in order to benefit retrofitting potential in our climate region, assist energy auditors in assessments, and to give homeowners renewed confidence in energy assessments and its rewards. No promise or guarantee of the benefits has been made

Virginia Tech Institutional Review Board Project No. 12-889
Approved October 17, 2012 to October 16, 2013

to encourage your participation. You may contact the investigators at a later time for a summary of interview and research results.

V. Extent of Anonymity and Confidentiality
Your name will remain confidential and your personal information will not be divulged. All notes and data recorded for each interview will not be associated with your name or employer in the final results. At no time will the investigators release your name to anyone other than individuals working on the project without your written consent. It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. Compensation
There will be no compensation provided.

VII. Freedom to Withdraw
You are free to withdraw from the interview at any time without penalty. You are also free not to answer any questions you choose without penalty.

VIII. Subject's Responsibilities
I voluntarily agree to participate in this study. I have the following responsibilities:

- Remain at the interview location at the scheduled time and place for the duration of the interview time, and respond to questions asked by the investigator

Virginia Tech Institutional Review Board Project No. 12-889
Approved October 17, 2012 to October 16, 2013

IX. Subject's Permission

I have read the Consent Form and conditions of this research. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

_____	_____	_____
Participant Name	Signature	Date

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Teni Ladipo	(703) 967-0783 / tladi001@vt.edu
Investigator(s)	Telephone/e-mail
Dr. Georg Reichard	(540) 818-4603 / reichard@vt.edu
Faculty Advisor	Telephone/e-mail
_____	_____
Departmental Reviewer/Department Head	Telephone/e-mail

If I should have any questions about the protection of human research participants regarding this study, I may contact Dr. David Moore, Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects:

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[NOTE: Subjects must be given a complete copy (or duplicate original) of the signed Informed Consent.]

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Approved October 17, 2012 to October 16, 2013

Appendix C: Energy Consumption Influence Parameter Input Information for Each Energy Modeling Tool

*Highlighted grey parameter fields are the 20 minimum influence parameters (Durak 2011)

Energy Consumption Influence Parameter Input Information	SIMPLE	REM/Rate	HESPro	TREAT	NEAT	*Key: X =Minimum O = Optional*
Year Built		O	X	X	X	
Zip Code	X	O	X	X	X	
Local Surroundings			O			
Height of Neighboring Houses			O			
Height of Large Shade Trees			O			
Exposure to Elements		O	O	X		
Orientation		O	O		X	
Windows		O			X	
Front Door			X		X	
Total Square Footage	X	O	O	X	X	
Footprint Area		O	O	X	X	
Foundation Type	X	X	O	X	X	
Foundation/Floor Insulation	X	X	O		X	
Volume						
Perimeter Length		O	O		X	
Shape of the House		O	O			
Form Factor						
Interior Ceiling Height		X	O	X	X	
% Vaulted Ceiling Type		X				
Number of Stories	X	X	O	X	X	
Number of Corners on Each Level		X				
Stories Above Ground Level		X	X	X		
Number of Rooms		X		X		
Types of Rooms				X		
Number and size of Windows		X	X	X	X	
Types of Window	X	X	X	X	X	
Window Shading	X				X	
Window Overhangs		X				
Window Leakiness					X	
Number and Size of Glass Doors		X	O	X	X	
Other Types of Doors		X	O	X	X	
Door Area					X	
Number and Size of Skylights			O	X	X	
Building Envelope Characteristics		O	O	X		
Wall Insulation	X	X	X	X	X	
Attic Insulation	X	X	X		X	

Energy Consumption Influence Parameter Input Information	SIMPLE	REM/Rate	HESPro	TREAT	NEAT	*Key: X =Minimum O = Optional*
Ceiling Inuslation			X			
Roof Insulation			X			
Weatherstripping or Caulking			X			
Similar Wall Construction		O	O	X	X	
Darkness of Exterior Walls			O	X		
Rim & Band Joist Properties		O			X	
Frame Floor Properties		O			X	
Extension of Roof Eaves or Patios		O	O			
Roof Slope			O			
Roof Reflectance and Color	X	O		X	X	
Infiltration	X	O	O	X	X	
Ventilation	X	O	O	X	X	
House Leakage (cfm @50 pa)		X	X	X	X	
Ducts: % in Attic	X	X	X			
Ducts: % in Basement/Crawlspace	X	X	X			
Ducts: % Supply vs. Total Supply		X				
Ducts: % Return vs. Total Return Area		X				
Duct Leakiness	X	O			X	
Duct Insulation	X	X	X			
Air Tightness	X	O	O	X	X	
Blower Door and Zonal Pressures					O	
Pressure Balance					O	
Pressure Pans					O	
Heating is not Forced Air (0-1)	X					
Number of Occupants	X		X	X	X	
Ages of Occupants			X	X		
Occupancy Patterns						
Showering Use (flow, time)	X			X	X	
Laundry	X		O			
Hours/Months AC is on		O	O			
Hot Water Demand			O	X		
Annual Utility Bills		O	O	X	X	
Space Usage Characteristics		O	O	X		

Energy Consumption Influence Parameter Input Information	SIMPLE	REM/Rate	HESPro	TREAT	NEAT	*Key: X =Minimum O = Optional*
Available Energy Sources						
LIGHTING						
# of Incandescent Light Fixtures		O	O	X	X	
# of Fluorescent Light Fixtures		O	O	X		
Light Fixtures Per Room		O	O	X	X	
Hours of Use			O	X	X	
Lighting Usage Intensity	X			X	X	
APPLIANCES						
Primary Refrigerator (Type/Year)	X	O	X	X	X	
Extra Refrigerators / Freezers	X	O	X	X	X	
Entertainment (TVs, PCs, etc.)	X		O	X		
Other Large Uses (500 kWh)	X	O	O	X		
Plug & Other Loads (kitchen, home office, etc.)	X	O	O	X		
Clothes Dryer Fuel	X	O	O	X		
Cooking/Oven Fuel	X	O	O	X		
Washing Machine		O	X	X		
Combustion Appliances Within Building				X		
Dishwasher		O	O	X		
Number of Showerheads					X	
Shower avg. GPM					X	
Appliance Locations		X			X	
ENERGY STAR APPLIANCES		O	O			
Bathroom Fans				X		
Hours of Use Per Appliance			O	X		
Appliance Annual Fuel Usage				X	X	
Building Systems Characteristics	X	X	X	X	X	
HEATING/COOLING						
AC SEER (none=0)	X	O	O	X	X	
Cooling Setpoints (°F)	X	X	O	X	O	
Heating Setpoints (°F)	X	X	O	X	O	
Primary Heating Fuel		X	X	X	X	
Primary Heating System Type	X	X	X	X	X	
Primary Heat Distribution Type		X	X	X	X	
Secondary Heating System		X	O	X	X	
Heat Recovery Ventilation System						
Operational Tests - Heating					O	

Energy Consumption Influence Parameter Input Information	SIMPLE	REM/Rate	HESPro	TREAT	NEAT	*Key: X =Minimum O = Optional*
Vent Tests - Heating					O	
Furnace Components - Heating					O	
Boiler Components - Heating					O	
Inspections - Heating					O	
Thermostat Type		X	O	X	O	
% of House Heated/Cooled by System		X	O		X	
% Conditioned Space Over Garage		X				
Year Heating/Cooling System Installed			X	X	X	
System Efficiency		X	X	X		
Ceiling Fans		O	O	X		
Whole House Fan			X			
Location of Heating System		X		X		
Input/Output Capacity		X	X	X	X	
WATER HEATER						
Primary Water heater Type/Fuel	X	O	X	X	X	
Secondary Hot Water Type/Fuel	X	O		X		
Year Purchased			X	X		
Location		O	O	X	X	
Temp Setting		O	O	X		
Energy Factor			O	X	X	
Recovery Efficiency			O	X	X	
Rated Input			O	X	X	
Storage Tank Capacity		O	X	X	X	
Insulation		O		X	X	
Operational Tests					O	
Vent Tests					O	
Inspectios					O	
Solar Fraction				X		
Piping			X	X		

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