The Impact of Energy Efficient Design and Construction on LIHTC Housing in Virginia

A REPORT TO **HOUSING VIRGINIA**

VIRGINIA CENTER FOR HOUSING RESEARCH AT VIRGINIA TECH

Executive Summary

The purpose of this report is to identify and verify possible benefits of the shift in housing policy by the Virginia Housing development Authority (VHDA) to encourage energy efficiency (EE) in the affordable rental stock in Virginia through the LIHTC program. The research addresses key issues related to Energy Efficiency and affordable housing through a rigorous measurement of economic impacts for low-income residents, distinguishing the effects of design, construction, technologies and behavior per unit. In addition, the research addresses how the policy to use EE might impact developers and owners in terms of property capital and operating costs. Data, analysis and findings focus specifically on facilities constructed to the EarthCraft MultiFamily standard in Virginia, one of the only datasets currently available that allows for this type of inquiry.

Executive Take-a-ways

Findings suggest the following executive take-a-ways due to energy efficiency (EE) in the affordable rental stock in Virginia through the LIHTC program:

1. *VHDA program incentives to use a green standard have been effective in encouraging developers to use the program but the focus is now on results*. Energy usage for developments in the study is 16.6% less than estimated and approximately 30% less than new standard construction. Based on an energy rate of $.1167/ kWh for the Commonwealth of Virginia in 2014 (http://www.eia.gov/), savings equal $54 per month on average. If the 2014 AMI for Virginia is $77,500 for a family of four, these cost savings equate to $648/year, or 2.7% for extremely low income households below 30% AMI, 1.6% for very low income households below 50% AMI and 1% for low income households below 80% AMI.

2. *Future design, construction and operation could increase energy efficiency in the affordable rental housing stock based on differences in performance among types of developments and units*. The *new construction development* sample of units, projected to use 4.7% less energy than the overall sample, actually uses 8% more energy than overall average sample. The *renovated development* sample of units, projected to use 24.3% less energy than the overall sample, actually uses 5.3% less energy. The *senior development* sample of units, projected to use 17% less energy than the overall sample, actually uses 7.8% more energy. The *non-senior development* sample of units, projected to use 16.5% less energy than the overall sample, actually uses 4.7% more energy than the sample average.

3. *Ventilation, refrigerator efficiency, water heater and Dryer efficiency, slab, simulated use, and people in units affect efficiency in the unit*.   Statistical modeling of technologies included in the unit and behavior of residents indicates ventilation, refrigerator efficiency, slab, and people in units accounted for 20%, 5%, 3%, and 4% of variability in energy use respectively. When adding simulated usage with the predictors above, ventilation, slab, people in unit, simulated use, water heater and Dryer efficiency accounted for 24%, 4%, 6%, 7%, 4%, and 3% of variability respectively.   Future design, construction and operation should consider these variables when attempting to increase energy efficiency in the affordable rental housing stock.

4. *In the design process, green certification agents add value as independent, third parties that implement green buildings*. This study notes the need for concurrent process that integrates designers, contractors, managers and other stakeholders critical to estimating and implementing the long-term goals of a green building. The integration of a "concurrent certification" process needs to begin early, continue throughout the design-build-operate process and can be measured along the way for better results in energy savings.

While managers are educating residents, high performance knowledge is not transferring to residents. As advanced technology becomes further integrated into the unit and our population ages, residents will become more reliant on technology for their health and wellbeing. In many cases high performance design and construction is adding systems (heat pump water heaters and fresh air systems) for which proper operation and maintenance will promote durability, reduce operating costs for owners and equate to lower utilities for residents. In the future, education of the operators and residents of high performance units becomes more critical.

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Introduction and Background

In its December 4, 2014 article "Homeowners Energized about Energy Efficiency," Builder magazine[1] reported that owner-occupied units surveyed in recent years completed at least one energy-efficiency project, representing over 9 percent of all owner-occupied units in the nation with 32,000 in homes constructed within the last four years. According to the article, "homeowners are indeed interested in efficiency, despite the *upfront costs*." Housing developers also report benefits from energy efficient design, construction operation and maintenance despite initial cost (Yudelson, 2008). Since 2006, AEC firms have increasingly put employees through certification training and certified projects at increasingly higher levels and showing internal commitment to sustainable principles (Yudelson 2008). While designing and building to a certified standard is now the price of admission for the industry at large, Yudelson argues that "the differentiating point is clearly now on results."

At the same time, the Virginia Housing Development Authority (VHDA) over the last five years implemented some of the most aggressive standards in the nation for energy efficiency and sustainable construction within the Low Income Housing Tax Credit (LIHTC) program. It has done this by providing a significant scoring incentive for applicants who choose to develop in compliance with green certification (LEED and EarthCraft) standards.

Therefore, the following work analyses developments that resulted from the recent policy shift and attempts to unbundle the impacts of EE for new and renovated and resident-specific housing through EE standards. While the nation's housing stock is moving towards energy efficiency and understanding its costs, research has not caught up with the trend. Specifically, the effect of housing technology and behavior on energy efficiency lacks definition in market-rate units and the rental affordable housing stock market.

The aim of this report is to identify and verify any benefits of the shift in housing policy to encourage energy efficiency (EE) in the affordable rental stock in Virginia through the LIHTC program. The research addresses how the use of an energy efficiency design and construction

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[1] http://www.builderonline.com/building/homeowners-energized-about-energy-efficiency_o?utm_source=newsletter&utm_content=jump&utm_medium=email&utm_campaign=BP_120814&day=2014-12-08&he=78237e9e2fbd61a2254d2f6a0dd1b263dfb45d0a

standard impacts LIHTC residents in terms of reduced utility costs. In addition, the research addresses how the policy to use EE might impact developers and owners in terms of property capital and operating costs. This study focuses specifically on facilities constructed to the EarthCraft Multifamily Program under Earthcraft Virginia standard, one of the only datasets currently available that allows for this type of inquiry.

The research design includes controls for pre-and-post-occupancy of EarthCraft Virginia structures in the Low-Income Housing Tax Credit program (LIHTC) program across the Commonwealth of Virginia. The work is limited in that it does not include controls for non-EE and EE units outside the affordable rental stock and is limited in sample size. Nevertheless, the authors cannot find previous work that has been able to establish a sample as large and comprehensive in data records as in the following pages.

In 2006, executives interviewed by Yudelson (2008) reported by 75% a high return on investment, although "hard" data for measuring this ROI is difficult to explain and produce. Our work aims to change that difficult reporting of data.

Literature Basis, Research Design and Data

The relationship between energy costs and housing affordability has been long established in research literature[2] and in public policy (e.g. LIHEAP, weatherization, housing subsidy utility allowances, DOE-HUD initiative on energy efficiency in housing). A basic internet search for "affordable housing" and "energy efficiency" produces 1,450 matches in the Energy Citations Database and 788 matches in peer reviewed publications. Although the impacts of the weatherization program have been extensively documented, the benefits of energy efficiency (EE) in new and renovated affordable housing are typically assumed and have not been rigorously analyzed.

As a result, the following research questions are based on the question of how building and unit energy efficiency (EE) design and construction impact actual energy use.

✓   What are the household utility costs savings based on pre-occupancy estimates of EE design (energy modeled savings) for new construction LIHTC projects?

✓   What are the household utility costs savings based on pre-occupancy estimates of EE design (energy modeled savings) for renovation LIHTC projects?

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[2] Lee, Chin and Martin, *Affordable Housing: Reducing the Energy Cost Burden*, Pacific Northwest Laboratory 1995; Koebel and Renneckar, *A Review of the Worst Case Housing Needs Measure*, HUD-OPDR, 2003.

✓ What are the actual household utility costs based on post-occupancy estimates for EE design among new construction and renovation LIHTC projects?

✓ What are the actual household utility costs based on post-occupancy estimates for EE design among new construction and renovation for senior-and-non-senior-based LIHTC projects?

✓ What are the net changes in household utility costs, pre-and-post-EE, new construction and renovation for senior-and-non-senior-based occupancy?

✓ What are the net effects of utility costs on the household's other consumption, in terms of reduced expenditures at LIHTC income levels by location?

To answer these questions, we collected data on Virginia's LIHTC properties by EarthCraft Virginia on characteristics of the building and unit (building location, unit location within building, size, design, and specific EE enhancements). EarthCraft Virginia collected and provided data on pre-EE occupancy designs, energy modeling and EarthCraft Virginia Checklists of construction specifications and improvements in terms of specific technologies involved in the LIHTC unit renovation. EarthCraft Virginia also provided energy modeling data on expected energy savings (based on Home Energy Rating Score (HERS) score) for the same LIHTC units as previously mentioned. Housing Virginia, used its contacts to gain access to occupant energy usage data, facility managers and owners in support of data gathering. WegoWise Inc., was then used to compile and track the energy usage data collected from LIHTC residents.

Research Methods

Researchers analyzed data from a sample of 312 total units, including improvements, construction costs, operating costs and occupants' utility consumption and costs for post-EE occupancy and pre-EE occupancy. New construction project units are in Arlington, Hampton, King George, Lynchburg, Petersburg and Wytheville. Renovated project units are in Abingdon, Arlington, Chesapeake, Christiansburg, Orange, Richmond, Scottsville and Virginia Beach. Senior unit LIHTC data are available for units in Christiansburg, King George, Petersburg and Richmond.

Aside from studying direct utility data, the research also utilized resident surveys to track behavior and compare past units to current, most likely more efficient, units. The survey provides another layer of information behind utility bills and energy efficiency.

We then used Industry-standard energy models to estimate the intended design and construction on energy efficiency for each occupant household. Model estimates of utility costs are per unit for EE designs and provide a nominally estimated design effect based on the commonly accepted Home Energy Rating Scale (HERS, see http://www.hersindex.com/). The Home Energy Rating Certificate (HERC) provides a summary of all items included in the model and technologies incorporated into each unit.

The team partnered with WegoWise Inc. to collect resident utility data and track energy use by month for each unit over one year. Energy usage data from WegoWise provide a benchmark for comparing to modeled technologies and are expected to vary based on occupant behavior per unit. As a result, this work also compares residents' utility bills to the estimated annual energy usage as a control measure.

The team will then use statistical analysis of modeled utility consumption for EE technology clusters, unit characteristics and resident behavior to correlate for net design effects and policy implications. The research is designed to isolate the effects of one common EE standard, new building effects (versus renovated facilities), resident behavior (family-based versus senior) and provide added benefit to policy discussion.

Anticipated Research Outcomes

The outcomes associated with a shift in housing policy to encourage energy efficiency (EE) in the affordable rental stock in Virginia have never been rigorously explored and documented. Because the LIHTC program in Virginia has experienced such a recent and dramatic shift to a standard that encourages energy efficiency in the affordable rental stock, the policy creates an opportunity to compare LIHTC housing for one common EE standard (EarthCraft Virginia) in terms of its energy performance and resident impact. Findings suggest areas for future design, construction and operation that could increase energy efficiency in the affordable rental housing stock.

As a result of using a green building standard, firms intent on green building are increasingly active in public relations on the topic. Our study considers one group solely intent on publicly espousing the merits of green building, EarthCraft Virginia. Results from the work therefore focus largely on a general understanding of benefits based on one certification "agent" in Virginia, while the technology and behavior studied in the work could scale to policy in the larger AEC community and adoption of innovative practices and policies. The work further aims to provide policy makers a rigorous quantification of gross and net impacts (economic and others) of EE affordable housing on low-income occupants, distinguishing for the effects of technology and occupant behavior.

Policy Basis

The efficacy of EE and sustainable designs for rental housing development is actively under consideration as policy makers in Virginia and the nation consider new green building standards. The research effort responds to increased public policy support for changes in housing development requirements that would be implemented by localities, housing authorities and other housing providers.

In the Commonwealth of Virginia, this work responds to policies implemented by the Virginia Housing Development Authority (VHDA) and other affordable housing providers both within Virginia and nationally. Over the past five years, VHDA has implemented some of the most aggressive standards in the nation for energy efficiency and sustainable construction within the LIHTC program. VHDA has done this by providing a significant scoring incentive for applicants who choose to develop in compliance with green building standards such as EarthCraft or LEED. EarthCraft Virginia's EarthCraft Multifamily program is a green building protocol and third party certification developed by Southface Energy Institute and the Greater Atlanta Homebuilders Association and is in use throughout the Southeast.

The incentives that VHDA has built into the program to use EarthCraft Virginia or LEED have previously been effective in encouraging developers to use the program. Typically, 80-90% of all successful LIHTC applicants are committed to using a green building protocol. In the case of Virginia over the last 5 years, 100% of the successful applicants for LIHTC (9% of all applicants) have been committed to meeting EarthCraft Multifamily standards.

The research looks beyond the LIHTC program in Virginia, though, as a means for guiding policy for LIHTC programs in other states. In addition, through answering questions about the impact of implementing EarthCraft or green building standards within the Virginia LIHTC program, the research informs all developers and property owners of the possible benefits of implementing a green building protocol in the broader rental stock.

Housing Affordability

Whether it is a rental payment or a mortgage payment, housing costs make up a large percentage of Americans' monthly spending. The U.S. Department of Housing and Urban Development (HUD) uses residents' levels of monthly income spent on housing to determine low-income classifications for housing assistance and affordable housing creation. The maintenance of affordable housing is vital for promoting vibrant communities and strong economies. Throughout history, the U.S. has used different approaches to alleviate housing payment burdens for low and moderate-income households. Federal government programs include public housing, housing choice vouchers, community development block grants (CDBG), and most recently, the Low-Income Housing Tax Credit (LIHTC). Today, the LIHTC is the largest low-income rental subsidy in the U.S and is an item of the Internal Revenue Code, not a federal housing subsidy (Schwartz, 103). To understand the impact EE policies can have on affordable housing it is essential to understand the role of the LIHTC.

LIHTC Overview

Enacted by Congress in 1986, the Low Income Housing Tax Credit program is based on Section 42 of the Internal Revenue Code. The goal of the program is to give the private development market an incentive to invest in affordable rental housing. The program finances rental housing for low-income households through an indirect Federal subsidy (LIHTC Basics). The Low Income Housing Tax Credit allows investors to reduce their federal income tax by $1 for every dollar of tax credit received (Schwartz, 103).

The Internal Revenue Service (IRS) distributes the tax credits to designated state agencies, which are typically state housing finance agencies. Each state is limited to a total annual tax credit allowance of $1.75 per state resident. Developers of qualified rental housing projects apply for the tax credits through said state agencies. If the developer is allotted tax credit through the state application process, they sell these credits to investors to raise equity for their project. The increase in capital in turn reduces the amount of money the developer would have to borrow. Since the developer's debt is lower for this tax credit property, they will be able to offer more affordable housing units (LIHTC Basics). As long as the property remains in compliance with the LIHTC program requirements, the dollar-for-dollar credit will be applied to the investor's federal income tax for 10 years.

Limited partnerships have been a common ownership structure for LIHTC projects. This means the developer is the general manager of the project while the investor plays a more passive role. The liability the investor has to the project is legally limited to the amount

invested in the project (Guggenheim, 140). Another common ownership structure of these projects is limited liability companies (LLC).

How Projects Qualify

Federal law guides the state's Low Income Housing Tax Credit allocation process. It requires that the state's allocation plan give priority to projects that "serve the lowest income families" and "are structured to remain affordable for the longest period of time" (LIHTC Basics). Federal law also requires 10% of each state's tax credit allocation go towards projects owned by nonprofit organizations. The program also sets eligibility requirements. A proposed project must:

✓ Be a residential rental property

✓ Commit to one of two possible low-income occupancy threshold requirements

- 20-50 Rule: At least 20% of the units must be rent restricted and occupied by households with incomes at or below 50% of the HUD-determined area median income (AMI)

- 40-60 Rule: At least 40% of the units must be rent restricted and occupied by households with incomes at or below 60% of the HUD determined AMI

- The AMI is adjusted for household size

- Many applications provide for 100% of the units to be affordable and many applications provide for units to be well below the 50% of AMI.

- On average, 96% of the apartments in a tax credit project are designated affordable (Schwartz, 112).

✓ Restrict rents, including utility charges, in low income units

✓ Operate under the rent and income restrictions for 30 years or longer, pursuant to written agreements with the agency issuing the tax credits.

- 15 year compliance period and subsequent 15 year extended use period

How the Program Affects Residents

Depending on the project, residents need to be within the 50% of the area median income range to qualify to live in a LIHTC project. Qualified residents receive an income benefit, quality benefit, and their rent payment depends on their certified annual income and the maximum rent set by the project. "Maximum rents are set for each size of unit, based upon 30% of maximum income for specified household sizes" (Guggenheim, 3). The maximum rent includes the estimated costs of utilities for a unit. New or refurbished units add a benefit of quality for residents of LIHTC projects, leading to higher standards of living and resulting in better health and increased economic opportunity. LIHTC projects are required to remain low-income for a minimum of 15 years and residents are protected for another three years beyond that period (Guggenheim, 3).

How the Program Affects the Plans

The impact a LIHTC project has on the design of units depends on the type of project. For instance, if a building is rehabilitated from an existing apartment structure the plans may not change and the fixtures and finishes are just upgraded. Redesigns for senior residents may include accessibility features, including ADA requirements and Universal Design standards. A factor that may impact floor plans is the addition of energy efficiency standards. If this is a requirement of the project then the overall design of units could be affected.

Program Limitations

The Low-Income Housing Tax Credit, like all housing programs, is not without its limitations. The first limitation Schwartz notes is the housing units financed by the program are charged a flat rent depending on AMI. Therefore, if a tenant's income decreases they will be spending more than 30% on their monthly rent. This limitation means extremely low-income families can rarely afford to live in LIHTC projects unless supplemented by federal housing vouchers (Schwartz, 123). The second limitation is the lack of incentive for building mixed income projects. The developer receives tax credits in proportion to the amount of low-income units therefore most of the projects are completely low-income. The lack of long-term sustainability of these projects mark a third limitation. After the 15-year affordability period, some projects convert their units to market-rate. Many of the LIHTC developments lack the resources and funding to replace building systems that need repair after 15 years of wear and tear.

Local Market Variables Affecting LIHTC

The presence of affordable housing in an area is directly related to a region's economy, population, and income levels. These variables play an important role in studying LIHTC projects and give a background on an area in which EE policies may be applied. By studying local areas at the town/city, county, and metropolitan statistical area (MSA) level, the local market variables that affect affordable housing in an area can be assessed. Eight variables analyzed for this study include: total population, median household income (owner occupied v. renter occupied), median family income, household type (family v. non-family), housing tenure (renter v. owner), percent below poverty, percent unemployed, and area median income (AMI) levels. Each variable's definition and significance is analyzed below:

- Total population: This refers to the total number of residents determined by the American Community Survey data in the corresponding town/city, county, or MSA. When studying affordable housing projects, population is an important factor because it gives a sense of the size of the community. When this value is compared to the size of the renter occupied housing units, more information on the vitality of the housing market can be assessed.

- Median household income (owner occupied v. renter occupied): "This includes the income of the householder and all other individuals 15 years old and over in the household, whether they are related to the householder or not. Because many households consist of only one person, average household income is usually less than average family income" (American Community Survey, 80). This can create important comparisons between the income of homeowners and the income of renters. A wide gap between the two indicates a problem with affordability in an area.

- Median family income: This refers to the summed incomes of all individuals, 15 years and over, related to the householder. See household type for a more detailed definition of family. Looking across geographic regions, important comparisons can be drawn by studying the various median family incomes.

- Household type (family v. non-family): This breaks down the total number of households into two categories: family and non-family. "A family consists of a householder and one or more other people living in the same household who are related to the householder by birth, marriage, or adoption" (American Community Survey, 75). A nonfamily household consists of individuals living alone or with nonrelatives. Household type is important when considering geographic location. In

some cities, non-family households may be higher due to younger, single residents or college students living together to afford housing closer to transportation or campus.

● <u>Housing tenure</u> (renter v. owner): This measures homeownership rates of occupied housing units. The rate of homeownership is important because in the U.S. it has come to serve as an indication of personal wealth and therefore a gauge of the nation's economy. The data can serve to aid planners in evaluating the stability and viability of housing markets. It can "also serve in understanding the characteristics of owner-occupied and renter-occupied units to aid builders, mortgage lenders, planning officials, government agencies, etc., in the planning of housing programs and services" (American Community Survey, 35). For this study, the information is essential in understanding the affordable housing market and therefore the potential impact EE policies can have on the LIHTC program. "A housing unit is owner-occupied if the owner or co-owner lives in the unit, even if it mortgaged or not fully paid for." Mobile homes are considered in the owner category if occupied by owners paying a loan on leased land. "All occupied housing units which are not owner-occupied, whether they are rented or occupied without payment of rent, are classified as renter-occupied" (American Community Survey, 35).

● <u>Poverty status</u>: This variable identities the percentage of population below the poverty threshold. Family or individual income determine the poverty threshold. If a person is within a family, their income for the last 12 months is compared to the appropriate poverty threshold for a person within a family of that size and composition. "If the total income of that person's family is less than the threshold appropriate for that family, then the person is considered 'below the poverty level,' together with every member of his or her family. If a person is not living with anyone related by birth, marriage, or adoption, then the person's own income is compared with his or her poverty threshold. The total number of people below the poverty level is the sum of people in families and the number of unrelated individuals with incomes in the last 12 months below the poverty threshold" (American Community Survey, 102). Knowing what areas have a high percentage of the population below poverty can help direct redevelopment and LIHTC projects. Areas with high poverty rates may need economic redevelopment and more low-income housing options. Poverty status serves as an indicator for areas for LIHTC development along with EE construction standards.

● <u>Employment status</u> (unemployment): The unemployment rate refers to the percentage of the civilian labor force that is unemployed. Unemployment status is defined when civilians 16 years or older are "(1) were neither 'at work' nor 'with a job but not at work' during the reference week, <u>and</u> (2) were actively looking for work

during the last 4 weeks, <u>and</u> (3) were available to start a job. Also included as unemployed are civilians who did not work at all during the reference week, were waiting to be called back to a job from which they had been laid off, and were available for work except for temporary illness" (American Community Survey, 61).

- <u>Area median income</u> (AMI): This variable compiles median incomes in a geographic area, usually at the MSA level, and finds the median number that separates the values into two equal parts. "For households and families, the median income is based on the distribution of the total number of households and families including those with no income" (American Community Survey, 80). HUD annually releases AMI data for the purpose of determining income limits and qualifications for housing subsidy programs. Under current laws and standards a household earning no more than the eighty percent of the AMI is classified as a low-income household. Households earning between thirty and fifty percent of the AMI are considered very low-income. Those households earning thirty percent or less of the AMI are deemed extremely low-income households. Income limits are adjusted dependent on family size. A family of four is considered the base; larger families are permitted higher income limits, smaller families are subject to lower income limits (HUD 2012a). Overall, HUD's assistance programs target families who fall under 60% of their AMI.

Resident Behavior Affecting LIHTC

Aside from mortgage and rental payments, resident behavior and utility bills affect housing affordability. The amount residents spend on water and electric bills is taken out of their monthly income jeopardizing their economic well-being. By tracking utility usage through residents' utility bills, the efficiency of the unit can be assessed. The key factors of resident behavior revolve around heating/cooling, water, and electricity. Residents use water at varying levels, this includes time in the shower to the frequency of use for the dishwasher and clothes washer. Residents also have varying preferences for air temperature, fresh air intake, and humidity level. Factors that influence electric bills include all aspects of heating and cooling, from the use of a thermostat, space heater, or fan, to the use of all major and minor household appliances. Non-electrical mechanical equipment and appliances and their energy categories are included in the study. The assessment of resident behavior allows for implementation of policies incentivizing EE building practices with the added benefit of educating residents on the most efficient use of their systems and appliances.

Energy Efficiency

The impact that energy efficient building design has on housing costs plays a key role in determining the future of EE policies in affordable housing construction standards. By studying energy efficient building practices and their effect on affordability, there will be a greater understanding of the high performance certifications and rating systems in place today- from EarthCraft to the larger context of LIHTC projects.

Energy Efficiency as an Influencing Factor on Affordability

In general, housing is constructed as inexpensively as permissible for its market type by meeting the minimum requirements for current code standards. This is done in order to keep first costs low, thus ensuring clients' financial accessibility and maximum profitability for developers and homebuyers alike. In the past, little consideration was given towards energy efficiency and the additional expense of operation (primarily conditioning cost) that result from building to minimum standards. Such practices have been found to be common when attempting to create housing accessible to low-income households (Southface Energy Institute 2009). As a result, housing built to a target cost point with short-term financial motives and to minimum standards is often not as energy efficient as it could be. This lack of energy efficiency creates a higher operating cost when compared to high performance construction methods and materials.

Prior works of research and government sponsored studies make clear the importance and impacts of energy efficiency (Gillingham et al. 2009). Energy efficient housing is critical when considering overall energy demand and consumption, as the impacts are complex and far reaching. In addition to environmental and economic implications, the fiscal health of a household can be closely tied to the cost burden of energy expenditures. The energy cost incurred from household operation can be significant; such cost has the potential to create financial hardship for a household. While this is true for all households, irrespective of income level, it holds especially true in the case of low-income households. While there are many definitions, typically a low-income household is one that earns less than half of the median income for their area. For these households, the cost of housing alone can take a significant portion of their gross income. It is accepted that housing cost should ideally not be more than 30% of one's gross income; it is often the case that low income households spend more than 30% of their gross income on housing and associated operating cost (Schwartz & Wilson 2010; Congressional Digest 2007).

Today, higher operating cost is a major factor in the affordably equation. Individuals finding themselves on the threshold of affordability can see their energy costs push housing

expenditures beyond the normally accepted 30%. The globally trending rise in energy consumption and cost will only further the financial burden placed on these individuals if energy costs escalate at the projected exponential rate (DOE 2011a). Additional hardships are realized because month-to-month and year-to-year energy costs are not constant. As household energy demands fluctuate, dependent on climate conditions, so do monthly energy costs. This erratic monthly variance in the percentage of income allotted for housing is destabilizing to family finances.

Further, while housing expenditures applied toward a mortgage (including additional construction cost for higher quality) builds equity, energy expenditures add nothing to a family's accrued value of ownership in a property. It is easy to become energy insecure when families are unable to afford their energy bills. As defined by Elevate Energy in a January 2014 report, energy insecurity happens when a household experiences at least one of the following in a year: they are threatened by utility shutoff, one of their utilities is shutoff or they are refused delivery of a heating fuel, they go with a day of no heat or cooling because of the inability to pay bills, or they are forced to use a cooking appliance as a source of heat (Elevate Energy, 6).

Non-energy Benefits: Societal, Utility, Tenant

In recent years, the rising cost of energy has prompted a shift towards more energy efficient homes regardless of end users' finances. This shift largely targets construction methods and materials that reduce heating and cooling cost, as they alone account for a large portion of a home's energy needs. At the most basic level, this type of construction often means creating a tighter building envelope with a higher thermal resistance, or R-value. While such measures result in additional upfront cost, it remains unproven whether operational cost savings over the life of a residence justify the greater first cost of energy efficient construction through reduced long-term energy expense. It is important that such decisions be considered for the lifetime operational cost when planning and constructing housing.

Importance of Energy Efficient Housing

When evaluating one's ability to financially cover housing expenditures, the common measures of affordability presented in the preceding section consider total housing expenditures inclusive of all utility expenses. "However, the cost burden of these utilities is frequently not given adequate consideration during the construction of a home" (Phillips

2005). Lee et al. (1995) noted the cost of energy bills is influenced so strongly by decisions made during design and construction that it necessitates taking a life-cycle perspective when evaluating housing. Lee further stated, "Investment in energy-efficiency measures may increase purchase price, yet decrease future energy bills."

The U.S. Department of Energy's *Energy Outlook* released in 2006 indicates that as a whole in 2001, United States households consumed 356 Billion kWh of electricity solely for the purpose of satisfying heating and conditioning needs (DOE 2005). This consumption equates to over 30% of total annual household electricity consumption being dedicated to space conditioning. This does not account for the many U.S. households using sources other than electricity to meet heating needs; often natural gas.

The DOE estimates that the typical household spends approximately 8-14% of their income on energy expenditures. Of this, a third typically is consumed by energy demands for heating and cooling needs (DOE 2005). This indicates that for the typical America household, heating and cooling cost consume approximate 3-5% of their gross annual income. This percentage is not insignificant when considering the rising housing cost burden. Today, more than one-in-three American homeowners and one-in-two renters are considered to be cost burdened (Mallach 2009). It is estimated that 12 million renters and homeowners dedicate more than half of their annual incomes to housing expenses (Congressional Digest 2007).

In a study examining the housing cost burden of Section 8 voucher program recipients, housing cost burdens averaged 36%. This study further indicated that for more than a third of these households their housing cost burden exceeded 40% of their income. Structural and climate differences were attributed to be contributing burden factors (U.S. General Accounting Office, 1990). The correlation between housing typology and conditioning costs has long been recognized as a factor affecting affordably.

Households Most Impacted by Energy Expenditures

All households are affected by energy expenditures and the rising cost of energy. However, not all households have the financial means to simply pay more for their required energy expenditures. Therefore, those households with low incomes will be burdened the most by future inflation. Phillips (2005) noted: "as residential energy costs increase exponentially, the burden of these costs will impact all Americans – but the disproportional negative impact of energy costs will be most severe for low-income Americans." Further, Lee et al. (1995) noted that lower income households lack access to capital and often have difficulty meeting lenders' qualification thus being unable or unwilling to pay for efficiency increases. Consequently their future energy expenses only further reduce the actual affordability of their housing.

In examining the role energy expenditures play in housing affordability Lee et al. (1995) calculated energy cost burden accounted for 13% of housing expenditures for households above the low income level. Comparatively, for a low-income household 25% of their total housing expenditures are dedicated to energy. Of the total energy consumed, over 40% was consumed by space heating and air conditioning (see Fig 1 and n*ote: calculations based data from the Energy Information Administration and the Department of Housing and Urban Development.)*

Figure 1: Low- Income Energy Expenditures (direct source: Lee 1995)
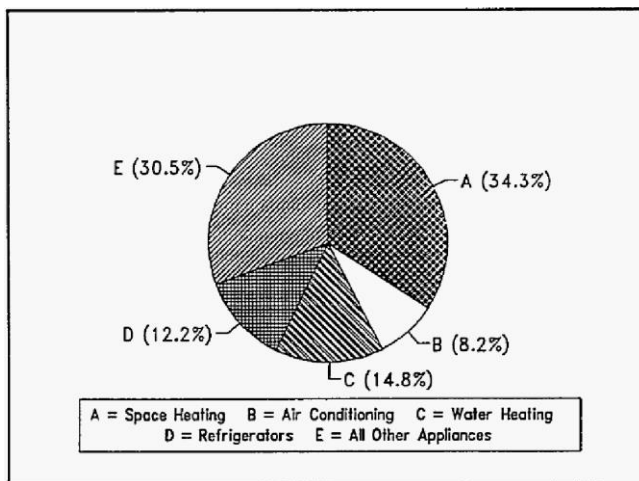
Disproportionate Energy Expenditures – The Financial Burden of Heating/Cooling Cost

The percentage of income that a homeowner dedicates to housing heating and cooling is not uniformly proportional to household income and home size. "There is an inverse relationship between household income and residential energy consumption and residential energy expenditures. Lower income groups consume and expend more per square foot for residential energy than do higher income groups in the United States" (Phillips 2005). Echoing this relationship, Lee et al (1995) noted that low-income households are burdened by residential energy costs more than other households. Their research states "[r]esidential energy expenditures are a key determinant of housing affordability; particularly for lower income households...household energy costs continue to place a major burden on lower income families" (Lee et al. 1995). This burden is only increased by the fact that low-income homebuyers often purchase older, smaller homes in poor condition which reflect lower energy efficiency (Collins et al., 2002).

The impact of heating and cooling cost is significant to low-income households. Studies have shown that households may be forced to forgo essentials in order to cover variances in energy bills. Nord and Kantor (2006) observed that seasonal variations in home heating and cooling costs resulted in food insecurity for low-income and poor households. Further reinforcing the connection between heat cost and financial burden was the observation that the prevalence of "very low food security was higher in high heating states than in high cooling states" (Nord & Kantor 2006). This same study found that food insecurity as a result of energy cost dedicated to heating and cooling was substantially higher in elderly households. Further, the cost burden of heating and cooling is distributed differently based on region and climate. In the U.S., southern states show a peak of electricity use in winter as well as in summer. (DOE 2005)

It is important to understand how energy efficiency affects the cost burden of housing for low and moderately low-income households. With an overall understanding of how energy efficiency affects affordability, it is important to understand how energy efficiency can be monitored through certifications and policies. Certification, rating systems and policies cannot only create incentives but also a platform for monitoring that can shape the development and redevelopment of affordable housing. By utilizing these tools to shape EE design, programs like LIHTC have the potential to lower residents' utility bills and lessen buildings' negative impact on the environment through lower energy and material consumption.

Energy Efficient Certification Programs Overview

Nationally and regionally, independent building contractors and tradespeople are the stakeholders primarily responsible for implementing green buildings in the residential built environment (McCoy, O'Brien, et al., 2012). These stakeholders are also primarily responsible for either veto or endorsement of innovative products, processes and systems in residential construction (Koebel, 2008; Koebel & McCoy, 2006; Koebel, Papadakis, Hudson, & Cavell, 2004; Koebel & Renneckar, 2003; Slaughter, 1993a, 1993b, 1998). According to Ng et al. 2010, "Green building means improving the way that homes and homebuilding sites use energy, water, and materials to reduce impacts on human health and the environment" (Ng, 2010). While the intent and concept is straightforward, early adopters among independent building contractors and tradesmen have recognized a need for communicating specific benchmarks of green building, similar to the "organic" label used for produce. This type of product certification helps to manage expectations, provide measurable deliverables, and establish a metric that can be tied to economic value. Similarly, high performance construction, such as green building, establishes expectations, measurable deliverables, and metrics for

professionals through rating certification programs training. Both are integral to green building and lend confidence to the risks in implementing a new and relatively unknown system. The industry has moved quickly to address these risks, as almost 50 local and regional green building labeling programs have emerged, many of which have resulted in pieces of national-level programs.

Residential Certifications and Rating Systems

The American Society of Quality defines a certification as, "a formal recognition that an individual (or firm) has demonstrated proficiency within, and comprehension of, a specific body of knowledge" (ASQ 2005). It also can represent qualification of a professional set of standards, commonly related to job requirements or as an extension of education for licensure (DeBaugh, 2005; Mulkey & Naughton, 2005). Regarding the world of energy efficient construction, individuals or firms are often certified as "capable" of performing work within certain standards, but must further have the building certified by a third party observer.

Distinct differences exist between certifications and rating systems. While certifications often require the successful completion of an assessment or examination, rating systems establish a set of standards by which the certified individual or firm must adhere in the process of construction of a certified product (Mulkey & Naughton, 2005; Schoneboom, 2005). Many firms do not place as great a value on individual certification; they rarely represent an assessment of knowledge (Adams, et.al. 2004) and, in residential construction, certifying the product, the home, requires an outside entity.

In contrast, rating systems "provide the option for builders, owners, and designers to establish a metric verifying the relative greenness of their homes" (Reeder, 2010). Three leading or emerging systems can currently be considered as specific to the residential construction environment: ENERGY STAR™ for Homes; LEED™ for Homes (LEED-H); National Association of Home Builders' (NAHB); National Green Building Standard (NGBS); and the emergent EarthCraft Homes program.

ENERGY STAR™ for Homes, established in 1996 as a joint effort of the US EPA and DOE, provides both a rating certification program AND energy efficiency training for its 8,400 high performance builder partners (as of 2010). As a result of program rigor, national brand recognition, and established training quality and qualifications of third party Home Energy Raters (HERS), ENERGY STAR™ certification has become a core component of many green building programs. The ENERGY STAR™ program maintains a focus on building science and the analysis of the building as an integrated energy system. It is worth noting that ENERGY STAR™ for Homes is in the process of implementing a 'version 3' update, not considered here,

which expands the scope of the program's focus, currently on thermal envelope and HVAC systems, to encompassing indoor air quality, water distribution and renewable energy.

Other green building rating certification programs include LEED for Homes (LEED-H), and the ICC 700 National Green Building Standard (NGBS). While both programs incorporate similar criteria for green building practices, they differ in the emphasis and accountability for these practices, mostly due to the differences in their origination and user base; AIA architects for LEED and NAHB Contractors for the NGBS. The NGBS is the only residential green building program that has been approved by the American National Standards Institute (ANSI) process as a standard, which is an important first step of the process to building code adoption.

The EarthCraft Homes program, created in 1999 by a partnership between Southface Energy Institute and the Greater Atlanta Home Builders Association, is regional to the southeast United States. According to the program's website, it "introduces green building to the construction industry in a way that could be easily integrated into the building process," making it quite accessible to builders. Since 1999, EarthCraft has become one of the largest regional systems for attainable green building goals in the country.

From a statistical perspective, ENERGY STAR for Homes dominates the rating certification program market, with more than 126,000 new homes certified in 2010 alone, bringing the total number of ENERGY STAR qualified homes to nearly 1.2 million to date. By comparison, LEED-H has a total of 5,834 certified projects (total since 2007 pilot program, count updated 8/24/2011) and NGBS has certified a total of 2, 795 (since ICC 700 Standard in 2007). Among the top three, McCoy et al. (2012) found several barriers specific to green building rating systems: Training is typically geared toward a specific rating certification and the tendency is to focus on earning "points," rather than the implementation of broader sustainability concepts; Categorization of points is by trade, which reinforces a "silo" approach to construction rather than the integrated approach to sustainability issues; Green building training does not cover production management, or building systems approaches; Building science training is well developed in ENERGY STAR certification, but limited in most green building training (McCoy, Pearce, et al., 2012).

Defining High Performance

Energy efficient construction is gaining acceptance as a sign of excellence in the trade, limiting the options in the market for firms who cannot bring these skills to a building project (McCoy, O'Brien, et al., 2012). Energy prices, regulation, and health or safety concerns are all factors that increase the need for the adoption of energy efficient and 'green' practices in the building construction field. A powerful and vital tool for achieving the adoption of these

practices is to increase the ability for compositional analysis, rather than discrete analysis, in building trades and related firms. Such a summary measure would enable stakeholders responsible for the creation and maintenance of the built environment to make informed decisions regarding energy efficiency and green building options, and to communicate these new options effectively across the supply chain.

In contrast, others have realized the importance of defining tools of performance, at a broad level, for their industry. Such metrics have become central to customers' ability to comfortably make purchasing decisions and trust in these decisions (for example, imagine buying an automobile without the mile per gallon, or mpg, calculation). While the Department of Energy (DOE) is currently making strides in this area through its Home Energy Score (http://www1.eere.energy.gov/buildings/residential/hes_index.html), no mpg exists for the homebuilding industry—let alone a Corporate Average Fuel Economy (CAFÉ) standard to drive future behavior.

By exploring concepts of performance within the realm of residential construction, this research can better inform EE policies for affordable housing development. According to Adomatis (2010), "the concept of ensuring performance in housing contains roots in the business concepts of quality and customer satisfaction" (Adomatis, 2010). Performance is integral to the assurance of quality in housing, which might in turn lead to satisfaction. Quality is subjective, though, and may be understood differently by consumers within and across markets. Summary measures of performance reduce speculation of quality for a product/service, a major barrier in the adoption and diffusion of green technology.

High Performance Housing

Many have attempted to define high performance housing, often contributing to confusion for the market. The following section therefore collects literature definitions on green and sustainable and high performance buildings to achieve a comprehensive definition for this term.

While designers and builders might define high performance buildings as ones that use innovative appliances and technologies, Turner and Vaughn (2012) warns a high performance house is not necessarily a "high tech" one (sensors and programmable appliances and equipment are likely to be common features in the near future). The current building sustainability literature considers consensus-based metrics (i.e., LEED, NGBS) to evaluate features in a green building project related to specific key indicators (i.e. energy efficiency, IAQ, site use, and others). Building performance is another focus area in the sustainable building literature that examines energy consumption, utilities, operations and maintenance,

and occupant health (Fowler et al. 2005), (U.S. EPA 2009), making it critical to evaluate the designed building's performance after construction.

It seems necessary given the array of rating systems and their differing emphases to define terms for performance in buildings and, as a subset, homes. Lewis et al. (2010) defined a green building as one "that is designed, constructed and operated to minimize environmental impacts and maximize resource efficiency while also balancing cultural and community sensitivity" (Lewis, Riley, & Elmualim, 2010). In the same article, sustainability is defined as development that meets the needs of the present, without compromising the ability of future generations to meet their own needs. As some may argue that these definitions are more theoretical than practical, within industry these definitions have often been applied while considering the triple bottom line: balancing environmental, economic, and social goals (Hodges, 2005; Lewis, et al., 2010).

The fifth edition of The Dictionary of Real Estate Appraisal sustainability (2010) describes green design and construction as the "practice of developing new structures and renovating existing structures using equipment, materials, and techniques that help achieve long-term balance between extraction and renewal and between environmental inputs and outputs, causing no overall net environmental burden or deficit" (Appraisal-Institute, 2010). The United States Energy Independence and Security Act (2007), defined a high performance building as "a building that integrates and optimizes on a lifecycle basis all major high performance attributes, including energy [and water] conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations."

Just as in commercial building, a high performance home might be a certified home but every certified home is not necessarily a high performing one. According to Korkmaz et al (2010), green, sustainable, and high-performance homes are designed and constructed to maximize the energy efficiency of the envelope, mechanical and lighting systems to provide superior quality in the indoor environment for enhancing occupant well-being (Korkmaz, Messner, Riley, & Magent, 2010). Such buildings are being widely adopted for their potential to reduce energy costs and improve the health and productivity of occupants. To achieve the set goals for sustainable high-performance housing projects within realistic financial and time constraints, though, superior planning, design, and construction processes are needed. For example, Talbot (2012) and Turner and Vaugh (2012) pointed out high performance housing characteristics for low to middle income households as requiring planning, creative and innovative design, and efficient implementation. A high performance house may also need to fit into federal and state goals, local law or others' needs (the home buyer, architect, builder or manufacturer).

High Performance houses are not necessarily easy to embrace, either. One of the primary barriers in the market is the owner's perception of higher first costs associated with these homes due to added personnel hours and use of innovative materials and technologies (Konchar & Sanvido, 1998). Again, the process used to deliver green building projects can be a remedy to this problem (Beheiry, Chong, & Haas, 2006; Lapinski, Horman, & Riley, 2006). Defining green building systems and performance could alleviate risks and remedy concerns for stakeholders involved.

An inclusive and comprehensive definition is first needed for high performance in housing. Literature suggests that there is no one standard definition; all emphasize energy efficiency, sustainability, and environmentally friendly products (Adomatis, 2010, 2012). In general, homes that can be described as high-performance are: 1) safer and healthier; 2) more energy and resource efficient; 3) more durable; and 4) more comfortable. Recent literature suggests that many professionals are now defining their practices as green without utilizing the prescriptive systems that avow these methods, though (Quirk, 2012; Tucker, et al., 2012)). Understanding the gap between prescribed methods and those that might be considered green best practice is a necessary step.

Energy Efficiency Measures for Virginia's LIHTC Program

Virginia is a state well suited for an investigation into EE policies for affordable housing. The LIHTC program is the largest current affordable rental housing program in the nation and results in the development of more than 2,000 apartments per year in Virginia, which is among the top 10 states in LIHTC production. Based on VHDA's green building requirements in its Qualified Allocation Plan (QAP), Virginia has recently become ranked as the highest state in the southeast of the U.S. for green affordable building. Virginia is also one of the top states in terms of attractiveness to tax credit investors as a result of its healthy economy, steady growth, and strong rental housing market. The combination of all of these factors makes the LIHTC program in Virginia an ideal target for this research. By understanding the EarthCraft Multifamily program and their use of the HERS Index, this research can better identify and verify the shift to EE policies used for affordable rental housing in Virginia.

EarthCraft

Certification under EarthCraft Virginia requires that a development meet three basic criteria. The first of these criteria is Energy Star Compliance. Secondly, a home must successfully pass all EarthCraft inspections; one after construction framing and a final inspection after full completion. Finally, a home must earn a minimum of 120 points on the

EarthCraft worksheet. According to EarthCraft's "True Cost of Ownership (2011)", the additional construction costs for an EarthCraft home are no more than 3% higher than that of traditional construction. EarthCraft Virginia maintains that homes built to their specs are in actuality cheaper when factoring in long term energy savings.

The EarthCraft Multifamily program started in 2003 to include certifications for renovated and newly constructed multifamily projects. Along with other EarthCraft programs, "EarthCraft Multifamily uses a HERS rating, program guidelines, a points-based worksheet, site visits, and diagnostic testing to verify that each project complies with program standards" (http://www.earthcraft.org/multifamily). Low-rise, mid-rise, and high-rise projects are all considered for certification under the EarthCraft Multifamily three-tiered certification process. The typical approaches to reach the Multifamily program requirements include: "[i]mprove insulation levels and installation quality, [b]etter than 'typical' low-e windows, [i]ntegrated ballast and compact fluorescent lighting, and [i]nstallation of ENERGY STAR rated appliances" (EarthCraft Multifamily Program Summary, Version 2014.4.08, p.3). Projects are eligible for the EarthCraft Multifamily program if they have "stacked units sharing a floor or ceiling with another unit" including rental apartments and ownership condos. Certain duplexes, row-homes and townhomes are also eligible for the program. Lastly, projects utilizing adaptive reuse, "transforming a building from a previously non-residential use" are also considered for the certification. The energy compliance requirements vary between these three types of EarthCraft Multifamily projects (EarthCraft Multifamily Program Summary, Version 2014.4.08, p.3-4).

Home Energy Ratings System

A home energy rating is an analysis of a home's energy efficiency per the Home Energy Rating System (HERS) Index. The HERS Index is a nationally recognized scoring system for measuring a home's energy performance. Based on the results of field testing and energy modeling, an energy rated home will receive a HERS Index Score. A score relates the home to the average standard American home. A score of 100 is equal to the standard home. Lower scores indicate a home performing better than the standard American home. A zero on the HERs index is given to a home demonstrating a net energy demand of zero. The HERS Index Score can be described as a sort of mile per gallon rating for houses. It provides prospective buyers and homeowners insight into how the home ranks in terms of energy efficiency. In addition to a HERS Index Score, a home energy rating also provides the homeowner with a detailed report regarding energy consumption for the home (Holladay 2011).

EarthCraft Virginia's Multifamily program uses the HERS rating and guidelines to analyze projects for energy efficiency standards. The Index generally looks at four categories:

mechanical system for heating/ cooling, mechanical system for water heating, insulation in the building shell, and lighting and appliance features. A certified RESNET Home Energy Rater completes diagnostic testing of the unit or building to complete a performance assessment in each of the categories. The data is then compiled into the Residential Energy Services Network (RESNET) software to calculate the HERS Index.[1] Detailed design data, along with the various development types on which data are collected and LIHTC encouragement to use the standard make the EarthCraft program ideal for studying energy efficiency units in the Commonwealth of Virginia.

For this study, researchers analyzed the Home Energy Rating Certificates (HERC) for each project. The HERCs varied from project to project whether the study was conducted at a unit or building level. The period of collection led to more HERCs for renovation projects. Various categories make up the Home Energy Rating Certificate (HERC). Generally, the HERC is divided into five sections: General Information, Mechanical System Features, Building Shell Features, Lights and Appliance Features, and Estimated Annual Energy Costs. Variables within each category are compared throughout all of the projects in this study. The significance of each HERS variable follows:

- Conditioned area: Total insulated floor area, of the unit or building, is measured in square feet and indicates how much floor space a unit has and therefore how much space has to be insulated and heated/cooled.

- Conditioned volume: Total insulated volume, of the unit or building, is measured in cubic feet and indicates how large a unit is because it takes into account ceiling heights. The larger the space, the more energy that goes into heating and cooling it.

- House type: The units measured in the study range from apartment units with one exterior wall, apartments with two or more exterior walls, entire apartment buildings, interior townhouse units, exterior townhouse units and lastly, duplexes. The more exterior walls a unit has the more insulation is needed to alleviate heat gain and loss from the inside and outside.

- Air-source heat pump: An air-source heat pump is "vapor compression heating and cooling equipment that uses the outdoor air as the heat source or sink for heat"(RESNET, 2014, p.2). Air-source heat pumps are fueled by electricity or gas. Air-source heat pumps are measured for efficiency in heating by a heating seasonal performance factor (HSPF) and in cooling by a seasonal energy efficiency ratio (SEER). Every residential heat pump in the U.S. has an EnergyGuide label that displays these

efficiency ratings. "The efficiency and performance of today's air-source heat pumps is one-and-a-half to two times greater than those available 30 years ago as a result of technical advances" (Air-Source Heat Pumps). By purchasing newer heat pumps with better EnergyGuide ratings, residents can save energy and money with a more efficient air-source heat pump.

● <u>Water heating</u>: An average household spends $400-600 a year on water heating, which makes up 14-18% of residents' utility bills. This makes water heating the second largest home utility expense (New Infographic and Projects, n.d.). "The energy factor (EF) indicates a water heater's overall energy efficiency based on the amount of hot water produced per unit of fuel consumed over a typical day" (Estimating Costs and Efficiency of Storage, n.d.). The higher the Energy Factor, the more energy efficient the water heater is.

● <u>Ventilation system</u>: "Ventilation is very important in an energy-efficient home. Air sealing techniques can reduce air leakage to the point that contaminants with known health effects such as formaldehyde, volatile organic compounds, and radon are sealed into the house. Ventilation also helps control moisture, which can lead to mold growth and structural damage" (Ventilation, n.d.).

● <u>Programmable thermostat</u>: Programmable thermostats allow for scheduled adjustments of the temperature in a unit or home. With programmable thermostats, residents are able to adjust the temperature for set intervals when they are not home or are sleeping. This saves energy by reducing the heating or cooling levels for hours at a time. The Department of Energy finds that residents can save 10% a year on heating/cooling costs by turning their thermostats up or down 7°-10°F from its normal setting for eight hours a day (Tips: Programmable Thermostats, n.d.).

● <u>R-Value</u> (ceiling flat, sealed attic, above grade walls, foundation walls, slab): "An insulating material's resistance to conductive heat flow is measured or rated in terms of its thermal resistance or R-value -- the higher the R-value, the greater the insulating effectiveness. The R-value depends on the type of insulation, its thickness, and its density" (Insulation, n.d.). "According to the U.S. Department of Energy (DOE), the typical U.S. family spends close to $1,500 each year on energy bills. DOE statistics show that, typically, 44% of a homeowner's utility bill goes for heating and cooling costs. DOE states that homeowners may be able to reduce their energy bills from 10% to 50% by taking certain steps. One of the major steps is increasing the amount of thermal insulation in their existing homes or purchasing additional insulation when buying new homes" (ICAA, n.d.).

- <u>Windows</u>: Windows are important when it comes to energy efficiency because they come in very close contact with outside air and gain heat from solar energy. The U-Factor is the "coefficient of heat transmission (air to air) through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films" (RESNET, 2014, p.8). "Solar Heat Gain Coefficient (SHGC) measures the fraction of solar energy transmitted and tells you how well the product blocks heat caused by sunlight. SHGC is measured on a scale of 0 to 1; values typically range from 0.25 to 0.80. The lower the SHGC, the less solar heat the window transmits" (Independently Tested and Certified Energy Performance, n.d.).

- <u>Infiltration Rate</u>: Infiltration is the "inadvertent exchange of outdoor and indoor air through small cracks and penetrations in home enclosures driven by pressure differences between the indoor and outdoor environment" (RESNET, 2014, p.5). It is measured in air changes per hour (ACM) or cubic feet per minute (CFM).

- <u>Lighting and appliances</u>: By switching to ENERGY STAR certified lighting from traditional, less efficient bulbs, residents can save about $14 annually per fixture (Lighting, n.d.). Appliances account for almost 20% of an average household's energy use. By installing ENERGY STAR appliances, residents can save $80 a year on their utility bills. Not only do these ENERGY STAR appliances have the ability to save residents money, they will last longer than standard appliances (U.S. Environmental Protection Agency, n.d.).

- <u>Estimated annual MMBtu</u>: MMBtu is 1 million Btu or British thermal unit. As defined by RESNET, the British thermal unit is an "energy unit equal to the amount of heat needed to raise one pound of water one degree Fahrenheit at a constant pressure of one atmosphere; equal to approximately 1055 joules.12 The lower the MMBtu, the more efficient the heating system. Heating, cooling, hot water, lights/appliances and photovoltaics are all factors that have MMBtu values associated with them. This allows for a summation of total estimated MMBtu for a unit.

Household Energy Consumption Influences

A variety of influences, either directly or indirectly, impact household energy use. These influences are important considerations for energy-use assessments and models such as the HERS rating index. According to the DOE (2011), the most significant contributors to residential energy consumption includes the domains of space heating, space cooling, water heating, lighting, electronics, and appliances. Durak (2011) reviewed previous research,

building science fundamentals, energy assessment tools, and commonly accepted business practices in order to identify a comprehensive list of energy consumption influence parameters that drive the demand and expenditure of energy consumption domains in the residential setting. Interrelationships between the energy consumption domains and identified household energy consumption influence parameters were investigated to aid in the future development of more accurate energy models. A summary of the relationship analysis undertaken for the study can be exemplified with the total square footage parameter. Total square footage impacts heating and cooling requirements as well as the lighting energy consumed by a household. The bigger the square footage, the more energy required to meet these needs. Total square footage of a house does not only impact energy consumption items, but can additionally affect other influence parameters such as footprint area, number of rooms, and volume. Changes to the total square footage can, in turn, alter the affected influence parameters and thus impact the energy consumption items they influence.

As a result of Durak's (2011) investigation, a condensed set of minimum influence parameters was derived from the comprehensive list to represent those needed to achieve a credible level of accuracy and confidence in energy assessments and the produced results (see table 1). The minimum influence parameters and their associated energy consumption items are summarized as follows.

Table 1: Minimum Set of Energy Consumption Influence Parameters (Table adapted from Durak 2011)

Energy Consumption Influence Parameter	Energy Consumption Domain				
	Space Heating	Space Cooling	Water Heating	Interior Lighting	Appliances & Electronics
Year Built	✔	✔			
Total Square Footage	✔	✔		✔	
Footprint Area	✔	✔			
Volume	✔	✔			
Perimeter Length	✔	✔			
Form Factor	✔	✔			
Shape of the House	✔	✔			
Interior Ceiling Height	✔	✔			
Number of Stories	✔	✔			
Number of Rooms	✔	✔		✔	
Number & Size of Windows	✔	✔			
Number of Occupants	✔	✔	✔	✔	
Ages of Occupants	✔	✔	✔	✔	
Building Thermal Envelope	✔	✔			
Space Usage Characteristics	✔	✔			
Infiltration	✔	✔			
Ventilation	✔	✔			
Zip Code	✔	✔			
System Characteristics	✔	✔	✔		✔
Occupancy Patterns	✔	✔	✔		✔

The RESNET software and HERS rating energy modeling data used for analysis in this study include the majority of the minimum consumption influence parameters identified by Durak (2011). Those not directly covered by the energy model include the number of stories, number and age of occupants, space usage characteristics, and occupancy patterns. This oversight could potentially be a limitation in regards to the accuracy of the modeled results. However, these omitted influence parameters are included in the resident behavior surveys for subsequent analysis in this study, which coincides with each facility's resident utility data. The influence parameters completely excluded from the data, or perhaps overlooked from the energy model were form factor and shape of the house. Form factor, which refers to the length and width of the house, and the shape of the house have similar functions in energy models where they are used to derive thermal envelope areas and volume. Additionally, they also have similar impacts on specific energy consumption domains (Durak 2011). Thus it is reasonable to assume that their absence would not significantly impact results produced by the data.

Methodology

This study is designed to isolate the effects of one common EE standard on energy efficiency of the unit, new building effects (new versus reno), and the total economic benefit to certain types of occupants (senior versus non-senior). The work also aims to benefit policy discussion by setting a baseline of modeled data, determining EE technologies present or missing in the developments and studying the energy use behavior of current occupants.

Data Sample

The sample planned for the study included units in developments across the Commonwealth of Virginia and specifically in counties shown in the map below. The research team planned to collect data on new construction units in Arlington, Hampton, King George, Lynchburg, Petersburg and Wytheville (yellow pins); renovated units in Abingdon, Arlington, Chesapeake, Christiansburg, Newport News, Orange, Richmond, Scottsville and Virginia Beach (red pins); and senior unit LIHTC units in Abingdon, Christiansburg, King George, Petersburg and Richmond (green pins). Abingdon was not sampled in the final data due to alterations in the technologies since the design and construction of the development.

While Figure 2 is not a completely representative sample, no previous work has been able to capture this amount of data for such a large geography and within one common standard and affordable housing LIHTC program.

Figure 2: Locations of sample of units in Virginia
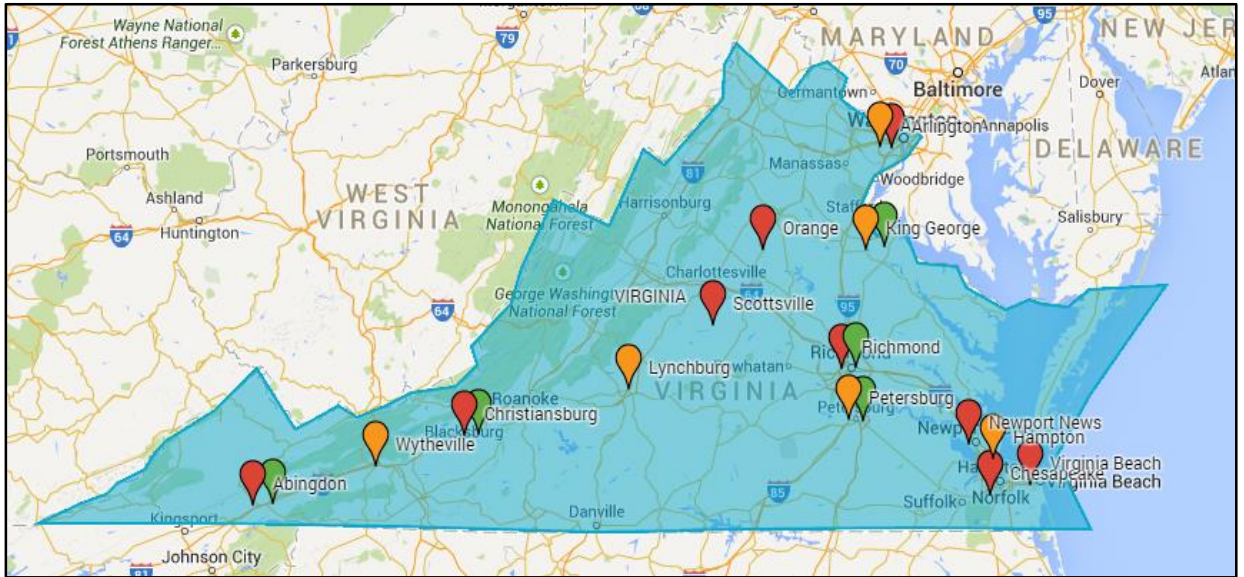
Selection of each project included its location within the Commonwealth and use of EE construction practices, EE retrofits, inclusion in the LIHTC program, and construction since 2009. Table 2 lists development location, development type, the number of HERS certificates (HERC) available pre and post construction, the number of Wegowise releases collected, and the number of behavior surveys administered on site. The final column represents records across all columns that are complete- we can therefore link unit data across all developments which is critical to accurate statistical modeling.

Table 2: Development and Unit Location Samples

Development Location	Dev. Type	HERC (Post EE)	HERC (Pre EE)	Wegowise Releases	Behavior Surveys	Complete Records
Chesapeake City	Family	33	31	31	33	31
Richmond City	Senior	22	0	23	23	22
Richmond City	Family	30	30	29	36	28
Orange Town	Family	20	17	18	21	17

Wytheville Town	Family	24	0	12	14	12
Lynchburg City	Senior/ Disability	15	0	13	16	13
Virginia Beach City	Family	23	23	21	24	21
Hampton City	Family	7	0	9	12	7
Arlington County	Family	0	0	3	6	0
Pulaski Town	Senior	18	0	17	18	16
King George County	Senior/ Disability	24	0	14	15	14
Arlington County	Family	5	0	5	3	3
Petersburg City	Senior	25	0	25	20	20
Christiansburg Town	Family	14	0	20	9	4
Scottsville Town	Senior	13	0	19	8	7
Totals		**273**	**101**	**259**	**258**	**215**

Survey Instrument

The team assessed resident behavior at each property via a voluntary survey. In order to get a well-rounded survey of EE practices within LIHTC projects in different parts of Virginia, a variety of energy measurements, along with local market variables, were gathered for each project. The survey is included in appendix XX of this document for reference. When reporting data later in this document, not all findings will contain the same total number, as respondents failed to answer survey questions differently and some provided release information unable to be verified for accessing utility records.

Data Collection Procedures

Local Market Variables

The research team assembled local market variables or market area characteristics using the American Community Survey and HUD's Median Income projections. American Fact Finder on the U.S. Census website provided place, county, and MSA data for each project. The Virginia Housing Development Authority's website was used to gather the HUD Median Income data for fiscal year 2014 for the larger MSA level. Local characteristics provided a better picture of the housing conditions in each project location in relation to population, income, household types, poverty levels, and unemployment rates.

Energy Modeling Data

Energy modeling data focuses on facilities constructed to the EarthCraft Virginia standard because it is one of the only datasets currently available that allows for this type of inquiry. The team collected modeled data for estimated usage through REM/Rate™ software from Architectural Energy Corporation (AEC), a proprietary software that "calculates heating, cooling, hot water, lighting, and appliance energy loads, consumption, and costs for new and existing single and multi-family homes."   The data were gathered from the Home Energy Rating Certificates (HERC) completed by EarthCraft Virginia. HERC "building summary" pages include the unit or building's HERS Index score, general information on the unit including size and type, the mechanical system features, the building shell features, lights and appliance features, and the estimated annual energy usage. A full list of variables included in this study can be referenced in the appendix.

Resident Utility Data

After establishing a benchmark of estimated energy usage in energy efficient LIHTC rental units, we collected actual use (termed observed use hereafter) of energy by occupants. In order to do this, the team accessed actual consumption records by month from © WegoWise Inc., an online platform for collecting the energy use of buildings and tracking utility performance. Wegowise collects energy consumption records per month per unit from utility companies for customers who have released their records.

By studying residents' utility data, the data shows energy usage patterns after EE standards have been applied to LIHTC projects. Residents were approached during a meeting at each project location set up by the research team. With incentives agreed upon by the property manager, residents were given the option of filling out a utility release form and a resident survey. The team collected the utility release form to monitor for research purposes only. By partnering with WegoWise, the team simply collected residents' utility account information and could then track energy usage by month for each unit in an online portal. The research team then downloaded all data in .csv format for the website.

Resident Behavior Survey

Aside from studying direct utility data, the research also utilized surveys to track resident behavior and compare past units to current, most likely more efficient, units.

Surveying many units in person is a difficult task. Therefore, when the research team reached out for consent for utility bill information, they also planned to collect responses for the resident behavior survey. To ensure privacy and confidentiality of data collected on resident behavior, researchers implemented a three-part approach to the research. First, contact with the property managers to make them aware of the process and instruct them not to collect resident data themselves. Second, the creation of a survey handout of the survey instrument with a Spanish translation. Lastly, we coordinated with property managers to a) hold meetings of residents for collecting survey data in person or b) email the link to the survey. The research team was on site to answer any questions regarding the survey and to ensure residents that their information would not be used for anything outside of the study's parameters.

As a result of consenting to participate, residents were also provided with a local business gift certificate of $5. Consent was collected before any surveys were distributed. Gift certificates were distributed on-site when surveys were conducted at meetings.

The survey gives another layer of information behind residents' current utility bills and is included in the appendix of this document for reference. Before conducting the survey, it was approved by Virginia Tech's Institutional Review Board (IRB). Surveys were anonymous in that no resident names were used during the surveying process, while addresses were collected on the survey for mapping behavior to each unit. Once the team collected, mapped, merged, and analyzed data, all records were destroyed in accordance with IRB policies.

It should be noted that many residents did not show up for the pizza party where data were meant to be collected. Therefore, members of the survey team went into the

developments and knocked on doors, asking people randomly to answer the survey and sign releases. Approximately 50% of all surveys were collected in this manner.

It is also important to note one limitation of this work. As previously mentioned, affordable housing resident surveys are often difficult to collect and implement, one reason why so few studies such as this work exist. The team therefore had an alternate plan for this possibility. When on-site collection processes did not work as planned, property managers were also asked to anonymously collect surveys left for residents. These surveys collected by property managers constituted approximately 10% of all surveys collected.

Statistical Modeling of the Sample

Since proposed hypotheses test the effect of different factors of design (estimated for energy efficiency) and occupant behavior on actual unit energy efficiency, the team collected data on variables that might provide a measurement of these phenomena. In total, we collected 312 records with various levels of missing data in each record. The team then compiled all data into one master spreadsheet with a tab delineating each variable. Appendix XX of this work includes a data dictionary of all variables collected across all units and residents in the sample.

In order to explore preliminary effect sizes for potential analyses, we entered n=11 data records into SAS software and computed the correlations between kilowatt hours (both observed and simulated) with 24 study variables. We then assessed the distribution of these correlations. With 250 expected records, we would have 80% statistical power to detect a correlation greater than 0.177 in magnitude. Since about 80% (38 out of 48) of the correlations we observed were greater than 0.177, we concluded that we would have adequate statistical power to detect effects in the data on the basis of 250 expected data records.

Once the team collected and logged complete data records, we conducted regression analysis to test correlations among measurement variables with estimated (based on designed energy efficient technologies) and observed energy usage. We specified 3 main models, including: 1) estimated energy usage for energy efficient technologies per unit, 2) observed (actual) energy usage for energy efficient technologies and observed behavior per unit and the difference of estimated and observed energy use for energy efficient technologies and observed behavior per unit for LIHTC residents.

Model 1: Estimated energy use

Three-hundred fifteen records were collected.   Yearly observed energy usage was calculated by summing kilowatt-hour usage from June 2013 to May 2014, and this total was divided by conditioned area. Observed energy usage was then subjected to statistical variable selection. The purpose of statistical variable selection is to choose a parsimonious predictive model for the outcome (energy usage) from a list of candidate predictor variables.   A parsimonious model is one that is as simple as possible (i.e. contains the fewest predictor variables) while maintaining good predictive performance for energy usage. The candidate predictors included both technological and behavioral predictors, and the list of candidate predictors is below.   Forward stepwise selection based on the Bayesian Information Criterion(BIC)[3] was performed using SAS version 9.3 (SAS Institute, Cary NC). BIC is a statistical metric which weights the likelihood of a given model with a penalty for additional predictors. Parsimony is achieved by restricting the addition of variables that do not provide an improvement in statistical prediction commensurate with the penalty incurred by their inclusion. The algorithm works iteratively by adding the single predictor to the model which improves prediction most at each step, with the capacity to remove obsolete predictors upon each new addition.   Full details of the algorithm are publicly available in the SAS online documentation.

One aspect of statistical variable selection is that exclusion of a predictor from the final model does not imply that the excluded variable is uncorrelated with energy use. Rather, the purpose of model selection is to determine which set of predictors offer unique predictive power over energy usage. For example, if the number of people in the unit is highly correlated with usage of appliances, and both are also individually predictive of energy use, then the model selection algorithm may include either people in unit or appliance usage but not both since the predictive information in these variables is redundant due to their own collinearity. The individual relationships between study variables and energy usage are depicted graphically in the following section of findings.

The team performed a statistical variable selection model exercise on simulated use. Since behavioral variables are naturally unavailable for simulated data, we restricted the candidate list of variables to those listed below. The purpose of this statistical exercise is to gain insight into technological features of the units which may be used within the simulation algorithm.

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[3] *Source*: "Estimating the Dimension of a Model" by Gideon Schwarz, The Annals of Statistics, Vol. 6, No. 2 (Mar., 1978), pp. 461-464. Institute of Mathematical Statistics: http://www.jstor.org/stable/2958889.

Model 2: Observed energy use

The team also performed a statistical variable selection model exercise observed energy use. Missing data were encountered during the course of statistical analysis. For this modeling approach, data records were included if they had non-missing entries for the outcome and all predictors variables. This resulted in a model with 158 records. Summer and Winter thermostat settings, humidity preference, shower length, and seasonal windows usage were excluded from the broad modeling exercise since missing data for these variables further reduced the sample size to 110 and none survived variable selection on the reduced set. Space heater comfort and fan comfort were missing for 97% and 63% of the total records, so these were removed from analysis as well. This complete-case approach is not completely optimal from a statistical standpoint as those incomplete records that are excluded may correspond to units which differ systematically from the units that provided complete records. This can lead to biased statistical estimation. Imputation techniques will be explored as a method to retain a greater proportion of the data in our forthcoming analyses.

Model 3: Comparison of observed and simulated use

Comparison of simulated energy use was accomplished in two ways. First, the set of units with both observed and estimated usage value were correlated. Second, simulated energy usage was entered into the candidate predictor the correlation of these is 0.065 across 200 units. Further, we entered simulated use as a candidate predictor results in a model which includes stimulated usage, Ventilation, slab, people in unit, simulated use, water heater and Dryer efficiency.

Findings

How to read the charts in this section

While designing and building to a certified standard is now the price of admission for the industry at large, "the differentiating point is clearly now on results." The hypotheses tested in this work examine different variables of energy efficiency design and construction and occupant behavior. Findings in this section report results with regard to energy efficiency across the sample and per unit in the sample.

Before presenting the findings of our study, we would first like to explain our presentation of data. In the following section, we present results in two major formats: 1) a frequency plot of each data point (value with which a data point appears) including a line for averages of the

various samples and 2) a bar chart of totals from each sample. Further, frequency data and bar charts are separated into 3 areas for reporting: 1) overall data numbers and averages per unit and across developments, 2) comparative data and averages between samples for new versus renovation units and 3) comparative data and averages between samples for senior versus non-senior units. Overall sample frequency charts (such as figure 3) contain dots that represent annual averages per unit. Data are records by unit that corresponded to a particular question or about which we collected releases or HERCs. Averages across all units in the sample are represented by a solid line across the chart and labeled by color. In reporting the figures, "below average" terminology refers to less energy usage and "above average" terminology refers to more energy usage for a sample population (i.e. senior) as compared to the overall sample average. New versus renovation and senior versus non-senior sample charts (such as figures 4 & 5), while separated by characteristics of the development, follow the same logic. Bar charts (such as figures 13 & 14) report overall totals and then overlay these amounts on top of the separated samples by development type.

General Findings

Based on HERC energy modeling software, the overall estimated energy use is 663 Kwh per unit per month on average. Figure 3 tracks the estimated, average monthly energy use (across 1 year) by unit from left to right on the x-axis (each dot as a recorded unit). Estimated energy use per unit is highly clustered by development. The majority of estimated monthly usage is between 400 and 900 kWh per month, a wide range with the majority of outliers above 900 kWh and some below 400 kWh. The new development unit sample average is below the overall sample average and estimated to use less energy than renovated developments, which are above the overall average. The senior unit sample average is below the overall average and estimated to use less energy than the non-senior sample, which is above average.

Figure 3: Estimated Sample Overall Values
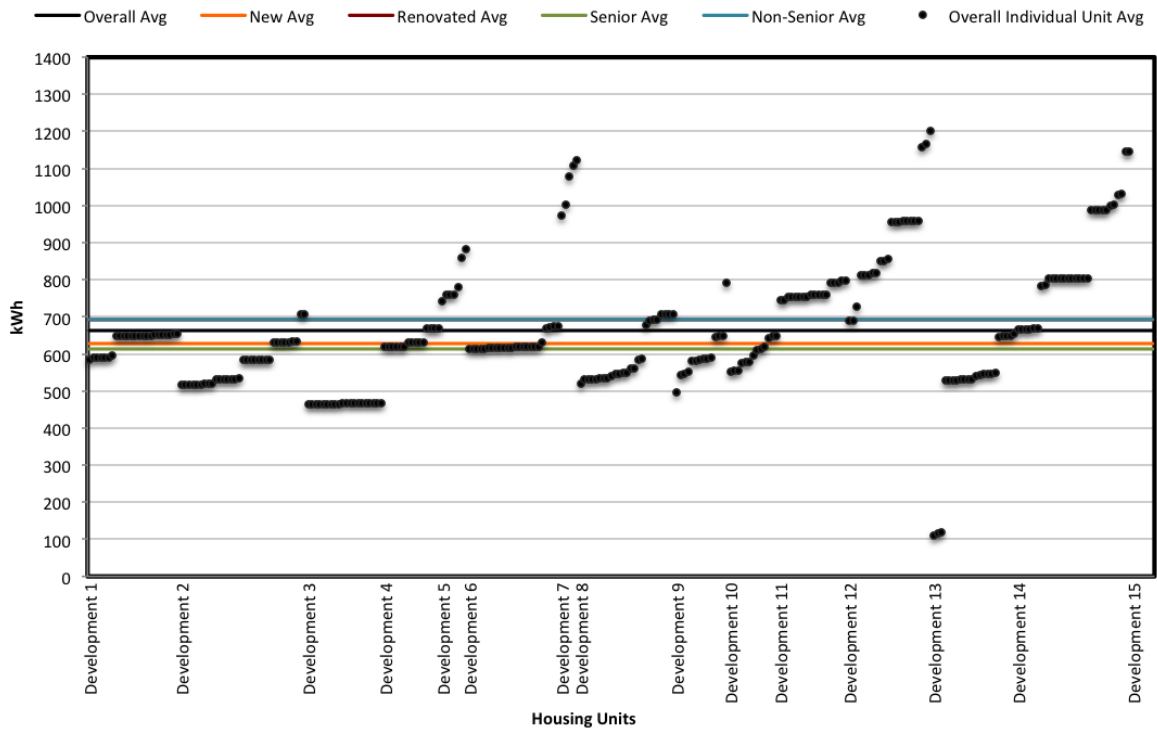
When isolating senior and non-senior estimated unit energy use samples (figure 4, below left), the non-senior sample contains the most variability by development. When isolating new versus renovated unit samples (figure 5, below right), the renovation unit sample contains the most variability in terms of estimated usage. Across the overall sample, the non-senior and renovation units are estimated to use the most energy.

Figures 4 & 5: Estimated New vs. Renovated Sample and Senior vs. Non-Senior Sample
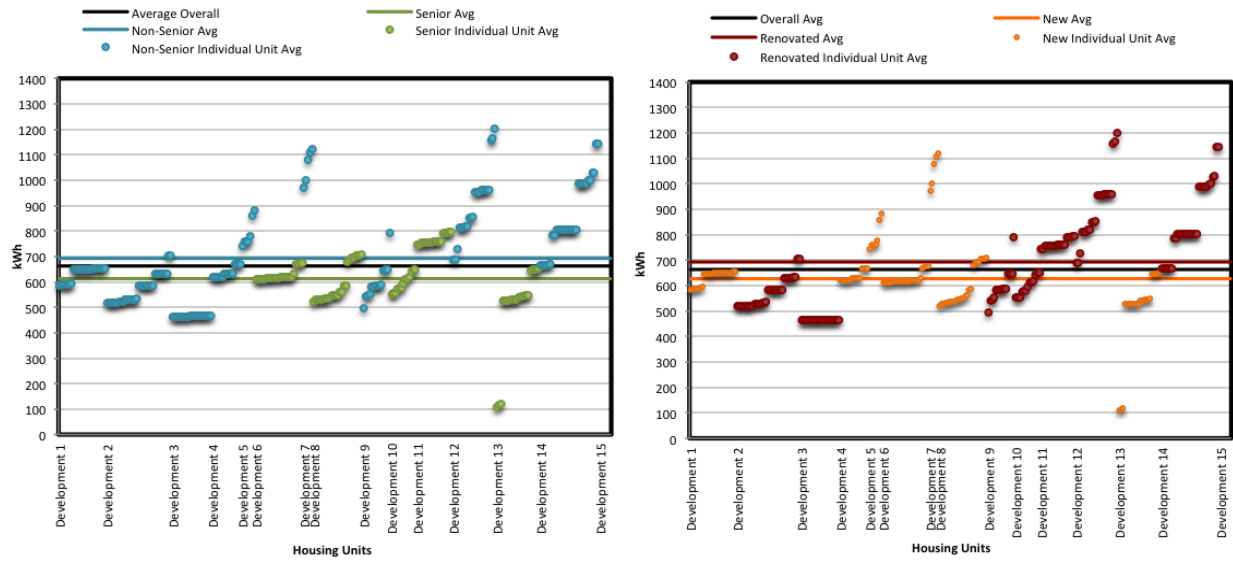
Observed Average Monthly kWh

Based on Wegowise tracking, the average, overall observed (actual) use is 553 kWh per unit per month. Figure 6 tracks observed monthly energy use per unit per month. In contrast with an estimated monthly range of 400 to 900 kWh per month, observed use exhibits considerable variability per unit and across developments. Despite the variability of actual use, residents are using less energy than estimated on average.

Also contrary to estimated use, the new unit sample is above the overall average and used the most energy across the sample (the renovated unit sample is below the overall average). Similar to estimated use, though, the senior unit sample is below average and uses less energy than the non-senior sample, which is above average. Therefore the renovated and senior samples contain the lowest actual energy use compared to the overall sample average.

Figure 6: Observed (Actual) Sample Overall Values
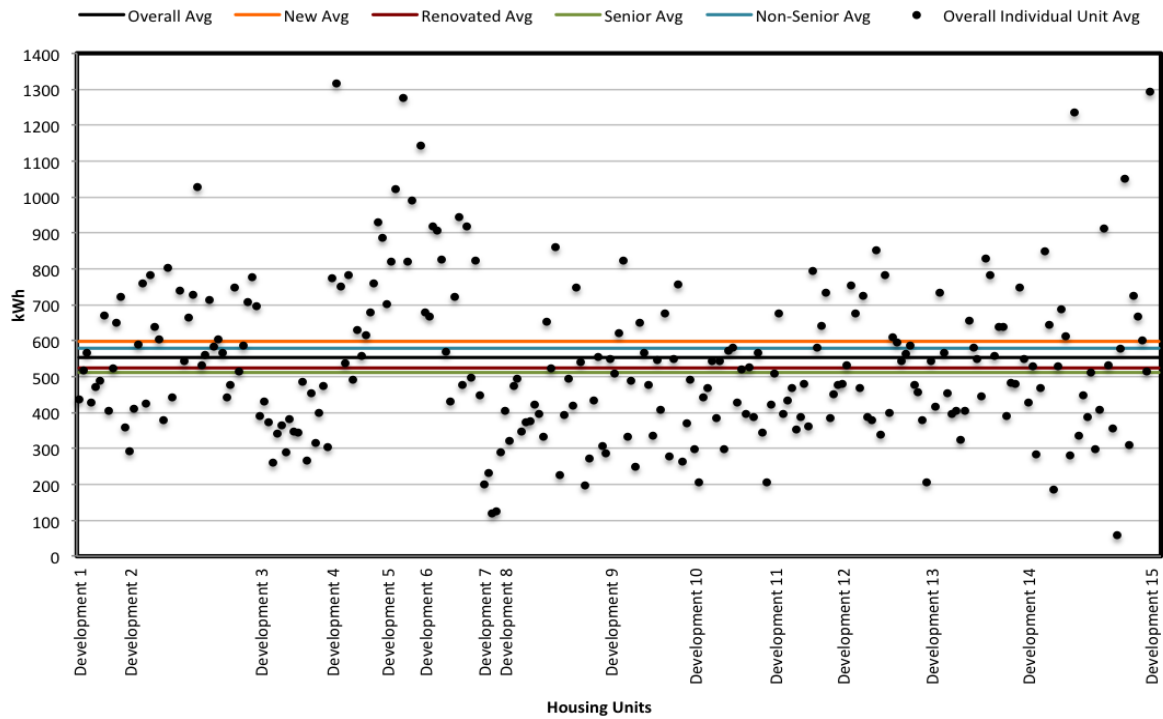
When isolating senior and non-senior observed unit energy use samples (figure 8), the non-senior sample contains more variability than the senior sample including more units with a high level of energy use. However, senior and non-senior sample averages do not vary much from the overall sample average. New and renovated samples (figure 7) both contain variability including many units with a high level of energy use. Similar to the senior and non-senior samples, new and renovated sample averages do not vary much from the overall sample average. Again, the non-senior and new units use the most energy.

Figures 7 & 8: Observed New vs. Renovated Sample and Senior vs. Non-Senior Sample
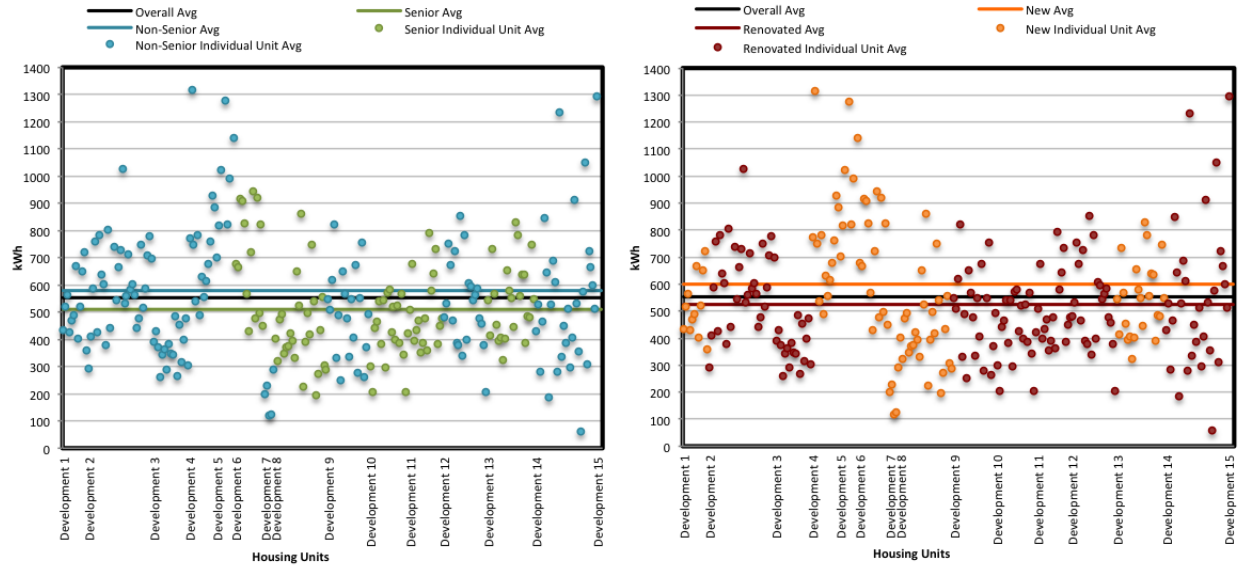
Observed Annual kWh by Conditioned Space

Estimated and observed energy use per unit does not necessarily provide a complete picture of usage. Controlling for variables that might highly correlate to energy use per unit, one uncovers a different picture of use. Below, figure 9 uses the conditioned area (size of the unit in square feet) to create a normal scale ("normalized") for observed use. Based on normalized observations of energy use, results per unit change. Controlling for square footage, the senior sample energy usage is now above the overall average. In other words, the senior sample uses more energy per month per square foot than non-senior residents (the lowest group and below average). The renovated sample is below the overall average and uses less than new units, which like seniors are above average. These findings are contrary to estimated usage but consistent with observed usage.

Figure 9: Normalized Observed Sample Overall Values
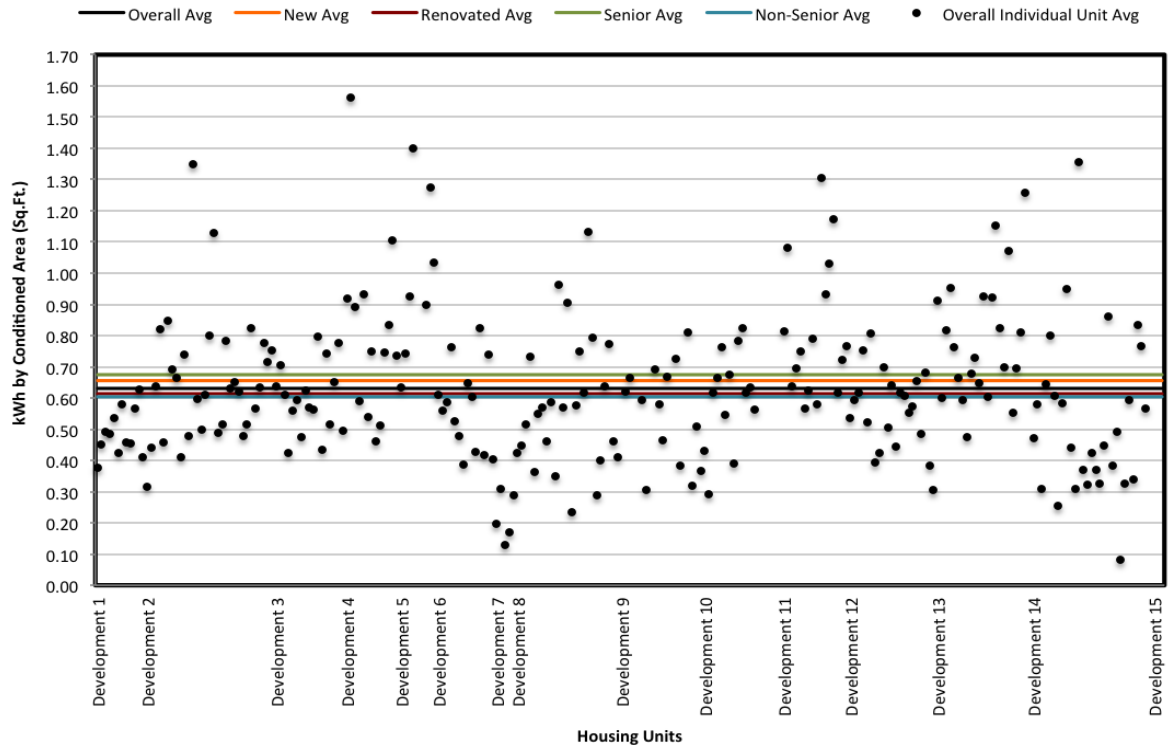
Again based on our "normalized" scale, when isolating senior and non-senior energy use (figure 10), the non-senior sample continues to have the most variability in terms of high-energy use. Further (figure 11), the non-senior new and renovated samples contain the most variability for high-energy use. When controlled for square feet, the average for each sample varies considerably less for new versus renovated construction. Per square foot, new, senior units use the most energy.

Figures 10 & 11: Normalized Observed New vs. Renovated Sample and Senior vs. Non-Senior Sample
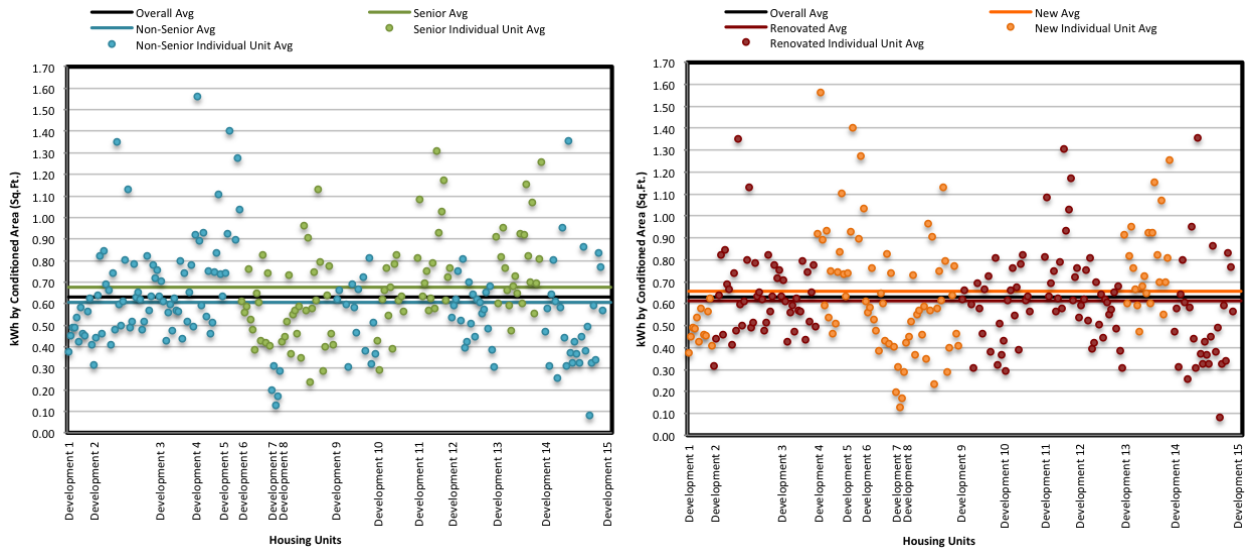
Trends of estimated versus actual usage

In summary, LIHTC residents in the Commonwealth of Virginia under the EarthCraft standard sampled here are using less energy than estimated in the simulation modeling. The observed use average is 16.6% less than estimated (553 Kwh/663 Kwh). Considering that observed use is on average 30% below current code levels of efficiency (based on HERS REM/rate values of 70 or below), the average observed use of the sample is 40% or more efficient than a standard new home built to International Energy Conservation Code (IECC) requirements at the time these developments were built.

For the sake of perspective, an explanation of HERS and code is relevant to this discussion. The reference (modeled) home (HERs 100) for REM/rate is based on International Energy Conservation Code (IECC) 2004 (a supplement to IECC 2003). RESNET uses the language "standard new home, which meets the current industry standard for home energy efficiency" (http://www.resnet.us/hers-index-score-card). Virginia has adopted the 2012 IECC as of this report, while the developments included are closer to 2009 IECC requirements.

Table 3 lists separate samples studied in this research, comparing: 1) the estimated sample group average, 2) the observed sample group average, 3) the normalized observed sample group average and 4) a summary comparison of samples averages by row and against the overall average for the entire sample.

Table 3: Trends in kWh

Sample Group	Estimated Sample Average (Mean)	Observed Sample Average (Mean)	Normalized Observed Sample Average (Mean)	Summary Comparison of Sample Averages
Overall	663	553	.63	16.6% less than estimated; sample contains variability.
New	627	598	.66	4.7% less than estimated; 8% above overall use; 4.7% above overall use per square foot; higher use variability.
Renovated	692	524	.61	24.3% less than estimated; 5.3% below overall use; 3.2% below overall use per square foot; lower use variability.
Senior	613	510	.67	17% less than estimated; 7.8% below overall use; 6.3% above overall use per square foot; lower use variability.
Non-Senior	693	579	.60	16.5% less than estimated; 4.7% above overall use; 4.8% below overall use per square foot; higher use variability.

Overall estimated energy use is 663 Kwh per unit per month on average with a majority ranging between 400 and 900 kWh per month. The overall observed sample contains considerable variability, meaning that many variables could be contributing to changes in actual energy use in the sample. We will discuss technology and behavior variables that could be affecting actual use in the coming section.

The *new construction development* sample of units is estimated to use 4.7% less energy than the overall sample, actually uses 8% more energy than overall average sample and uses

4.7% more energy than the overall average sample based on square footage. New development actual energy usage contains higher variability per unit than the average unit.

The *renovated development* sample of units is estimated to use 24.3% less energy than the overall sample, actually uses 5.3% less energy than overall average sample and uses 3.2% less energy than the overall average sample based on square footage. Renovated development actual energy usage contains variability, but it is lower on average per unit.

The *senior development* sample of units is estimated to use 17% less energy than the overall sample, actually uses 7.8% more energy than overall average sample and uses 6.3% more energy than the overall average sample based on square footage. Senior development actual energy usage contains variability, but it is lower on average per unit.

The *non-senior development* sample of units is estimated to use 16.5% less energy than the overall sample. It actually uses 4.7% more energy than the sample average and uses 4.8% less energy than the overall average sample based on square footage. Non-senior development actual energy usage contains higher variability per unit than the average unit.

Not only does the actual average energy use per unit vary considerably, the estimated energy use from design and construction modeling varies in the sample as well. Estimated model average variability suggests that design and construction for energy efficient units could be performed within tighter values across the sample, which could result in increased unit efficiency.

Tools for modeling housing energy could require changes. RESNET has always had a standard (and modeling protocols) for single family detached which does not necessarily translate to MF modeling. For example, the algorithms used projecting impact for infiltration are based on model is for single zoned housing, while MF units have multiple zones (apartment to corridor, apartment to apartment, apartment to ambient). There is currently an effort to clean this up within RESNET by formalizing the MF standard (http://www.resnet.us/blog/wp-content/uploads/2014/08/Adopted-RESNET-Guidlines-for-Multifamily-Ratings-8-29-14.pdf).

Sample groups, while containing internal, per unit variability, exhibit averages that do not range far from the overall average. This result suggests that the sample group variability could contain common reasons across the affordable housing population. When controlled for square feet, the range of averages for the entire sample varies even less, suggesting that variability is not increased by square footage.

The following sections will describe technologies included in each unit and then dive into the sample in terms of resident characteristics and reported behavior that could result in variability in actual energy use.

Describing the Technologies

Many consider technologies included in the units to be one of the most important factors that drives energy efficiency. Energy efficiency literature in housing mentions technology in the design or construction of the unit to be the front line of variables that impact energy consumption and are measureable and controllable within the unit. The following section reports on individual unit records and averages units across the overall sample, separating technologies by sample group like previous sections.

Before describing technologies per unit, it is important to note that a low amount of variability in the design and use of a technology reduces the probability that the technology will drive variability in energy usage across the overall sample.

A majority of sample units are on a slab-on-grade. Still, 26% of the units in the sample contain a conditioned space below the unit, which can affect energy use. The new development sample contains 58% slab, 33% above conditioned space and 9% conditioned basement. The renovated development sample contains 79% slab, 21% above conditioned space and 0 conditioned basement. The senior and non-senior development samples are relatively similar in their percentages.

Table 4: *foundat*: Foundation type

foundat	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
Slab	191	70	71	58	120	79	64	63	127	74
Above conditioned space	71	26	40	33	31	21	38	37	33	19
Conditioned basement	11	4	11	9	0	0	0	0	11	6
Total	273	100	122	100	151	100	102	100	171	99

All units contain Air-source heat pump heating efficiency above a level of 8 HSPF or heating season performance factor. As previously mentioned, while such a technology represents efficiency in the sample, it contains low variability and reduces the probability that this

technology affects energy usage in the sample. The same reasoning will apply to upcoming technologies with low sample variability.

Table 5: *HP_HSPF*: Air-source heat pump heating efficiency

HP_HSPF	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
<8	0	0	0	0	0	0	0	0	0	0
>8	273	100	122	100	151	100	102	100	171	100
Total	273	100	122	100	151	100	102	100	171	100

A majority of sample units contain a heat pump with a seasonal energy efficiency ratio (SEER) cooling efficiency above 14 SEER. Building code has recently required that all air-source cooling systems move above SEER of 13, making most systems efficient. The new and non-senior sample groups contain outliers that could be due to a reporting of EER (as opposed to SEER), as SEER above 13 was required by code when these units were built.

Table 6: *HP_SEER*: Air-source cooling seasonal efficiency

HP_SEER	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
10-12	7	3	7	6	0	0	0	0	7	4
13-14	0	0	0	0	0	0	0	0	0	0
>14	266	97	115	96	151	100	102	100	164	96
Total	273	100	122	100	151	100	102	100	171	100

A majority of sample units contain 40-59 gallon water heater tanks. The senior sample group contains some of the smaller water heater tanks, which makes sense. The renovated sample requires some of the largest units in terms of people, as it contains some of the outliers for the largest size water tanks.

Table 7: *WH_size*: Water heater tank size in gallons

WH_size	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
20-39	13	6	0	0	13	13	13	15	0	0
40-59	179	80	122	100	57	55	71	85	108	77
60-80	33	15	0	0	33	32	0	0	33	23
Total	225	101	122	100	103	100	84	100	141	100

The amount of duct leakage in a unit is important for the energy efficiency of the heating and cooling system. Duct leakage also impacts comfort, IAQ, and infiltration/ex-filtration due to pressurization/de-pressurization of apartments and interstitial spaces. The average level of leakage (in terms of CFM25) is 24.9 for the overall sample. EarthCraft Multifamily modeling measures duct leakage to outside the envelope in relationship to conditioned floor area. In this case, an average 24.9 CFM25/ average conditioned floor area of sample (lets say 1000 sq ft for easy math) = 2.5% duct leakage/conditioned floor area.

Table 8: *D_leak*: Duct leakage in CFM25

D_leak	Overall	New	Reno	Senior	Non-senior
Mean	24.9	22.8	26.2	18.0	25.8
Std. Err	0.9	1.9	0.8	1.1	1.0
Upper 95%	26.6	26.6	27.7	20.3	27.8
Lower 95%	23.1	18.9	24.6	15.7	23.9
N	195	75	120	24	171

A majority of sample units contain "none" for the ventilation system. Of those with ventilation systems, "balanced" is the next most common technology and "air cycler" is third most common.

New units have the most amount of systems that qualify as ventilation systems, with renovated units containing the least. <u>All</u> construction projects meeting the EarthCraft Multifamily standard must have fresh air/mechanical ventilation systems while REM/rate doesn't require that one reflect the system in the model if it is without controls and a mechanical damper.

Table 9: *V_type*: Ventilation system type

V_type	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
None	194	71	56	46	138	91	43	42	151	88
Exhaust only	13	5	0	0	13	9	13	13	0	0
Supply only	5	2	5	4	0	0	0	0	5	3
Balanced	37	14	37	30	0	0	22	22	15	9
Air cycler	24	9	24	20	0	0	24	24	0	0
Total	273	101	122	100	151	100	102	101	171	100

A majority of sample units contain a programmable thermostat for setting the cooling temperature in the unit. Programmable thermostats ensure better accuracy when heating and cooling a unit. Programmable thermostats often require education so that they can be set properly and used effectively, though.

Table 10: *P_cool*: Programmable cool

P_cool	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
No	55	20	7	6	48	32	18	18	37	22
Yes	218	80	115	94	103	68	84	82	134	78
Total	273	273	122	100	151	100	102	100	171	100

A majority of sample units contain highly insulated ceilings above an R-value of 30, meaning that they conform to code as expected. Those units containing "none" are units

below others in a building where insulation is not required by code. Often, these units have some amount of insulation for acoustics, while not reflected in the HERC model due to a lack of deltaT for conductive loss. New and senior units report the most instances of "none."

Table 11: *C_R*: Ceiling flat R-value

C_R	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
None	86	32	50	42	36	24	49	48	37	22
<13 - 30	0	0	0	0	0	0	0	0	0	0
>30	185	68	70	58	115	76	53	52	132	78
Total	271	101	120	100	151	100	102	100	169	100

A majority of units contain an R-value of 13-18 in the walls above grade. Such a sample is in keeping with code standards but suggests that the insulation of the walls does not go far beyond code or towards higher efficiency. The renovated and non-senior units contain the least amount of above-grade wall insulation value. A value of "none" in the renovated and senior units is likely due to interior units that do not require insulation.

Table 12: *AG_R-value*: Above grade walls R-value

AG_R-value	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
None	13	5	0	0	13	9	13	13	0	0
<13	23	8	0	0	23	15	0	0	23	13
13-18	199	73	104	85	95	63	86	84	113	66
19-30	38	14	18	15	20	13	3	3	35	20
>30	0	0	0	0	0	0	0	0	0	0
Total	273	100	122	100	151	100	102	100	171	99

A majority of sample units contain no R-value at the slab-on-grade edge, most likely due to the location of the unit (inside units might not be modeled as having insulation, or listed "none," if a conditioned space is next to them). Renovated units have the most instances of minor amounts of insulation, in terms of R-value, while new units tend to have higher R-values when modeled with insulation.

Table 13: *S_edge_R*: Edge slab R-value

S_edge_R	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
None	194	71	75	61	119	79	59	58	135	79
<13	55	20	23	19	32	21	19	18	36	21
13-18	24	9	24	20	0	0	24	24	0	0
19-30	0	0	0	0	0	0	0	0	0	0
>30	0	0	0	0	0	0	0	0	0	0
Total	273	100	122	100	151	100	102	100	171	100

Similar to slab edge R-value, a majority of sample units contain no R-value under the slab-on-grade. Nevertheless, this was code at the time of construction and must be included. Again, the lack of reported and modeled insulation and R-value must be due to the location of the unit. When modeled, new and non-senior units contain higher R-values under the slab.

Table 14: *S_under_R*: Under slab R-value

S_under_R	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
None	162	59	53	43	109	72	68	67	94	55
<13	111	41	69	57	42	28	34	33	77	45
13-18	0	0	0	0	0	0	0	0	0	0

19-30	0	0	0	0	0	0	0	0	0	0
>30	0	0	0	0	0	0	0	0	0	0
Total	273	100	122	100	151	100	102	100	171	100

U-value is the inverse of total R-value of an assembly and used to determine window efficiency. A lower U-value means better efficiency in contrast to R-values, where a higher value means better efficiency. R-value represents individual material thermal resistance values, and can also represent the totaled R-values for an assembly of materials (like the wall assembly in the previous table i.e. R_{total}-value), while U-Value represents the inverse of a total assembly's R-value (i.e. $1/R_{total}$-value). Therefore windows (as an assembly) are reflected in U-Value to account for the window glazing and frame. A majority of sample units contain a U-value of 0.4 - 0.5 in the windows, which is equivalent to an R-value of 2.5. Renovated and non-senior units contain the least amount of insulation in terms of window assembly U-value. Almost no units tend to have higher U-values than 0.5.

Table 15: *W_U*: Window U-value

W_U	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
<0.3	0	0	0	0	0	0	0	0	0	0
0.3-0.4	59	22	26	21	33	22	13	13	46	27
0.4-0.5	212	78	94	77	118	78	89	87	123	72
0.5-1	2	1	2	2	0	0	0	0	2	1
>1	0	0	0	0	0	0	0	0	0	0
Total	273	101	122	100	151	100	102	100	171	100

Solar Heat Gain Coefficient (SHGC) is another value used to determine window efficiency as it defines the amount of solar energy that is reflected back away from the unit. Solar heat gain can allow heat in the winter and lead to overheating in the summer. A majority of sample units contain a SHGC value of 0.35 - 0.5 in the windows, which is an expected middle-of-the-

road value for Virginia. Renovated and senior contain units the most units with SHGC above 0.5, possibly due to the location of the windows or sensitivity of the occupants.

Table 16: *W_SHGC*: Window SHGC

W_SHGC	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
0-0.35	0	0	0	0	0	0	0	0	0	0
0.35-0.5	252	92	119	98	133	88	84	82	168	98
0.5-1	21	8	3	2	18	12	18	18	3	2
Total	273	100	122	100	151	100	102	100	171	100

Surprisingly, the sample units are relatively evenly spread across many levels of air infiltration and do not contain a majority of the sample in the lowest levels of infiltration. New and senior units contain the tightest construction envelopes, based on infiltration rates of the sample.

Table 17: *IC_ACH*: Infiltration rate, cooling in ACH Natural

IC_ACH	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
<0.3	0	0	0	0	0	0	0	0	0	0
0.3-0.4	86	38	55	74	31	21	59	76	27	18
0.4-0.5	75	33	19	26	56	37	19	24	56	38
>0.5	64	28	0	64	42	0	0	0	64	44
Total	225	99	74	100	151	100	78	100	147	100

A majority of sample units contain 100% efficient interior lighting. Renovated and senior units contain the least amount of efficient interior lighting.

Table 18: *Int_light*: Percent interior lighting

Int_light	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
0%	0	0	0	0	0	0	0	0	0	0
10%	18	7	0	0	18	12	18	18	0	0
75%	23	8	22	18	1	1	0	0	23	13
100%	232	85	100	82	132	87	84	82	148	87
Total	273	100	122	100	151	100	102	100	171	100

A majority of sample units contain efficient refrigerators that use less than 400 kWh per year. Almost half of the overall sample contains mid-range refrigerator efficiency. Renovated and senior units contain the most refrigerators at the lowest level of efficiency (highest level of energy usage).

Table 19: *Ref*: Refrigerator (kWh/yr)

Ref	Overall		New		Reno		Senior		Non-senior	
	N	%	N	%	N	%	N	%	N	%
0<400	139	51	37	30	102	68	38	37	101	59
401-500	1	0	0	0	1	1	0	0	1	1
501-600	115	42	85	70	30	20	46	45	69	40
601-700	0	0	0	0	0	0	0	0	0	0
>700	18	7	0	0	18	12	18	18	0	0
Total	273	100	122	100	151	101	102	100	171	100

73% of sample units contain efficient dishwashers with new and non-senior units containing the most by a slim margin. Renovated units and senior units contain the least amount of efficient dishwashers.

Table 20: *DW_EF*: Dishwasher energy factor in cycles/kWh

DW_EF	Overall	New	Reno	Senior	Non-senior
Mean	0.73	0.75	0.71	0.71	0.74
Std. Err	0.00	0.00	0.01	0.01	0.00
Upper 95%	0.74	0.76	0.73	0.74	0.75
Lower 95%	0.72	0.75	0.69	0.69	0.74
N	273	122	151	102	171

Of sample units, the average level of efficiency (in terms of pounds/kWh) is 2.86. Meaning, the average clothes dryer meets or exceeds the DOE 2011 standard for efficiency, while not the 2015 amended standard. ACEEE reported that clothes dryers use 5.8% of all residential energy consumption and vary by 33% to dry the same load of laundry. The renovated units contain the least amount of variability in terms of efficiency, while all groups contain variability.

Table 21: *D_EF*: Clothes dryer energy factor in pounds/kWh

D_EF	Overall	New	Reno	Senior	Non-senior
Mean	2.86	2.89	2.85	2.97	2.80
Std. Err	0.01	0.02	0.01	0.01	0.01
Upper 95%	2.88	2.92	2.87	3.00	2.82
Lower 95%	2.84	2.85	2.82	2.94	2.77
N	273	122	151	102	171

Summary of Technology Trends

Typically when modeling a 1-story duplex vs. a stacked duplex with the same floor area and envelope area, the 1-story is projected to have higher loads and be less efficient since you have more surface area in contact with the ground and attic conditions. A majority of sample units are slab-on-grade construction. 26% of the units in the sample contain a conditioned space below the unit. The new development sample contains 58% slab, 33% above conditioned space and 9% conditioned basement. The renovated development sample contains 79% slab, 21% above conditioned space and 0 conditioned basement.

All units contain air-source heat pump heating efficiency above a level of 8 HSPF. A majority of sample units contain a heat pump with an efficiency rating above 14 SEER. Low variability reduces the probability that these technology factors affect energy usage in the sample. Also, building code has recently required that all air-source cooling systems move above SEER of 13, making the majority of systems in the sample energy efficient.

The majority of water heaters are 40-59 gallons in size. Current specifications show that Energy Star water heaters of this range in size consume approximately 4622 kWh per year and cost $492 - $531 per year to operate (based on 2007 national average electricity cost of $.107 per kWh). The senior sample group contains smaller water heater tanks as well; they would not need larger water heaters for single unit residents. The renovated sample group contains a majority of the largest water units and also has units with the largest number of people.

The average level of duct leakage in the overall sample is 24.9 CFM25 with the senior and new construction developments containing the lowest amount of leakage in CFM25 on average. According to popular websites like "Energy Vanguard" the standard of "tight" house construction sits at 25 CFM25 and below. Meaning, on average the sample is built to high performance standards with which the industry agrees.

Ventilation systems without controls and a mechanical damper are not often reported in the REM/rate modeling. This is likely a reason that a majority of sample units are reported as having a ventilation system of "none." Of those with ventilation systems, "balanced" is the next most common technology and "air cycler" is third most common. The lack of a ventilation strategy can affect health and comfort of the occupant through moisture build-up and particulates from cooking. Unhealthy environments can also affect the lifecycle of a building and its maintenance costs. As reflected in the units with "none," uncomfortable environments could cause residents to use less energy-efficient settings on the thermostat or auxiliary heating and cooling appliances (i.e. "plug-ins").

It is important to also differentiate between mechanical fresh air ventilation and spot-exhaust (bath fans and range hoods). Effective ventilation in MF housing is an important issue for the industry as buildings become high performance. New units have the most amount of ventilation systems reported, with renovated units containing the least reported systems.

A majority of sample units contain a programmable thermostat for setting temperature in the unit. Programmable thermostats ensure better accuracy when heating and cooling a unit and can improve unit efficiency when used properly.

A majority of sample units contain highly insulated ceilings above an R-value of 30, meaning that they conform to code as expected. Those units containing "none" are units below others in a building (i.e. in a ceiling where insulation is not required by code), meaning they are likely adjacent to a conditioned space which should improve efficiency. New and senior units report the most instances of "none."

A majority of units contain an R-value of 13-18 in the walls above grade. Such a sample is in keeping with code standards but shows the variability that might occur even in high performance developments. For example, one renovated development doesn't have insulation in above grade walls because the National Park Service wouldn't allow it if the developer wanted to maintain historic tax credits. The renovated and non-senior units contain the least amount of above-grade wall insulation value. As with ceilings, a value of "none" in the renovated and senior units is likely due to interior units that do not require insulation between walls and are adjacent to conditioned space.

A majority of sample units contain no R-value at the slab-on-grade edge, a place where energy transfer is known to happen. Similar to slab edge R-value, a majority of sample units contain no R-value under the slab-on-grade, also a place where energy transfer is known to happen.

A majority of sample units contain a U-value of 0.4 - 0.5 in the windows, which is equivalent to an R-value of 2.5. Floor to glazing ratios (the amount of window area per square footage) are typically more favorable in affordable housing compared to market rate - this is typically a benefit for energy efficiency that is reflected in energy models. Reported window U-values will include windows, door glazing and sliding doors/French door glazing and door glazing U-values tend to be higher than window U-values which could skew results slightly. Renovated and non-senior units contain the least amount of insulation in terms of window assembly U-value. Almost no units tend to have higher U-values than 0.5, which makes sense considering available market technology in residential construction in the US.

A majority of sample units contain a SHGC value of 0.35 - 0.5 in the windows, which is an expected middle-of-the-road value for Virginia (Virginia has fewer days of high heat where

glazing needs to control radiation for the interior environment). Renovated and senior units contain the most units with SHGC above 0.5, which could lower cooling demand/load and raise heating demand/load depending on the location of the window.

Air infiltration rate in highly efficient units is also important. It is measured typically using a blower door test and used to determine air tightness and efficiency of the enclosure of the unit, as data reported in this study reflect unit-level, unguarded blower door testing. Surprisingly, the sample units are relatively evenly spread across many levels of air infiltration and do not contain a majority of the sample in the lowest levels of infiltration. Such variability is often a factor of the construction process or unit location- 1st floor slab on grade concrete is typically a good air barrier versus a middle floor unit that has more opportunity for bypasses. Market variability, contractor education, architectural details (or lack thereof) can also impact air infiltration in the field. Still, each unit must fit within a testing level of efficiency to satisfy EarthCraft standards, which means they are more efficient than standard new construction units. New and senior units contain the tightest construction envelopes, based on air infiltration rates (renovated units often have retain existing drywall and air seal the structure as much as possible, thus making it difficult).

Efficient interior lighting is another way to achieve energy efficiency in the unit. Efficient lighting is calculated as a percentage of fixtures in the unit. A majority of sample units contain 100% efficient interior lighting. Renovated and senior units contain the least amount of efficient interior lighting, but not by a large margin. Anecdotally, designers and constructors report that new construction projects typically have more efficient fixtures compared to the renovation of older apartments because many do not add to the overall fixture count in the unit, they just replace.

Appliance efficiency also contributes to energy efficiency in the unit as well as heating and cooling loads. A majority of sample units contain efficient refrigerators that use less than 400 kWh per year. Almost half of the overall sample contains mid-range refrigerator efficiency. Renovated and senior units contain the most refrigerators at the lowest level of efficiency (highest level of energy usage).   Anecdotally, designers report that ADA compliant refrigerators tend to be less efficient (even when Energy Star rated) than non-ADA, a possible explanation for lower efficiency in the senior sample.

Similar to refrigerators, dishwasher efficiency affects energy consumption in the unit: less water is heated to wash dishes. 73% of sample units contain efficient dishwashers with new and non-senior units containing the most by a slim margin and Renovated and Senior units containing the least. Anecdotally, many of the senior units report not using the dishwasher.

Finally, the dryer is an appliance whose efficiency is also important for overall energy efficiency in the unit. Of sample units, the average level of efficiency (in terms of pounds/kWh) is 2.86. Meaning, the average clothes dryer meets or exceeds the DOE 2011 standard for efficiency, while not the 2015 amended standard.

Describing Residents

Characteristics of the residential unit in the overall sample and sample groups can affect energy consumption and are directly related to behavior in the unit. The following section reports on individual unit records, averages and totals units across the overall sample and separates resident responses by sample group like previous sections. Following the section is a reporting of trends for the residential units included in this work.

Average People in Unit

The overall number of people in units is 1.78 on average. The new development sample contains 1.52 people on average compared to the renovated development sample which has 1.95 people per unit on average. The senior development sample contains 1.35 people on average compared to the non-senior development sample which has 1.99 people per unit on average.

Figure 12: Average People in Unit
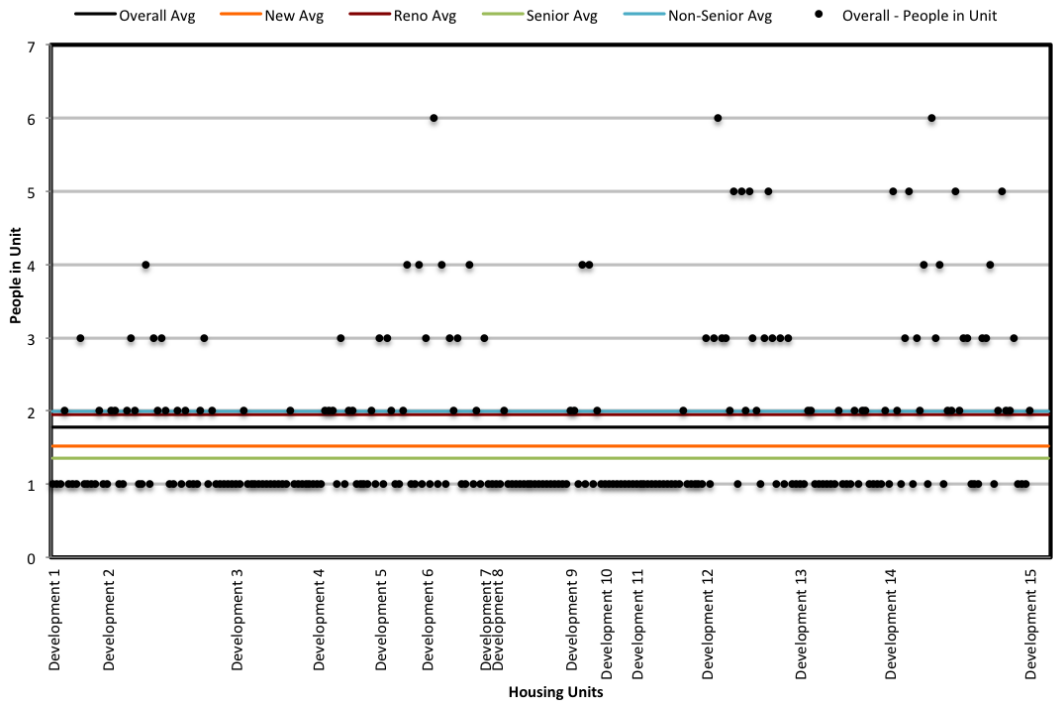
Ages of People in Study

Depending on the ages of people living in a housing unit, the amount of energy consumed could vary considerably. 142 respondents are between the ages of 30 to 59 and represent a majority of the sample. 135 Respondents are 60 and over, a close second in total number. The new development sample contains 155 people compared to the renovated development sample, which contains 292 people. Renovated units in the study also account for a majority of the under 5, 5 to 9, 10 to 19 and 20 to 29 age ranges. Not surprisingly, the senior development sample contains a majority of 60 and over respondents, which the non-senior group does as well. The non-senior group contains ages across the range while the senior sample contains few people below 30 in age.

Figures 13 & 14: Ages of People in Study in New vs. Reno and Non-Senior vs. Senior
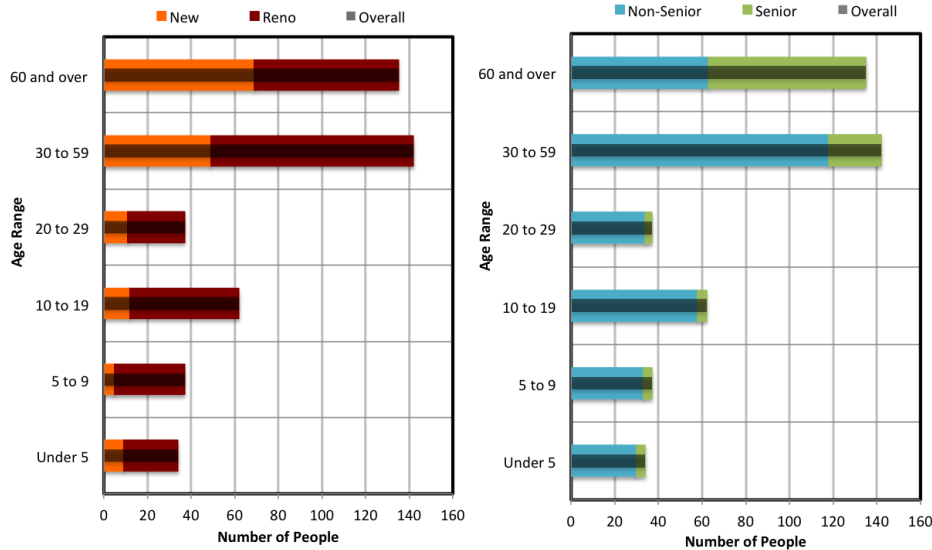
Housing Type by Unit

With a total of 100 units, the majority of the housing types sampled are apartment end units. Apartment inside units is a close second in total number with 75. Also no duplex units are part of the survey responses and no multifamily whole (master-metered) buildings are included in the sample. The renovated sample includes a majority of townhouse inside units and apartment end units. The new unit sample is relatively evenly spread between townhouse end units, apartment end units and apartment inside units. Similar to the renovated sample, non-senior units were mostly townhouse inside units and apartment end units. Senior respondents were a majority of apartment inside units.

Figures 15 & 16: Housing Type by Unit in New vs. Reno and Non-Senior vs. Senior
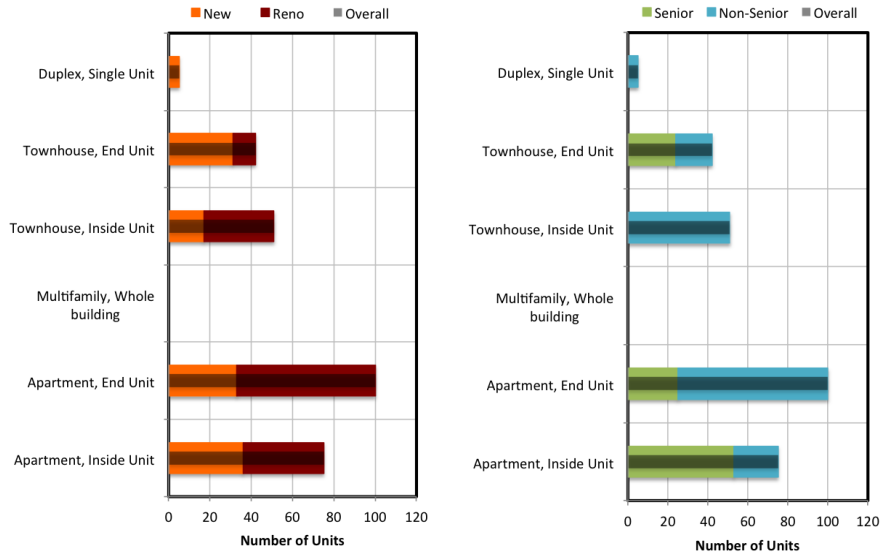
Number of Bedrooms in Sample

A majority of the number of bedrooms in units sampled is 1, with 2 being second by a slim margin. The new development sample contains more 2 bedroom units compared to the renovated development sample which contains a majority of 1 bedroom units. Renovated units also contain a considerable amount of 2 and 3 bedroom units in the sample. The senior development sample is 1 bedroom by majority compared to the non-senior development sample which has a majority of 2 bedroom units with 3, 4 and 5 bedroom units present.

Figures 17 & 18: Number of Bedrooms in New vs. Reno and Non-Senior vs. Senior
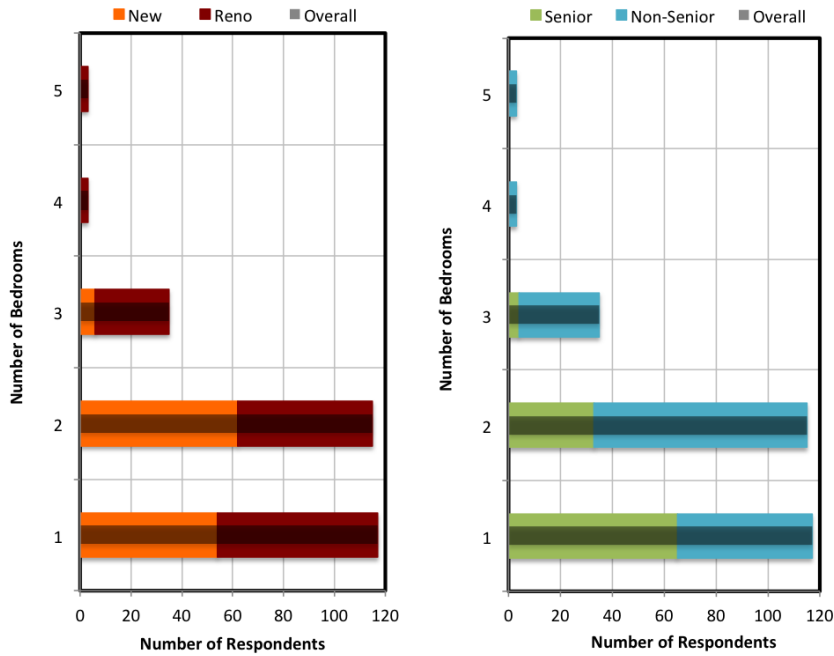
Housing Satisfaction of Sample

Across the sample, residents are more satisfied with the affordable, energy efficient housing in this study than their previous housing. Many more of the renovated unit sample reported the "same" satisfaction. Similarly, the non-senior sample contained many more "same" satisfaction responses.
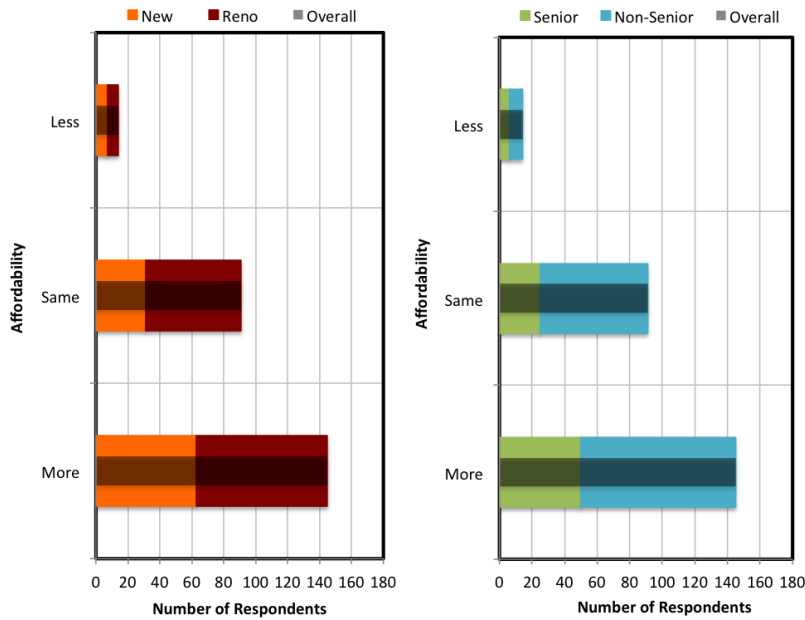
Figures 19 & 20: Housing Satisfaction in New vs. Reno and Non-Senior vs. Senior
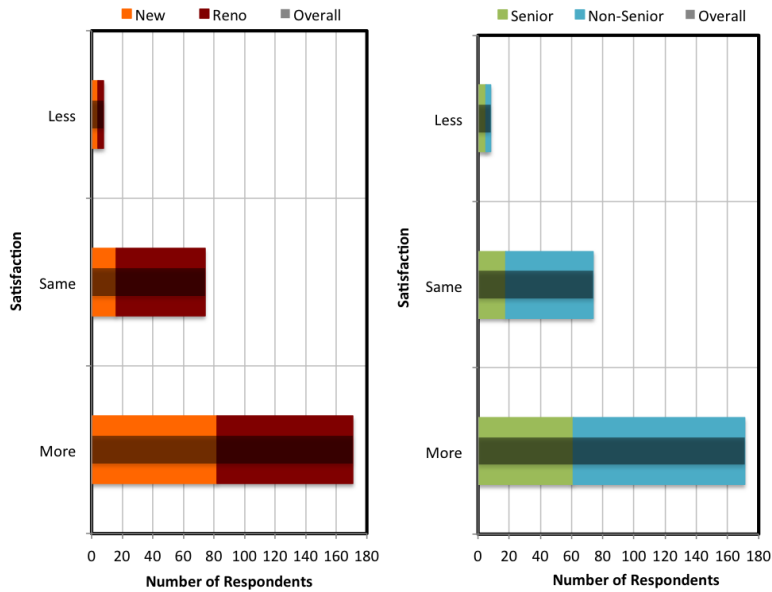
Housing Affordability of Sample

Similar to housing satisfaction, a majority of residents consider their current housing more affordable than their previous housing. It is notable that more people consider the housing at the "same" level of affordable than in the satisfaction responses. The sample also has more instances of "less affordable" responses, although still very few. A majority of new and renovated units, senior and non-senior units report as "more affordable." The non-senior, renovated units report the most "same and less affordable" responses in the overall sample.

Figures 21 & 22: Housing Affordability in New vs. Reno and Non-Senior vs. Senior

Utility Affordability of Sample

A majority of residents consider utilities in their current housing more affordable than their previous housing. Similar to housing affordability, those people who consider utilities "less" affordable are more than in the satisfaction responses, while still less than 10% of the sample. A majority of new and renovated units, senior and non-senior units report "more affordable" utilities. As with housing affordability, non-senior, renovated units report the most "same and less affordable" responses in the overall sample.
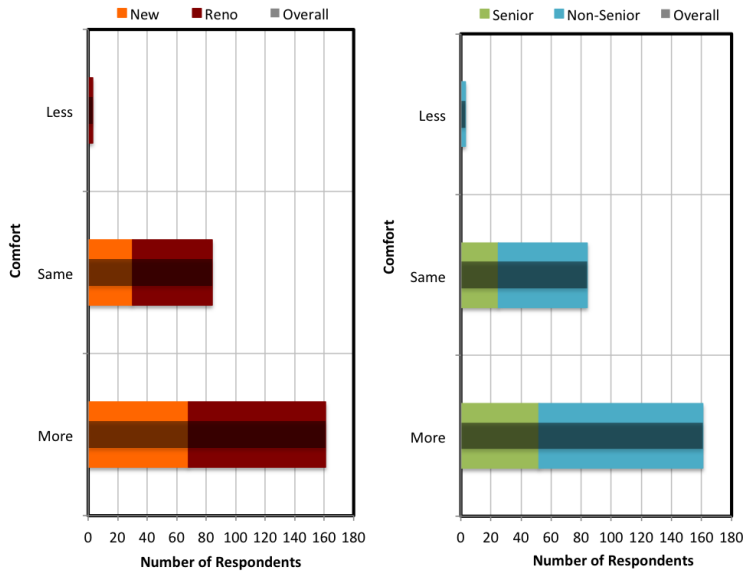
Figures 23 & 24: Utility Affordability in New vs. Reno and Non-Senior vs. Senior
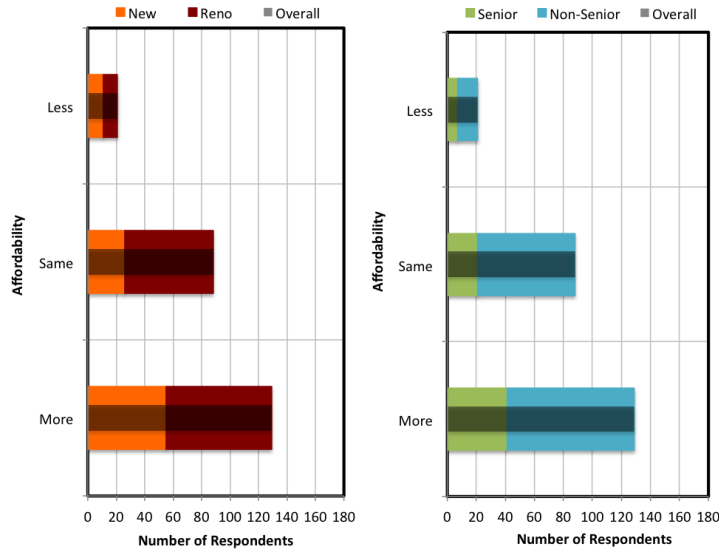

Summer and Winter Comfort of Sample

A majority of residents consider their current housing more comfortable in the summer than their previous housing. Very few consider the housing to be "less comfortable" in the summer. The renovated and non-senior unit samples contain the majority of those responses who consider the housing to be "same" in terms of comfort with non-senior unit samples reporting the majority of "more" in terms of comfort.

Figures 25 & 26: Summer Comfort in New vs. Reno and Non-Senior vs. Senior

Like summer, a majority of residents consider their current housing more comfortable in the winter than their previous housing. Very few consider the housing to be "less comfortable" in the winter. The renovated and non-senior unit samples contain the majority of those responses who consider the housing to be "same" in terms of comfort with non-senior unit samples reporting the majority of "more" in terms of comfort.

Figures 27 & 28: Winter Comfort in New vs. Reno and Non-Senior vs. Senior
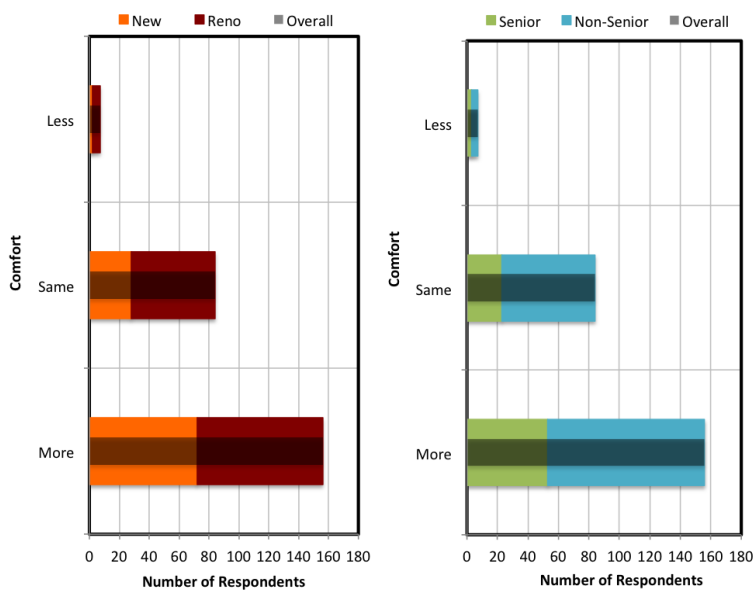
Summary of Sample Trends

The make-up of a housing unit, in terms of age, can have an effect on appliance use, thermostat settings, and hot water use (among other factors), all of which affect energy use. The ages of 30 to 59 represent a majority of the sample. 135 Respondents are 60 and above, a close second in total number. The new development sample contains 155 people compared to the renovated development sample, which contains 292 people. Renovated units in the study also account for a majority of the under 5, 5 to 9, 10 to 19 and 20 to 29 age ranges.

Like insulation values (wall or ceiling) the location and orientation of the housing unit can have an effect on energy consumption and is therefore noteworthy. The majority of the housing types sampled are apartment end units which contain the most surface area (or thermal enclosure) exposed to ambient conditions (compared to interior, middle floor units). Apartment inside units are a close second. The renovated sample includes many townhouse inside units and apartment end units while the new unit sample is relatively evenly spread between townhouse and apartment end units and apartment inside units. Non-senior units are mostly townhouse inside units and apartment end units while senior respondents are a majority of apartment inside units. Combining data on the differences in insulation values and the mix of unit locations suggests a possible reason for the variability of actual versus designed energy use.

The number of bedrooms increases the footprint of conditioned space, which can affect the overall and normalized energy use of the unit. A majority of the number of bedrooms in units is 1, with 2 being second by a slim margin. New construction contains a majority of 2 bedroom units, renovated developments contain a majority of 1 bedroom units and a considerable amount of 2 and 3 bedroom units in the sample. The senior development sample is 1 bedroom by majority. Non-senior developments have a majority of 2 bedroom units with 3, 4 and 5 bedroom units present.

Residents report being more satisfied with their current housing than previous housing. While a minority, the renovated and non-senior units report more "same" satisfaction, as opposed to "more." Many reasons could exist for a lack of "more" satisfied responses: for example, renovated units place residents back into the same development as before.

A majority of residents consider their current housing and utilities more affordable than their previous housing, while those reporting "same" level of affordability increases over the satisfaction responses. Non-senior, renovated units report the most "same and less affordable" housing affordability responses in the overall sample. Those who consider utilities "less" affordable are less than 10% of the sample. A majority of new and renovated units, senior and non-senior units report "more affordable" utilities. As with housing affordability, non-senior, renovated units report the most "same and less affordable" responses in the

overall sample. In some cases, residents reported confusion regarding a "utility" bill versus a "light" bill, which could be skewing these results. It is also possible that residents are not noticing the benefits of the energy efficient systems, similar Jevons paradox where improvements in technology cannot be relied upon to reduce fuel consumption.

Comfort in the summer and winter can be a determining factor in housing energy consumption and is therefore important to gauge. For example, one might expect that "hot spots" or pockets or warm walls from lack of insulation or thermal bypasses common in attached housing could reduce comfort for occupants in the units. A majority of residents consider their current housing more comfortable in the summer and winter than their previous housing. Very few consider the housing to be "less comfortable." In summer, the renovated and non-senior units report the majority of "same" with non-senior unit samples reporting the majority of "more" in summer. The renovated and non-senior unit samples contain the majority of winter "same" comfort responses with non-senior unit samples reporting the majority of "more" in winter.

Describing the Behavior

Characterizing behavior in the overall sample and sample groups is also important. Reported behavior by residents provides additional variables that could impact energy consumption. The following section reports on individual unit responses, totals units across the overall sample and separates resident responses by sample group like previous sections. Following the section is a reporting of trends across behavior responses.

Thermostat Settings in the Summer

A total of 111 residents report keeping their thermostat between 68 - 72 degrees in the summer and represent a majority of thermostat settings in the sample. A close second in thermostat settings is between 72 - 75, representing the other side of the central tendency. Another way to view this behavior is that few residents keep their thermostat below 68 and above 75 in the summer. The renovated and non-senior development samples contain the most responses below 72 degrees, a common threshold for summer thermostat setting.

Figures 29 & 30: Thermostat Settings in Summer in New vs. Reno and Non-Senior vs. Senior
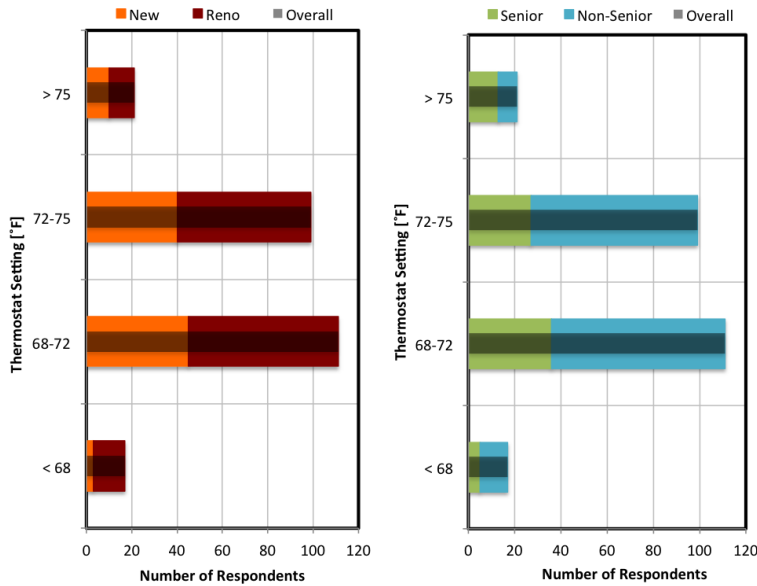
Thermostat Settings in the Winter

A total of 118 residents report keeping their thermostat between 72 - 75 degrees in the winter and represent a majority of thermostat settings in the sample. Second in thermostat settings is between 68 - 72, with many more residents reporting a winter thermostat setting of above 75 degrees. Another way to view this behavior is that few residents reported keeping their thermostat below 68 in the winter. The non-senior development samples contain the most responses above 68 degrees, a common threshold for a winter thermostat setting in energy efficient housing.

Figures 31 & 32: Thermostat Settings in Winter in New vs. Reno and Non-Senior vs. Senior
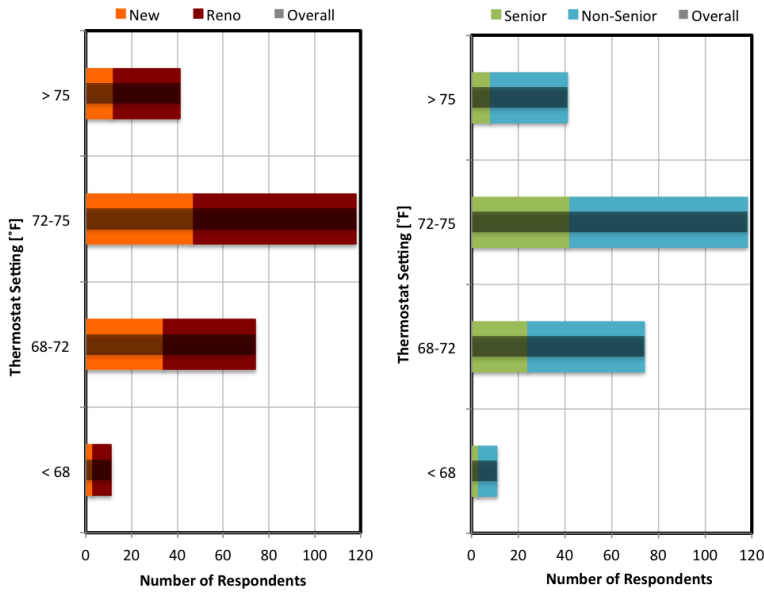
Reported Window Usage

164 residents report opening a window during one part of the year. A majority of residents report opening a window in the Spring with the Fall and Summer being close seconds. Many fewer residents report opening a window in the winter. The non-senior group contains the most reports of a window open.

Figures 33 & 34: Window Usage in New vs. Reno and Non-Senior vs. Senior
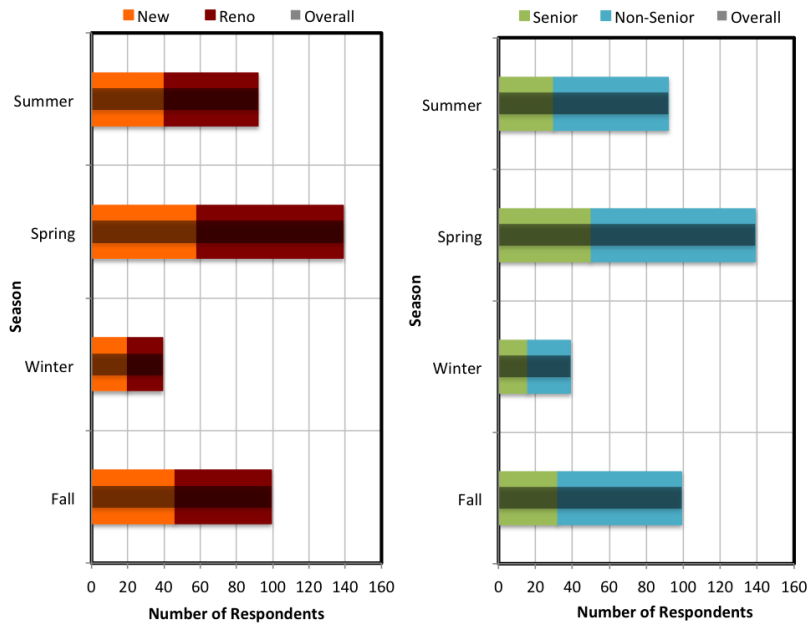
Reported Noise Disturbance

A majority of residents report never having a noise disturbance. Some developments contain a considerable amount of noise disturbance sometimes with many less reporting frequent noise disturbance. If frequent noise disturbance were common, one might expect that the walls would also contain considerable thermal bridging and/or lack of insulation, which is not the case in our sample.

Figure 35: Noise Disturbance
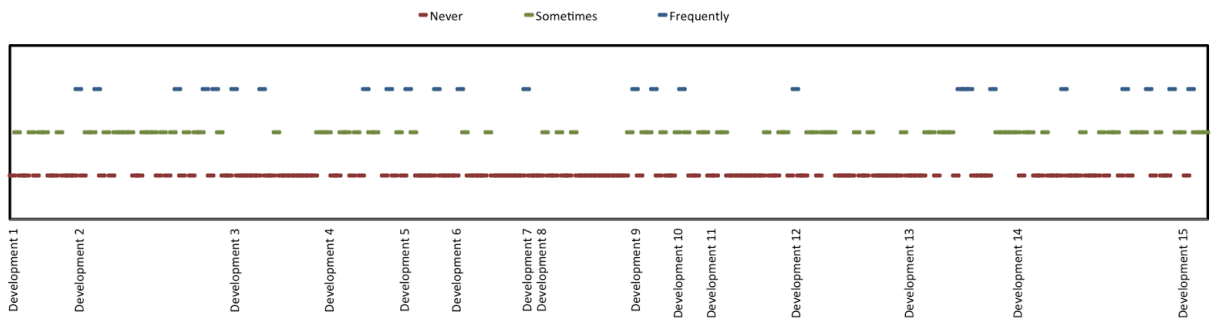
Reported Humidity Preference

While the ability to gauge medium versus dry interiors is difficult in a survey questionnaire, residents report that a majority do not prefer the interior of their unit to be humid. That said, a majority of residents report "medium" humidity in the unit, as opposed to "dry" conditions.

**Figures 36 & 37:** Humidity Preference in New vs. Reno and Non-Senior vs. Senior
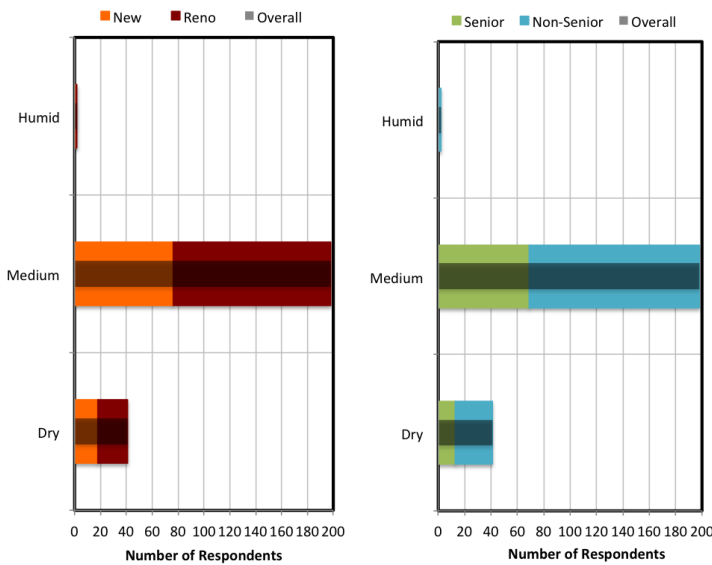
Reported Shower Length

Shower length, especially if hot in temperature, requires more energy by the water heater, an appliance that typically uses high amounts of energy in the home on average. A majority of units report medium length showers. Many units report short showers with fewer reporting long showers.

Figures 38 & 39: Shower Length in New vs. Reno and Non-Senior vs. Senior
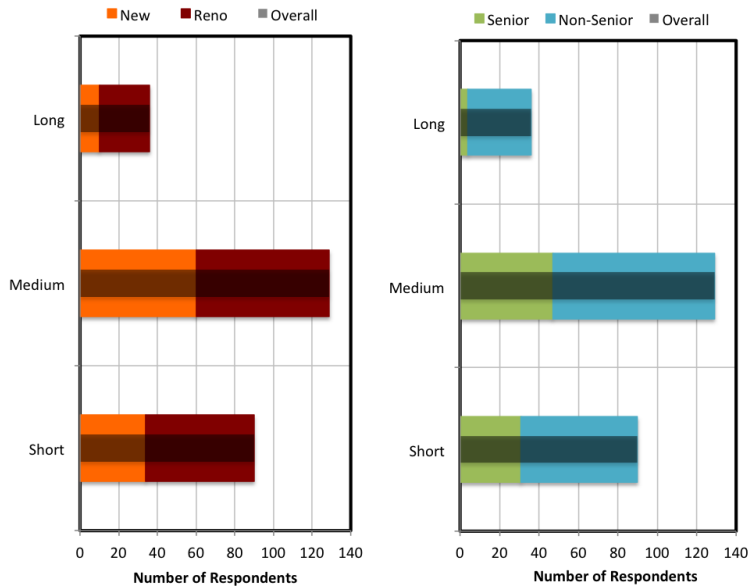
Reported Dishwasher Use

Similar to shower length, washing dishes by hand requires hot water from the water heater and could consume more energy and be less efficient. 164 residents report washing dishes by hand including the non-senior sample with families in the unit.

Figures 40 & 41: Dishwasher Use in New vs. Reno and Non-Senior vs. Senior
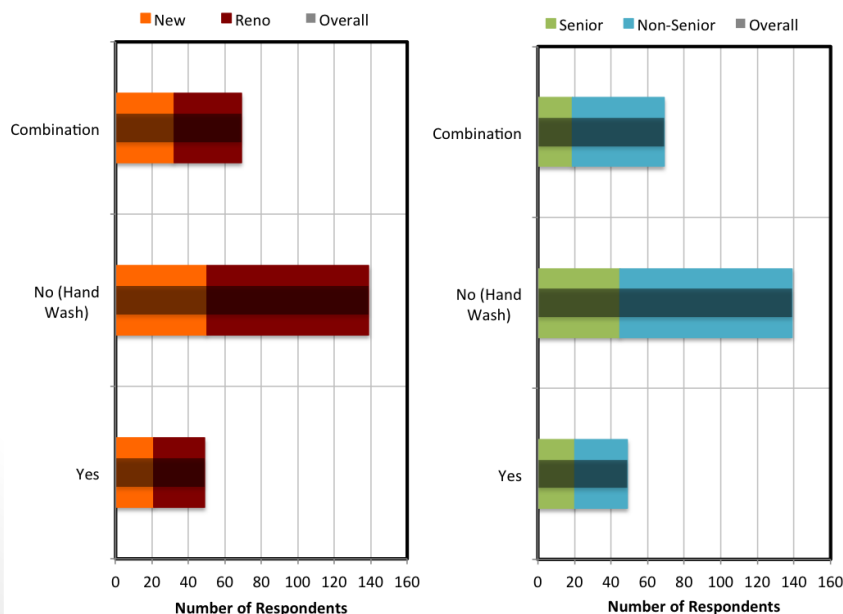
Reported Washer and Dryer Use

150 units, or a majority of residents, report no washer and dryer being in the unit. Few hang dry their clothes after using the washer, while many report both using the both a dryer and washing machine, even if not in the unit. Nevertheless, the sample units in this study do not contain a large amount of washing machine or dryer use and therefore utility consumption.

Figures 42 & 43: Washer and Dryer Use in New vs. Reno and Non-Senior vs. Senior
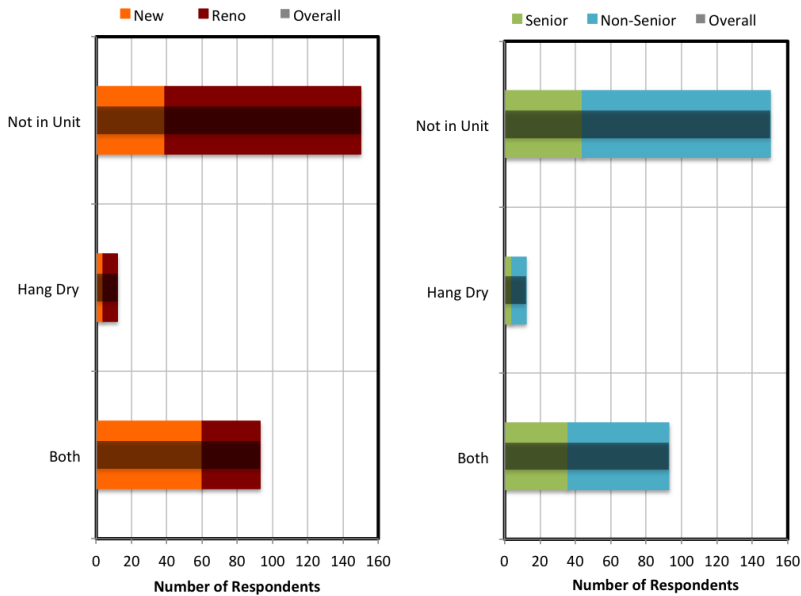
Reported Education
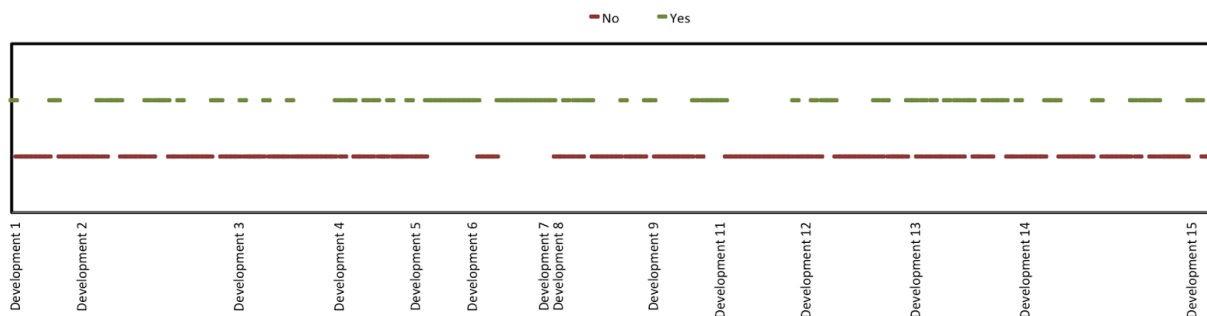
A majority of residents report no education on the technology placed into the unit. Anecdotally, education of the residents seems to be one area where much improvement could happen, even at a basic level. When researchers talked with managers, however, they explained and educated residents on the technologies involved in their units. Nevertheless, residents still seem to lack understanding.

Figure 44: Resident Education

Summary of Behavior Trends

Resident behavior regarding thermostat set points is contrary to our expectations. A majority of residents report a thermostat range between 68-72 degrees in the summer, with few residents reporting their thermostat above 75. The renovated and non-senior development samples contain the most responses below 72 degrees. A majority of residents keep their thermostat between 72 - 75 degrees in the winter with some residents reporting a winter thermostat setting above 75 degrees. Another way to view this behavior is that few residents report keeping their thermostat below 68 in the winter. These set point findings suggest that there could be an impact on dew point for units, increasing the potential for moisture problems and interstitial condensation risks, which could also affect long-term durability and health. Further, estimated modeling outputs assume a thermostat setting of 70 degrees in the winter and 75 degrees in the summer based on energy modeling best practices. These set points should provide comfort in high performance homes. Therefore, behavior could indicate a need for updating energy modeling best practices related to high performance settings and affordable housing.

164 units report opening a window during one part of the year: a majority in the Spring with the Fall and Summer close behind and few residents reporting opening a window in the winter. The non-senior group contains the most reports of a window open.

Noise disturbance is one way of determining wall and window specification and construction quality. A majority of residents report never having a noise disturbance. Some developments contain a considerable amount of noise disturbance sometimes with many less reporting frequent noise disturbances. If frequent noise disturbance were common, one might expect that the walls would also contain considerable thermal bypasses due to improper air sealing or a lack/improper installation of thermal or sound attenuation insulation, which is not the case in our sample.

Elevated levels of humidity can highly affect the durability of above-code green construction in the long term (the authors acknowledge that a certain amount of humidity is expected in the unit). Relative humidity (RH) in a unit is often affected by outside conditions and interior infiltration, showers, breathing/sweating and cooking. Further, the capacity to dry the interior of a unit is reduced in high performance housing due to the reduction of natural air changes. A majority of residents report that they do not prefer a humid interior environment, though. While the ability to gauge medium versus dry interiors in a survey format is difficult, findings suggest that a majority of residents do not keep a "dry" environment. A majority of units report medium length showers, with many reporting short showers and fewer reporting long showers.

Based on RH and shower length, the concern over the increased latent load in efficient housing combined with the lack of measured resident education makes it critical that high-performance project teams incorporate technologies that are capable of increasing the control of unit-level relative humidity to ensure building durability and promote occupant health. For example, current health science guidance from ASHRAE 62.2 for relative humidity (RH) ranges in housing is 40-55%, within the range of our findings. Nevertheless, designers and constructors of affordable housing probably do not expect residents to be intentionally adding additional RH to the unit.

A majority of residents (164) report washing dishes by hand, including the non-senior sample with families in the unit. Fewer report a combination of dishwasher and hand washing of dishes, suggesting that respondents use more hot water in washing their dishes.

The washer and dryer appliances can also represent a large part of monthly energy consumption. A majority of residents report no washer and dryer in the unit and therefore do not represent a large amount of utility consumption within the energy footprint of this study.

Despite management's explanations of technology in the units, a majority of residents report no education and feel that they lack understanding of the technology in the unit. As advanced technology becomes further integrated into the unit, education of the resident in using technology becomes more critical. As our population ages and seniors become more reliant on technology for their health and wellbeing in the unit, education again seems to be a large area of need.

In many cases high performance design and construction is adding systems (heat pump water heaters and fresh air systems) to which maintenance staff and residents may not have been previously exposed. EarthCraft Virginia often calls this phenomenon "giving someone keys to a new car when they don't have a drivers license." Resident education could bridge the gap between design/construction and maintenance/management as well, making sure all

involved understand the benefits of the systems. Operating and maintaining systems per manufacturer requirements helps promote equipment durability, should reduce operating costs for owners and equate to lower utilities for residents.

Modeling Correlates of Technology and Behavior

Recall that the purpose of this statistical exercise is to select a subset of predictors that describe energy usage based on the observed data. For these exercises, energy usage was divided by conditioned area. A full list of candidate variables for the modeling is as follows: IC_ACH; foundat; WH_type; WH_size; V_type; P_cool; C_R; S_attic_R; AG_R_value; S_edge_R; S_under_R; W_SHGC; Int_light; Ref; WH_EF and D_EF. Not every variable collected was included in the candidate list due to statistical dependencies among candidate predictors.

After using complete case deletion, there are 222 observations subjected to the selection routine. Statistical variable selection based on the Bayesian Information Criterion[4] as used to reduce the larger list of candidate predictors down to Water heater efficiency, Infiltration rate, sealed attic R-value, foundation type, ventilation type, window solar heat gain coefficient, and percent interior lighting. Briefly, BIC is a statistical measure that favors simpler but more predictive models by weighing the likelihood of a given model including a penalty for additional parameters. BIC was used as the criterion within a stepwise selection procedure to choose a final set of predictors. The adjusted r-square is 0.94 for this model, indicating that this model accounts for 94% of the variability in these simulated usage data. The semi-partial eta-squared values for Water heater efficiency, Infiltration rate, sealed attic R-value, foundation type, ventilation type, window solar heat gain coefficient, and percent efficient interior lighting are 36%, 8%, 16%, 7%, 1%, and 3% respectively.

Model 2: Observed energy use

Statistical variable selection based on the Bayesian Information Criterion resulted in a model that included ventilation type, refrigerator efficiency, slab edge, and the number of people in the unit as predictors for observed energy usage. Model selection proceeded as described above. The adjusted r-square value for this model is 0.27, indicating that within these data, 27% of the variability in observed usage is attributable to the predictors which were selected for the model. Semi-partial eta-square analysis was conducted to further attribute this predictive performance to the individual model variables. Ventilation, refrigerator efficiency, slab, and people in units accounted for 20%, 5%, 3%, and 4% of

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[4] Schwarz, Gideon. Estimating the Dimension of a Model. Ann. Statist. 6 (1978), no. 2, 461--464. doi:10.1214/aos/1176344136. http://projecteuclid.org/euclid.aos/1176344136.

variability respectively. Units with an Air cycler exhibited greater efficiency than units with none, exhaust only, and balanced ventilation systems, but not as efficient as supply only. Perhaps surprisingly, units with refrigerators with 501-600 kWh used less energy than units with less than 400 kWh refrigerators, even though the former is a more efficient appliance. One speculation is that this finding could be a senior/handicap (500+kWh ADA appliance) not having as many trips inside the appliance compared to a non-senior/family apartment with more residents using a more efficient appliance. The significance could also be due to other characteristics of those units that happened to have more efficient refrigerators, and this results merits further investigation. Other refrigerators ratings were sparsely represented in these data and therefore excluded from this analysis. The number of people inhabiting a unit was positively associated with energy usage, meaning more people in the unit leads to an increase in energy use on average. Lack of slab-edge insulation indicated lower energy use than units with increased slab insulation, and this may be due to the interior/non-interior status of the units.

Model 3: Comparison of observed and simulated use

Modeling observed usage as a function of simulated usage alone indicates that only .4% of the variability in observed usage can be accounted for from the simulated values. Despite this low individual association, simulated energy usage (normalized by conditioned area) survives statistical model selection. Entering simulated use as a candidate predictor results in a model that includes Ventilation, slab, people in unit, simulated use, water heater and Dryer efficiency. The adjusted r-square for this model is 0.376, indicating about 40% of the variability in this response can be accounted for by the model. Individual variability accounted for by Ventilation, slab, people in unit, simulated use, water heater and Dryer efficiency was 24%, 4%, 6%, 7%, 4%, and 3% respectively. The ability of the simulated data to work in concert with other predictors to enhance prediction of observed usage is a potentially useful application of the simulation approach.   In other words, simulation software and the efficiency measures most affecting energy use should be aligned for better tracking of useful analysis in future work. Deciding on a central set of indicators that all simulation software deems appropriate for modeling seems to the first step in this direction.

Discussion of Local Affordability

In the coming section we describe energy cost savings of the data sample based on local affordability data and the latest energy costs averaged across the Commonwealth of Virginia for October 2014 (http://www.eia.gov/). All of the projects studied are within Virginia yet contain unique market area characteristics that make affordability differ at a local level. The researchers collected American Community Survey data to better define each locality across

project sites. In order to have a consistent field of data, we used the 2012 5-year estimate and demographics on place, county and MSA level. With a better understanding of affordability characteristics, one can get a complete picture of the effects energy efficiency could have on a local affordable housing market.

We first looked at the local median renter occupied income for renter occupied households per development location. Table 22 lists median renter occupied income for each development.

Table 22: Median Renter Occupied Income

	Project Location	Town AMI	County AMI	MSA AMI
Median Renter Occupied Income	Arlington	$79,831.00	$79,831.00	$64,450.00
	Chesapeake	$40,206.00		$38,033.00
	Virginia Beach	$46,961.00		$38,033.00
	Christiansburg	$34,923.00	$23,059.00	$22,321.00
	Lynchburg	$23,519.00		$25,521.00
	Orange	$27,762.00	$36,949.00	
	Petersburg	$24,153.00		$34,909.00
	Richmond	$26,371.00		$34,909.00
	Scottsville	$31,786.00	$41,362.00	$36,895.00
	Wytheville	$18,715.00	$24,129.00	

Admittedly, calculating cost savings and its effect on local affordability is a rough measure, so we chose to use a conservative approach. In table 23, we list the estimated energy use for standard new construction per month by development (A). Here, we caution the reader that the average energy use is relative to the number of units collected, the size of the unit, the number of people in the unit and various other possible reasons for its measure. Column A should not be seen as a local average, for example, and is a variable and relative number.

We derive column A from the Wegowise data of actual energy use on average per unit per development (column B). Column B is 60% of column A based on the 40% savings reported

earlier in our findings over new standard construction units (observed energy use averaged 16.6% over estimated energy use, which was 30% more efficient than new standard construction on average). Column C is energy savings per month per unit or the difference between column A and B.

Table 23: Median Renter Occupied Income Energy Savings in kWh

		(A)	(B)	(C)
Project Location	**Town Median Renter Income**	**Estimated Energy Use for Standard New Construction in Locality in kWh**	**AVG Monthly Energy Use in Sample Locality in kWh**	**Energy Savings per Month (kWh)**
Arlington	$79,831.00	315	189	126
Chesapeake	$40,206.00	1097	658	439
Virginia Beach	$46,961.00	962	577	385
Christiansburg	$34,923.00	648	389	259
Lynchburg	$23,519.00	1230	738	492
Orange	$27,762.00	603	362	241
Petersburg	$24,153.00	730	438	292
Richmond	$26,371.00	905	543	362
Scottsville	$31,786.00	718	431	287
Wytheville	$18,715.00	815	489	326

In table 24, column A is copied directly from the previous table. Column B is calculated using the most recent energy costs averaged across the Commonwealth of Virginia for October 2014 (http://www.eia.gov/), which was a rate of $.1167/ kWh. Columns C, D and E further break down these cost savings at 30%, 50% and 80% of Town median occupied renter income for each location respectively, assuming that renters pay 30% of monthly income towards housing costs.

Table 24: Median Renter Occupied Income Energy Savings in kWh

Project Location	Town Median Renter Income	(A) Energy Savings per Month (kWh)	(B) Energy Savings per Month ($)	(C) AVG Cost Savings @ 30% AMI	(D) AVG Cost Savings @ 50% AMI	(E) AVG Cost Savings @ 80% AMI
Arlington	$79,831.00	126	$14.70	2.45%	1.47%	0.92%
Chesapeake	$40,206.00	439	$51.19	16.95%	10.19%	6.37%
Virginia Beach	$46,961.00	385	$44.89	12.75%	7.65%	4.78%
Christiansburg	$34,923.00	259	$30.26	11.54%	6.93%	4.33%
Lynchburg	$23,519.00	492	$57.42	32.6%	19.53%	12.21%
Orange	$27,762.00	241	$28.16	13.53%	8.12%	5.07%
Petersburg	$24,153.00	292	$34.08	18.82%	11.29%	7.05%
Richmond	$26,371.00	362	$42.25	21.34%	12.82%	8.01%
Scottsville	$31,786.00	287	$33.53	14.08%	8.44%	5.27%
Wytheville	$18,715.00	326	$38.04	27.17%	16.26%	10.16%

The approach to calculating savings presented above has limitations, though. All costs are based on median renter income, the sample for this study, and would differ for area median income, a common number used in affordable housing. Median renter household income are the most applicable numbers to use since they give the best picture of renter income in the area as opposed to the median family income which would also include owner occupied households. Median household income for renters may seem low because it includes one person households and households with multiple unrelated individuals (age 15 old and over). Another limitation could be the size of the unit, the make-up of the unit and the number of units collected by location. For example, Arlington shows a low energy use, which could be due to technology but is also likely due to the lower amount of data points for this location. That said, Arlington would likely only increase in energy usage and therefore increase its share of percentage of monthly household payments.

Conclusions

The research addresses key policy issues related to EE and affordable housing. The research provides policy makers with a rigorous quantification of gross and net economic impacts of EE affordable housing on low-income occupants, distinguishing the effects of new construction and EE designs and systems.

Since 2006, AEC firms are increasingly putting their employees through certification training, certifying projects at increasingly higher levels and showing internal commitment to sustainable principles (Yudelson 2008). While designing and building to a certified standard is now the price of admission for the industry at large, "the differentiating point is clearly now on results."

The purpose of this report is to identify and verify possible benefits of the shift in housing policy to encourage energy efficiency (EE) in the affordable rental stock in Virginia through the LIHTC program. The research focuses on results from the use of an energy efficiency design and construction standard for LIHTC residents in terms of reduced energy use (and therefore utility costs). In addition, the research addresses how the policy to use EE might impact developers and owners in terms of property capital and operating costs. This study focuses specifically on facilities constructed to the EarthCraft Virginia standard, one of the only datasets currently available that allows for this type of inquiry.

As previously described, the research design includes controls for pre-and-post-occupancy of EarthCraft Virginia structures in the Low-Income Housing Tax Credit program (LIHTC) program across the Commonwealth of Virginia. The work is limited in that it does not include controls for non-EE and EE units outside the affordable rental stock and is limited in sample size. Nevertheless, the authors cannot find previous work that has been able to establish a sample as large and comprehensive in data records as in the previous pages. Hard data for measuring EE ROI is difficult to explain and produce. Our work aims to change that difficult reporting of data.

Defining the Market for this Work

Green building has been defined in many ways and via many means. Yudelson (2008) was relatively comprehensive in his definitions as follows:

- ✓ "A green building is one that considers and reduces its impact on the environment and human health. A green building is designed to use less energy and water. This is achieved through better development practices, design, construction, operation and maintenance."

✓ "A green building is one using design and construction practices that reduce or eliminate negative impacts of buildings on the environment and occupants."

Based on Yudelson's definitions, findings indicate that the sample of our study does indeed fit the definition of green building. In fitting our study to the growing body of research that defines green building, we will be able to apply findings broadly and integrate this work across many different fields. While previous research and green building programs have focused on leading edge projects, which were 25% of the market, this work further opens the scope of available green buildings through the field of affordable housing.

Some previously theorized that the "bar" would continue to be raised by leading edge projects. Our study looks at that "bar" from the standpoint of energy use and major areas of future growth in the market of affordable housing- senior versus non-senior and new versus renovation.

Energy Use and Savings

Previous research has estimated that using high-performance energy design and construction techniques would save 25-30% of energy use over conventional building practices. As building code becomes more stringent, this number might become more elusive, or diminish as leading edge simply becomes standard. For now, though, how do our numbers compare?

Findings indicate that average energy usage for developments sampled is 553 kWh per unit per month. This amount is 16.6% less than estimated per unit and approximately 30% less than standard new housing at the time that these developments were built. Based on an energy rate of $.1167/ kWh for the Commonwealth of Virginia in 2014 (http://www.eia.gov/), this equates to a savings of $54 per month on average (553 kWh is 46.6% of 1017 kWh/month X $.1167/kWh). If the 2014 AMI for Virginia was $77,500 for a family of four, these cost savings would equate to $648/year.

While many view EE savings as an addition to income, thereby increasing the ability of the household to afford housing (or anything), we propose the impact on affordability from EE in a different light. A Virginia household at 30% AMI has an annual income of $23,250 — that's $1,938 per month. That household can afford to pay 30% for shelter costs, or $581.25. If EE can save them $54 on their energy bill, it has increased their ability to afford housing by ($54/$581.25 or) 9.3%. For households at 50% AMI, the savings equal 5.6% and for households at 80% AMI it is 3.5%.

Our findings suggest an opportunity for the research to help inform and calibrate energy code moving forward. Estimated model average variability suggests that design and construction for energy efficient units could be performed within tighter and more consistent

values across the sample, which would result in increased overall unit efficiency. Regarding energy use, sample groups, such as new versus renovated units and senior versus non-senior, contain internal variability while not ranging far from the overall sample average suggesting common factors to the affordable housing population. Variability is not increased by square footage, yet the number of people in the unit does seem to affect use. Research therefore suggests opportunity for improved modeling tools.

A recent NY Times Article on fuel prices discusses the impact of savings for lower-income groups in the US (Cardwell and Schwartz, January 17, 2015). According to the article, "the latest drop in energy prices — regular gas in New England now averages $2.35 a gallon, compared with $2.94 in early December, and it is even cheaper in the Midwest at $1.95 — is disproportionately helping lower-income groups, since fuel costs eat up a larger share of their more limited earnings.

While the global oil prices have recently been lowered, future volatility in energy costs is possible. The more owners and residents can affect energy use and understand its side effects, the more that housing will need to design and build for less use.

Defining the Technologies

The units sampled in this study contain the following average characteristics in their inclusion of technologies, all of which might affect energy use:

- ✓ The new development sample contains 58% slab, 33% above conditioned space and 9% conditioned basement. The renovated development sample contains 79% slab, 21% above conditioned space and 0 conditioned basement.

- ✓ The majority of water heaters are 40-59 gallons in size. Current specifications show that Energy Star water heaters of this range in size consume approximately 4622 kWh per year and cost $492 - $531 per year to operate (based on 2007 national average electricity cost of $.107 per kWh). The senior sample group contains smaller water heater tanks and the renovated sample group contains the largest water heater units.

- ✓ The average level of duct leakage in the overall sample is 24.9 CFM25 with the senior and new construction developments containing the lowest amount of leakage in CFM25 on average, meaning, on average the sample is built to high performance standards with which the industry agrees.

- ✓ A majority of sample units contain no ventilation system. New units have the most amount of ventilation systems(while this could be the result of an energy penalty in the modeling), with renovated units containing the least reported systems.

✓ A majority of sample units contain a programmable thermostat for setting temperature in the unit.

✓ A majority of sample units contain highly insulated ceilings above an R-value of 30. New and senior units report the most instances of "none" and could be losing energy efficiency as a result.

✓ A majority of units contain an R-value of 13-18 in the walls above grade. The renovated and non-senior units contain the lowest R-value in above-grade wall insulation.

✓ A majority of sample units contain no R-value at the slab-on-grade edge and/or under the slab-on-grade, likely due to the interior location of the units.

✓ A majority of sample units contain a U-value of 0.4 - 0.5 in the windows. Renovated and non-senior units contain the least amount of insulation in terms of window assembly U-value. Almost no units tend to have higher U-values than 0.5.

✓ A majority of sample units contain a SHGC value of 0.35 - 0.5 in the windows. Renovated and senior units contain the most units with SHGC above 0.5.

✓ Surprisingly, the sample units are relatively evenly spread across many levels of air infiltration and do not contain a majority of the sample in the lowest levels of infiltration. New and senior units contain the tightest construction enclosures, based on air infiltration rates.

✓ A majority of sample units contain 100% efficient interior lighting. Renovated and senior units contain the least amount of efficient interior lighting, but not by a large margin.

✓ A majority of sample units contain efficient refrigerators that use less than 400 kWhs per year. Renovated and senior units contain the most refrigerators at the lowest level of efficiency (highest level of energy usage).

✓ 73% of sample units contain efficient dishwashers with new and non-senior units containing the most by a slim margin and Renovated and Senior units containing the least.

✓ Of sample units, the average level of dryer efficiency (in terms of pounds/kWh) is 2.86 exceeding the DOE 2011 standard for efficiency, while not the 2015 amended standard.

New Construction Developments

The *new construction development* sample of units is estimated to use 4.7% less energy than the overall sample, actually uses 8% more energy than overall average sample and uses 4.7% more energy than the overall average sample based on square footage.   New development actual energy usage contains higher variability per unit than the average unit. The new unit sample is relatively evenly spread between townhouse and apartment end units and apartment inside units. New construction contains a majority of 2 bedroom units.

Ventilation represents an energy penalty (adding load to the heating/cooling when conditioning outside air) in efficient housing. Anecdotally, designers and constructors report finding new ventilation systems cut off by maintenance staff after occupancy of the unit. If so, new construction energy variability could be due to proper/improper use of mechanical ventilation systems.

Renovation Developments

The *renovated development* sample of units is estimated to use 24.3% less energy than the overall sample, actually uses 5.3% less energy than overall average sample and uses 3.2% less energy than the overall average sample based on square footage. Renovated development actual energy usage contains variability, but it is lower on average per unit. Renovated units in the study account for a majority of the under 5, 5 to 9, 10 to 19 and 20 to 29 age ranges. The renovated sample includes many townhouse inside units and apartment end units. Renovated developments contain a majority of 1-bedroom units and a considerable amount of 2 and 3 bedroom units in the sample.

Senior Developments

The *senior development* sample of units is estimated to use 17% less energy than the overall sample, actually uses 7.8% less energy than overall average sample and uses 6.3% more energy than the overall average sample based on square footage. Senior development actual energy usage contains variability, but it is lower on average per unit.   Senior respondents are a majority of apartment inside units. The senior development sample is 1 bedroom by majority.

Non-Senior Developments

The *non-senior development* sample of units is estimated to use 16.5% less energy than the overall sample. It actually uses 4.7% more energy than the sample average and uses 4.8% less energy than the overall average sample based on square footage. Non-senior development actual energy usage contains higher variability per unit than the average unit. Non-senior units are mostly townhouse inside units and apartment end units. Non-senior

developments have a majority of 2 bedroom units with 3, 4 and 5 bedroom units present. The non-senior group contains the most reports of a window open during the year.

While a minority, the renovated and non-senior units report more "same" satisfaction, as opposed to "more" in their current housing satisfaction, the most "same and less affordable" housing affordability responses in the overall sample and consider utilities "less" affordable, while less than 10% of the sample.

Very few consider the housing to be "less comfortable." In summer, the renovated and non-senior units report the majority of "same" with non-senior unit samples reporting the majority of "more" in summer. The renovated and non-senior unit samples contain the majority of winter "same" comfort responses with non-senior unit samples reporting the majority of "more" in winter.

Behavior Trends

Thermostat set points are contrary to researchers' expectations. Few residents report their thermostat above 75 in summer and few residents keep their thermostat below 68 in the winter. These set points should provide comfort in high performance homes. These set point findings suggest that there could be an impact on dew point for units, increasing moisture, which could also affect long-term durability and health. Further, estimated modeling outputs assume a thermostat setting of 70 degrees in the winter and 75 degrees in the summer. Behavior could indicate a need for different code requirements related to high performance settings.

Few residents report noise disturbance, which is one measure of higher quality construction in the sample. A majority of residents report that they do not prefer a humid interior environment, but do not keep a "dry" environment, and a majority of units report medium length showers, with many reporting short showers and fewer reporting long showers.

A majority of residents (164) report washing dishes by hand, including the non-senior sample with families in the unit, and few residents have a washer and dryer in the unit

Correlates of Energy Efficiency

Statistical modeling of energy use per unit used a dependent variable of average energy use per month divided by conditioned space in terms of square footage. The following percentages provide a rank order of the effect of the variables on energy use per unit.

In modeling estimated energy use, statistical values for water heater efficiency, infiltration rate, sealed attic R-value, foundation type, ventilation type, window solar heat gain coefficient, and percent of efficient interior lighting are correlated to 44%, 12%, 21%, 5%, 10%, 1%, and 0.3% of energy use respectively.

Modeling observed (actual) energy use, ventilation, refrigerator efficiency, slab, and people in units accounted for 20%, 5%, 3%, and 4% of variability respectively. Units with an air cycler exhibited greater efficiency than units with none, exhaust only, and balanced ventilation systems, but not as efficient as supply only. Perhaps surprisingly, units with refrigerators with 501-600 kWh used less energy than units with less than 400 kWh refrigerators, even though the former is a more efficient appliance. One speculation is that this finding could be a senior/handicap (500+kWh ADA appliance) not having as many trips inside the appliance compared to a non-senior/family apartment with more residents using a more efficient appliance. The significance could also be due to other characteristics of those units that happened to have more efficient refrigerators, and this results merits further investigation.

Including simulated usage as a predictor for observed energy use aims to draw determine whether energy simulation can contribute to the modeling of observed usage alongside technology and behavioral predictors. Inclusion of simulated usage in the model revealed that ventilation, slab, people in unit, simulated use, water heater and dryer efficiency in accounting for 24%, 4%, 6%, 7%, 4%, and 3% of variability respectively. We found that the ability of the simulated data to integrate well with other predictors would enhance prediction of observed usage and is a potentially useful application of the simulation approach for future work.

Barriers in the Market

Executives surveyed by Yudelson in 2008 were more aware of indoor air quality associated with green building and less aware of the energy and resource savings involved. The more executives were involved in green building projects, the more they believed in its value in terms of impact on health, wellbeing and economic benefits. The 2006 survey of 872 executives concluded that:

- ✓ 57% said initial cost was too hard to justify;

- ✓ 56% said they added significantly to first cost;

- ✓ 52% said the market would not pay a premium for these services;

- ✓ 36% said the process was too complicated with too much paperwork;

- ✓ 30% said the market was not comfortable with new ideas and technologies;

✓ Only 14% DID NOT see sustainable design as a market barrier.

Typically green buildings are measured against new standard construction based on price. While this study does not report cost differences of green versus non-green, other economic incentives are evident. Initial cost arguments are somewhat immaterial to the discussion, though. For example, LEED (commercial) in 2006 is now a "de facto" level of basic construction in terms of cost and quality. Owners, designers, builders and operators have been figuring out how to build high performance on a cost-friendly budget since the recession began in 2007. Long-term implications for operations and maintenance now make the economic returns understandable and feasible.

Previous work reported that "hard" data for measuring EE ROI is difficult to explain and produce. One way to encourage data that measures ROI for owners and managers is policy that would allow for easier unit-level data collection. For example, VHDA and developers could require lease agreements to capture this information at the time of leasing to allow for year-to-year tax credit pool analysis.

Owners are also beginning to see liability from "sick building syndrome" and unhealthy living environments due to the toxins in conventional buildings. Green building through an integrated and verified process could serve owners as a risk mitigation tool into the future. Recently, RESNET and REM/rate released an evaluation/development of multifamily (MF) specific standards and modeling protocols as additional tools to improve evaluation of buildings.

Regarding Third Party Agents for Green Building

While results from the study focus largely on a general understanding of benefits based on one certification "agent" in Virginia (EarthCraft Virginia), the technology and behavior studied in the work scale to all certification programs and adoption of innovative practices and policies in the larger AEC community. Yudelson (2008) states "as a design tool, green certification consultants (ECVA) have proven their value as an independent 3rd party to help organize the work of design teams tasked with creating green buildings." Results clearly indicate that the work of these agents is reducing energy use in the units over new standard housing. Green certification agents have proved their value as independent, third parties who help create green buildings. So, what is next? The variability in estimated energy use within the unit and actual energy use points to new directions. There exists a need for a concurrent process that integrates designers, contractors, managers and other stakeholders critical to estimating and implementing the long-term goals of a green building.

The process of commissioning a building is also an important reason for independent third party verification of green buildings and facilities. Without a well-orchestrated commissioning process the building cannot be guaranteed to perform the way it was intended. The units in this study perform as intended suggesting more reason to engage certification agents in future green developments. A "concurrent certification" process would need to begin early, continue throughout the design-build-operate process and can be measured along the way for better results in energy savings.

Certification agents are also ideal for educating operators and residents of a development. Managers insist that they are educating residents, yet the knowledge is not transferring, according to informal interviews with residents. As advanced technology becomes further integrated into the unit, education of the resident in using technology becomes more critical. As our population ages and seniors become more reliant on technology for their health and wellbeing in the unit, education again seems to be a large area of need.

In many cases high performance design and construction is adding systems (heat pump water heaters and mechanical fresh air systems) to which maintenance staff and residents may not have been previously exposed. EarthCraft Virginia often calls this phenomenon "giving someone keys to a car when they don't have a drivers license." Resident education could bridge the gap between design/construction and maintenance/management as well, making sure all involved understand the benefits of the systems. Operating and maintaining systems per manufacturer requirements helps promote equipment durability, should reduce operating costs for owners and equate to lower utilities for residents.

The Role of Policy

Government plays a strong role in supporting green building causes- incentives, cost relief, regulations and promotion. While our report is not focused on the benefits and barriers of these policies to the industry, data support a case for continuing such policies if solely on the basis of energy use and savings to the residents.

As a result, LIHTC programs beyond Virginia, with different climates that could benefit from reduced energy usage by residents, could see these reported findings as a means for guiding policy for LIHTC programs elsewhere. In addition, the findings could guide developers and property owners in benefits from implementing a green building protocol in the broader rental stock, by type and resident of those developments. The previously mentioned RESNET and REM/rate evaluation of Multi-Family-specific standards and modeling protocols will help with decision-making as we move forward.

Moving Forward

Moving forward, the groups poised to gain advantage from green building are the mechanical and electrical engineers and contractors in commercial facilities. Is that the case in residential? Maybe not immediately, as the technology is still relatively similar to previous technology, is not centrally maintained and operated and relies heavily on the resident use patterns. Still, education of the resident on these systems as they become more complicated is key to the success of the technology in having an effect on energy use.

Shared spaces and appliances are one direction forward (for example some developments currently share water heaters among multiple units). Could entryways and other appliances be shared into the future to reduce the load and isolate certain technologies that really could be better serving many instead of one? A central thermostat for shared spaces and corridors of buildings could change interior wall needs for thermal resistance, for example. The current research has not completely measured washer and dryer use and its impact on the amount of energy use per unit, as these are shared in central locations for residents. Many of the central facilities would be appropriate for renewable technologies as well, which some developers are using as the price becomes affordable.

The future might provide a job market for "performance specialists" who work with homeowners and contractors to guarantee a certain amount of energy usage, within a range, and require that certain details are followed. Auditors in today's market have not yet been able to utilize tools and data to reach this level of accuracy and current certification agents do not assume the risk of guaranteed performance. In the future, our ability to reduce the risk of behavior will allow all stakeholders to assume more risk comfortably and profit as a result.

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