Sustaining Energy Efficiency: Longitudinal Evidence of Virginia's Low-Income Housing Tax Credit Properties

A Highlight Report to Housing Virginia

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Executive Summary

This report shares findings from a multi-year study that measured the energy performance of Virginia's green building multifamily housing stock. Over the last ten years, the Virginia Housing Development Authority (VHDA) has utilized green building rating system incentives as a policy vehicle in the Low-Income Housing Tax Credit (LIHTC) program to encourage energy efficiency (EE) in the affordable rental stock in Virginia (Climate Zone 4). The research addresses key issues related to EE and affordable housing through the measurement of actual, unit-level energy use in 237 apartments across 15 developments. Data are used to evaluate the effects of year to year operation, climate and behavior on energy use. Data, analysis and findings focus specifically on facilities constructed and certified to the EarthCraft Multifamily (ECMF) rating system in Virginia, one of the only datasets currently available that allows for this type of inquiry. As a second component of the study, development cost data were analyzed for 24 developments containing 1,351 apartments to compare the cost for building green versus non-green. Findings suggest VHDA's green building incentives in the LIHTC program have been successful in promoting affordable housing development that saves residents on average 45% on their annual energy costs at little cost difference compared to non-green housing.

Executive Takeaways

Findings suggest the following executive take-a-ways about energy and development cost in the affordable rental stock in Virginia's LIHTC program:

Energy Use	✓ VHDA's green building incentives in the LIHTC program have been successful in promoting affordable housing development that saves residents on average 45% on their annual energy costs at little cost difference compared to non-green housing. ✓ Over 3 years, residents of sampled LIHTC units are saving more energy than estimated during design, saving more energy than observed in year one (Y_1) and saving more energy than new standard construction estimates. ✓ Over 3 years, findings continue to indicate a significant reduction of energy costs for LIHTC residents. From low-income to extremely low-income housing units, residents can save between 3.1 and 8.3 percent of total annual housing costs from energy efficiency respectively. ✓ Over 3 years, the average per unit energy use intensity (EUI) is 55% more efficient than the National average and 43% more efficient than the Virginia average for multifamily rental housing. ✓ Over 3 years, building technology and resident behavior continue to be strongly correlated, yet fewer variables remain significant in reducing energy consumption. ✓ Research suggests that education on high performance housing (HPH) technologies is an opportunity for significant energy usage and cost savings. Residents that reported receiving education on their apartments had a lower average energy usage monthly and annually (over 3 years) by almost 15% (14.8 %) and a lower energy bill by $10.56 per month.

Development Costs	✓ The difference in the total cost between green and non-green LIHTC developments is not statistically significant nor does cost statistically correlate to energy usage in the unit. ✓ Data indicate a higher average total cost for non-green developments of 6.2% or $7.15 per square foot compared to green developments. Data for LIHTC green developments indicate a lower average cost by 13% or $10.08 per square foot in direct or "hard" costs and a higher average by 6.9% or $2.93 per square foot in indirect and soft costs. ✓ Green building consultant fees represent $0.36 per square foot or 0.38% of Total Development Costs. These fees do not appear to be a main contributor to higher soft costs in green developments sampled. ✓ The 3 year energy usage study results did not indicate a significant correlation between development costs and energy usage. Green buildings that were low cost to build realized just as much energy savings for residents as higher cost green buildings

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Average Monthly Energy Usage: Average Monthly Energy Usage refers to actual kilowatt-hours (kWh) of energy used by residents per month averaged across the entire sample.

EarthCraft: EarthCraft is a green building certification program that serves the Southeastern United States. EarthCraft has adapted over the years to address new challenges in the Southeast's built environment. Over the course of the program's 18 year history, more than 40,000 homes, multifamily units and light commercial spaces have been certified. EarthCraft Multifamily (ECMF) is the basis for the analysis in this report.

EUI: (Energy Use Intensity) EUI is a measure of energy usage per square foot per year (kBTU/sq ft./Yr.) at the site (as opposed to source). EUI is a common energy use normalization method that allows for the comparison of buildings with different square footages. EUI also known as a unit's "average annual energy footprint."

EUI Site Average: EUI site average is a measure of energy usage per square foot per year across a development.

PPI: PPI refers to the "Producer Price Index." According to the US Bureau of Labor Statistics, PPI "measures the average change over time in the selling prices received by domestic producers for their output." For analysis of costs to produce a building in this work, we use the PPI, as opposed to the CPI or "Consumers Price Index." According to the US Bureau of Labor Statistics, CPI "examines the weighted average of prices of a basket of consumer goods and services, such as transportation, food and medical care. It is calculated by taking price changes for each item in the predetermined basket of goods and averaging them." For analysis of costs of energy consumption in this work, we use the CPI.

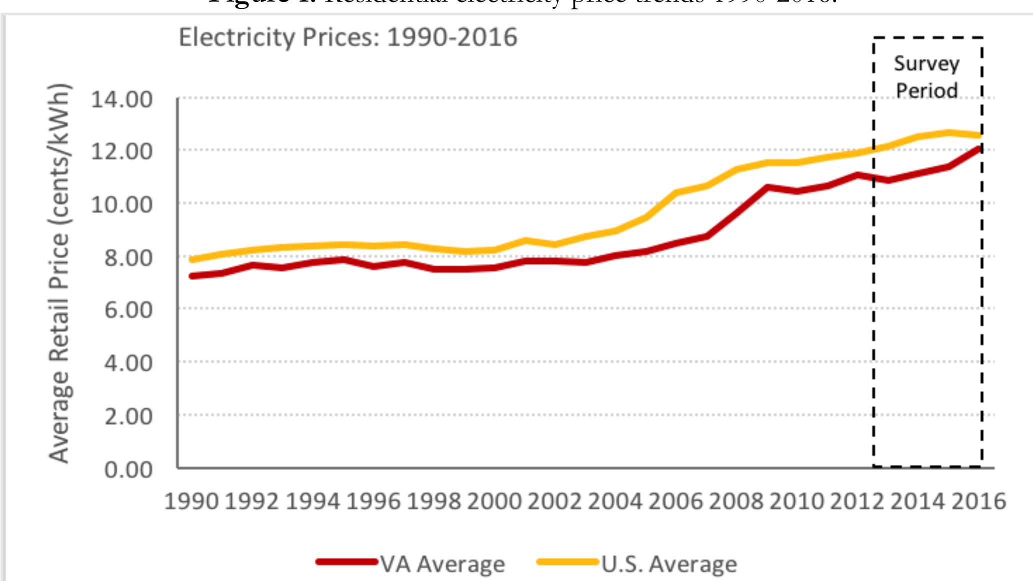
Introduction

Buildings are complex socio-technical systems, yet housing professionals often perform their work lacking a formal post-occupancy feedback process that informs the goals for building performance. The industry has an energy efficiency information gap- it currently lacks verified energy performance standards and real-time data feedback post-occupancy for a residential project. Instead, energy use feedback is delivered to residents by static, non-salient and sometimes difficult to understand utility bills. These bills, representing the primary form of energy use feedback are made available often days, if not weeks after the energy was used by the resident. In sub-metered housing developments, builder-developers suffer from further informational and feedback lag. Gaps and lags in information create uncertainty for residents on fixed incomes and builder-developers investing in housing. This work reduces the energy efficiency information gap by providing empirical evidence of sustained energy use reductions and development costs following the use of a 3rd party verified energy efficiency program in multifamily housing.

Background

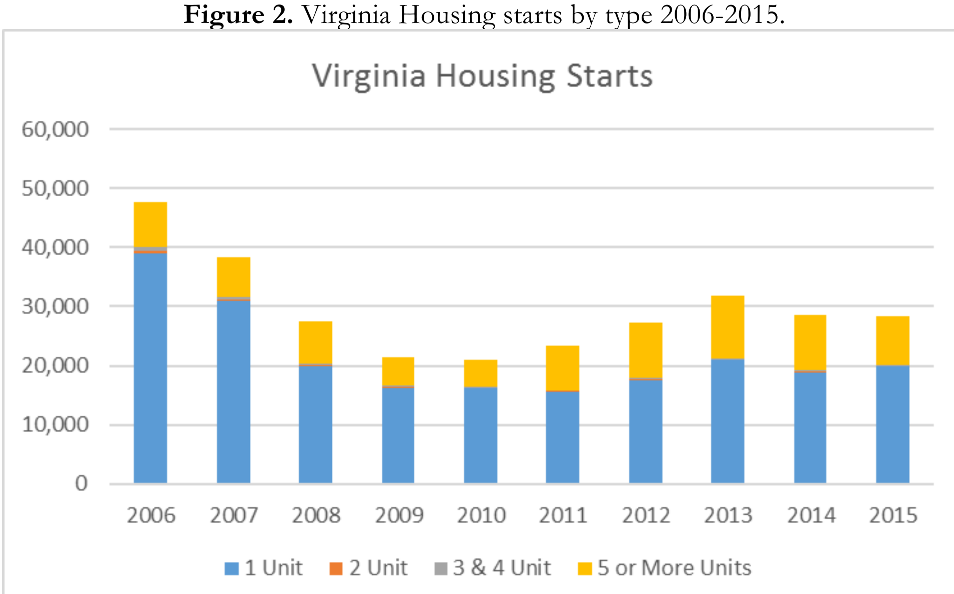
Figure 1 graphs residential electricity price ($/kWh) trends for the United States and Virginia from 1990-2016. Virginia electricity pricing is trending with national pricing. Virginia electricity prices have increased by an average of 1.5% per year over 25 years and 3% annually over the last ten years.

Figure 1. Residential electricity price trends 1990-2016.



Based on these trends, Virginia LIHTC builder-developers could expect a 22.5-45% increase in electricity costs over the 15 year tax credit project compliance period. In tenant paid, sub-metered developments, the housing's affordability is directly impact by rising energy costs. If the electricity is sub-metered and paid by the resident, they are directly impacted by the raising electricity costs. Conversely, builder-developers that own properties with sub-metered, tenant paid utilities are indirectly impacted by the rise in electricity prices. The misalignment between electricity cost burden and building investment creates a split-incentive. A split-incentive[1] occurs when one party (builder-developer) invests in efficiency improvements, yet another party (the renter) receives the direct benefit of reduced utility bills. The split-incentive of builder-developer investment in energy efficiency with the tenant receiving the direct benefit has been described as a market failure and burden to widespread adoption of energy efficiency in multifamily housing. This market failure is important because multifamily housing production has been strong over the last ten years. Figure 2 indicates the number of housing starts in Virginia since 2006, also showing the percentage of 5 and more (multifamily) units as part of total housing production. The trend of rising electricity costs and multifamily starts creates a need to better understand post-occupancy building performance to help overcome the split-incentive in multifamily rental housing.

Figure 2. Virginia Housing starts by type 2006-2015.



Better alignment between occupant behaviors and performance goals of architecture, engineering and construction (AEC) professionals could benefit stakeholders throughout the residential supply-chain, leading

[1]ACEEE. (2009) Retrieved from http://aceee.org/fact-sheet/multifamily-and-manufactured-housing-program

to better informed project teams, greater market penetration of energy efficient buildings, reduced risk for housing providers and higher levels of user satisfaction. This study specifically reports statistical correlates of actual energy use, occupant behavior and technology in multifamily housing units across one and-three-year data. The work builds on previous work by the research team[2] (termed Study Y_1 hereafter) in year one which focused on 3rd party verified, affordable high performance housing (HPH) units and found significant direct and indirect effects of behavior and technology on energy efficiency.

The main objective of this research is to further study variability in the green building stock, including costs, energy usage and implications for educating residents of Virginia's affordable housing stock. We begin by appending data on energy efficient building technology and resident behavior variability (Study Y_1 data) in energy use with years two and three. We then collect and append Study Y_1 data with financial information on the cost variability of green versus non-green housing, setting a basis to motivations for an energy efficient property portfolio. Both sides of the equation will benefit through education from the resulting information.

Another objective of this research is to identify the impact of educational interventions that encourage EE in the affordable rental stock in Virginia through examining residential energy usage, technology and behavior in LIHTC developments. A LIHTC resident's motivation and ability to maximize the energy efficiency of their home is linked to their understanding of energy. Previous studies have shown linkages between personal pro-environmental behavior, such as efficient energy use, and level of education (Poortinga, Steg and Vlek 2004) (Nair, Gustavsson and Mahapatra 2010). The connection between the education and reduced energy consumption is a topic of debate, but targeted occupant education has been shown to be an effective method for reducing energy consumption (Delmas, Fischlein and Asenio 2013) (Zografakis, Menegaki and Tsagarakis 2008). Even for residents who are not financially incentivized to conserve energy have been motivated to develop energy saving behaviors through education (McMakin, Malone and Lundgren 2002). The research presents preliminary findings from educating Virginia's affordable housing residents on energy efficiency and aims to unpack correlates among three years of data on education of EE technologies versus those without education.

Uncertainty due to expected performance and initial cost of adoption often reduce the probability of realizing anticipated returns on housing innovation, promoting path dependency as builders primarily use proven technologies (Harvey 2013; Beerepoot and Beerepoot 2007; El-Shagi, Michelsen and Rosenschon 2014). For green building, there is mounting evidence that these gains are capitalized in the prices of residential buildings (Aroul and Hansz 2011; Bloom, Nobe and Nobe 2011; Dastrup et al. 2011; Kok and Khan 2012). Household

[2] http://www.vchr.vt.edu/wp-content/uploads/2015/02/Housing-VA-LIHTC-Study-Full-Report.pdf

energy prediction is significant to the policy and strategy that affect energy use reduction, economic development, and environmental sustainability (Zhao et al. 2015) as well. Many studies have investigated buildings' energy performance and its associated factors such as construction technology, building enclosure, building envelope, heating, ventilating, and air-conditioning (HVAC) systems, indoor environmental quality, lighting and appliances, weather and occupant behavior (Tavares & Martin 2007). Few studies have focused on the relationship between construction cost and energy use.

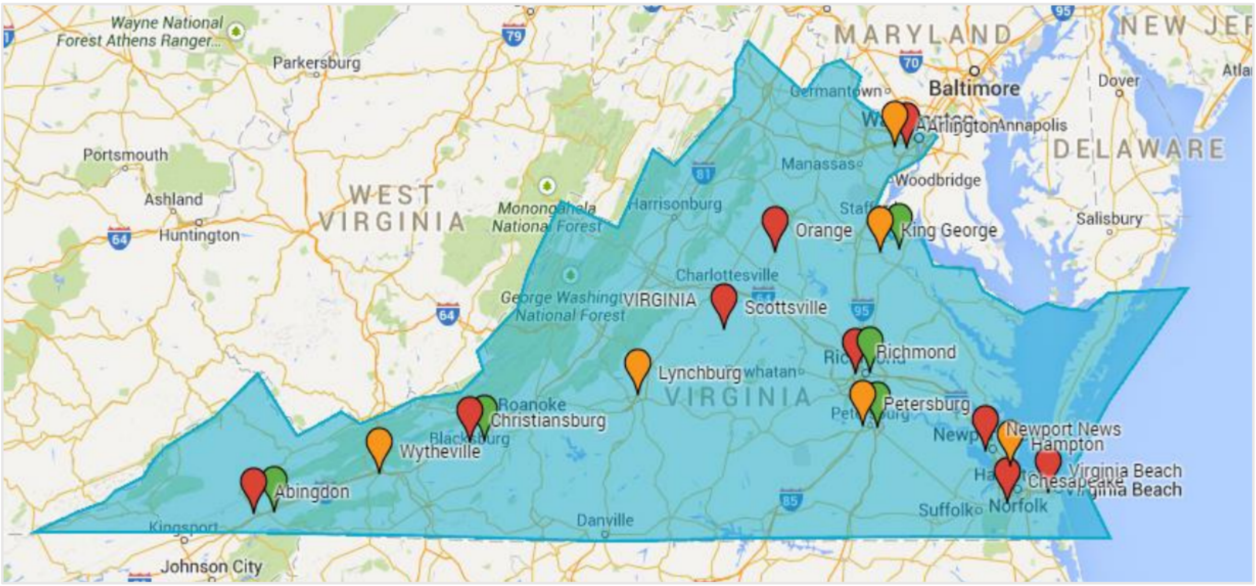
SAMPLE CHARACTERISTICS

The sample utilized for the energy use component of this work is comprised of 15 LIHTC projects that were previously evaluated in Study Y_1. Selection of each project for the energy use study included its location within the Commonwealth (Figure 3), EarthCraft certified by Viridiant[3] (formerly EarthCraft Virginia) and constructed and/or renovated since 2009. The energy efficiency scope for new and renovation projects follow a design and construction process that balances performance goals and prescriptive requirements in the EarthCraft program. Project teams engage Viridiant staff during the conceptual design phase for energy efficiency goal integration prior to applying for LIHTCs. Once funded and nearing a permit set of project documents, teams participate in a Design Review with Viridiant staff, reviewing project details, system integrations and energy simulations. As the project is mobilized on site, Viridiant Technical Advisors meet with on-site construction staff and subcontractors to review energy efficiency goals, provide 3rd party verification and perform diagnostic testing to confirm goals set during design are executed throughout construction process. The typical new construction project scope includes: enclosure air-sealing and testing, space conditioning duct sealing and testing, high efficiency equipment, appliances and lighting. The renovation projects in the sample can be described as deep energy retrofits, with 30-40% energy efficiency improvement goals achieved through a typical scope including enclosure air-sealing and testing, space conditioning duct sealing and testing, high efficiency equipment, appliances and lighting.

[3] http://www.viridiant.org/

Sample Types and Locations

Figure 3. Energy usage study locations of sample developments and units.



Notes: red pins: Reno projects, orange pins: New Construction projects, green pins: Senior projects.

Previous work (Zhao et al., 2017) correlated the concepts of building technology, occupant behavior and energy consumption over one year from May 2013 to April 2014. The authors selected variables in computational analysis that correlated relationships among the concepts. Variables relevant to this work included: 1) observed annual energy consumption (ECo) to measure unit-level energy usage and 2) 11 variables to measure resident behaviors (for example, thermostat set points). Secondary analysis used observed energy use as the response variable (i.e., dependent variable) and the other 13 variables served as the predictor variables (i.e., independent variables) and which were distilled from the team's condensed literature review that characterized them as highly relevant to energy usage.

Study Y_1 indicated that technological advances in building systems directly contribute to 42% of energy efficiency. Behavioral factors, summer temperature setting, winter temperature setting, humidity setting, dishwasher usage, washer/dryer usage, and education on building systems contained quantifiable evidence supporting the hypothesis that building technology and resident behaviors interact with each other and ultimately affect residential energy consumption (Zhao et al., 2017). Now with three years of longitudinal energy use data, the current study (termed Study Y_3 hereafter) utilizes a similar mixed-methods approach to understand changes in the relationships of building technology, occupant behavior and climate data over time for multifamily energy use from May 2013 to April 2016.

For the development cost analysis, researchers collected construction cost data from 24 developments totaling 1,351 multifamily units in Virginia. The cost sample is comprised of the 16 original Study Y_1 projects, as well as 8 non-green LIHTC projects built by a builder-developer that is still actively producing LIHTC housing in Virginia. Buildings were a mix of new construction and rehabilitation projects built between 1998 and 2012 as VHDA-funded LIHTC multifamily developments. Projects built as non-green were built prior to 2008, when the VHDA green scoring criteria was implemented. Projects represent a variety of geographic locations across the Commonwealth.

This work contributes to the knowledge around energy consumption, capital costs and paybacks by comparing actual costs over 15 years for non-green and green multifamily projects in the Virginia LIHTC program. The work also focuses on the latent relationship between construction cost and actual energy consumption in high performance housing. Results from this study reinforce the ability to use cost data and identify critical variables for energy prediction. The work will advance the information exchange around actual costs of green buildings and the ability to capitalize on possible gains while also identifying the need to address key barriers to EE technology diffusion in the housing market.

Sample Methodology

It is important to note that the sample size changed from our previous, 1-year study to this study of energy usage in the LIHTC sample over 3 years. The sample size of the 1-year study was 207 observations and the following 3-year study contains 237 observations. The researchers collected the construction cost data from 24 developments totaling 1,351 multifamily residential units in Virginia. Table 1 provides an overview of the Energy Use, Cost Analysis and Energy Use + Technology + Occupant Behavior + Development Costs sample. Monthly energy consumption data were collected through a partnership with industry collaborators. The energy use data for each residential unit were averaged from May 2013 to April 2014. The average energy use per unit was normalized by the square footage of the unit similarly to the cost data normalization.

Table 1. Project sample summary.

	Energy Use		Cost Analysis		Energy Use + Technology + Occupant Behavior + Development Costs
	Y1	*Y3*	*Green Developments*	*Non-Green Developments*	*Green Developments*
Developments	15	15	16	8	9
Units	207	237	1159	203	197

For the sample reporting "education/training on building systems and energy," we examined two education interventions among a total sample of 230 units in the following formats: 1) residents reporting no education and 2) residents reporting education by property managers upon signing a lease or receiving educational modules when signing utility bill release forms. Determining influences on the variability of energy usage by residents will inform policies for education and incentives.

The research team collected cost data per Development. Costs were based on project Final Cost Certifications (e.g. 8609 Application) submitted to VHDA and then sub-categorized by Construction Specifications Institute (CSI) divisions of work, including both the direct costs of facilities and buildings, and the indirect costs of sites and organizations. The construction cost, basic building information, and technical building data were collected in 2014 and 2015 as observed (actual) records through the aid of builder-developers.

While unit-level is the basis of analysis for much of the energy usage portion of this study, the sample size for the cost data analysis would have to be much larger to enable a unit level analysis. Instead, cost per square foot ($/ft^2) is the unit of analysis used in the cost data analysis. Similar to previous work (Trachtenberg et al. 2012) and due to varying methods used to report costs, the site construction and acquisition costs are not reported including: land, demolition and existing structure fees. The researchers removed non-residential costs; calculating cost per unit from dividing the total construction cost of all included units by the number of units in the development and cost per square foot from dividing total construction cost of all included units by total square footage of residential units only. Since projects were completed from 1998 to 2012, the construction cost data were adjusted using the Producer's Price Index (PPI), for 2013 dollar value, as previously defined (Ang et al. 2007). Green developments generally contained larger unit sizes, resulting in a lower price per square foot. The researchers are not suggesting that the unit size differences in green and non-green unit sizes are not dependent on green building, but may be driven by market conditions and/or LIHTC policy. The study uses a square foot analysis to normalize this difference. Average costs are analyzed at a total cost level and at a subcategory level unpacked between hard (direct) and soft (indirect) costs. Soft costs are further detailed into eight standard cost subcategories for each development.

Finally, to correlate energy use, technology, occupant behavior data and development costs we collected the monthly energy consumption data over the past three years for a sample of 159 residential units from nine developments located in nine cities (see Table 2). These 159 units are included in our sample, as opposed to our population, as they also align with available unit-level energy data. The researchers collected monthly energy consumption through a partnership with industry collaborators and averaged from January 2013 to Jun 2016. The average energy use per unit was normalized by the square footage of the unit. 38 instances (residential units) without electricity data were removed from the initial 197.

Table 2. Summary of green development cost sample

Development Code	Location	Cost Certification (Year)	Number of Units
D1	King George	2012	18 units
D2	Chesapeake	2012	32 units
D3	Richmond	2008	29 units
D4	Arlington	2011	5 units
D5	Orange	2012	19 units
D6	Scottsville	2012	13 units
D7	Richmond	2012	22 units
D8	Lynchburg	2011	14 units
D9	Hampton	2011	7 units

ENERGY USE NORMALIZATION

Comparing the performance of developments and units is a critical component of this work. There are varying development types and sizes within the sample, so data normalization is necessary. Table 3 provides an overview of the Y_3 sample project type and resident population within the sample, as well as average development and unit sizes. Energy use data were normalized by dividing the annual energy use (converted from kWh/yr to kBtu/yr) by the conditioned area of each unit (square footage of the apartment) to develop an Energy Use Intensity (EUI) value per apartment per site, reflecting the energy used per square foot per year or kBtu/ft^2/yr. The application of site EUI metrics for building performance benchmarking is similar to the mile per gallon (MPG) rating system used in the automobile industry; providing stakeholders throughout the supply chain with a standardized performance metric. Site EUI is a common normalization method utilized to compare energy use across different building types, sizes and occupant populations.

Table 3. Y_3 energy usage sample per development type, resident type and average unit size

Division	Developments (*N*)	Units (*N*)	Residential Development Area (Avg. ft^2)	Avg. Unit Size (ft^2)
Overall	15	237	73,035	843
New	7	96	57,034	877
Renovation	8	141	73,408	816
Senior	5	89	36,405	732
Non-Senior	10	148	102,218	917

Nationally, site EUI is used by government agencies including the Department of Energy and Environmental Protection Agency, industry standards organizations such as ASHRAE (American Society of Heating Refrigeration and Air-conditioning Engineers), the American Institute of Architects (AIA), the 2030 Challenge and more recently to support city benchmarking policies in New York City and Austin, Texas.

Key Takeaways

Energy Use Over 3 Years

✓ Over 3 years, residents of sampled LIHTC units are saving more energy than estimated in design and construction, saving more energy than observed in year one (Y_1) and saving more energy than new standard construction estimates. Overall, Study Y_3 sampled units saved 40.3 % or 4,608.87 kWh and $524.03 over 1 year and saved 45 % or 5,169.37 kWh and $587.76 per year over three years versus standard new construction.

- ✓ Study Y_3 findings continue to indicate a significant reduction of energy costs for LIHTC residents. Regarding energy use, Study Y_1 data indicated a lower average energy cost of $524 annually than new standard construction estimates[4] (New Standard Construction Est. Energy Use – Obs. Use Y_1/ New Standard Construction Est. Energy Use). Compared to new standard construction estimates, Study Y_3 data indicate financial savings of $49 per month or $588 annually for LIHTC residents.
- ✓ While the Y_1 and Y_3 studies normalized energy cost data by using the same kWh price over the three years of the study, energy prices in Virginia have risen over this study period as described in the Background section of this report. If today's prices were used to calculate savings, the savings would be greater.
- ✓ From low-income to extremely low-income housing units, residents can save between 3.1 and 8.3 percent of total annual housing costs from EE respectively. Based on the 2015 HUD Income Limits for a 4-person family ($78,400.00) in Virginia, savings equate to 3.1% of housing costs for low-income households, savings equate to 4.9% of housing costs for very low-income households, savings equate to 8.3% of housing costs for extremely low-income households.

Table 4. Annual energy use (kWh) summary

	Estimated Use		**Measured Use**	
Division	New Standard Construction Est. Energy Use (kWh Annually)	Est. Energy Use (kWh Annually)	Obs. Use Y_1 (kWh Annually)	Avg. Obs.Use Y_3 (kWh Annually)
Overall	11,428.57 ($1,299.43)	8,000.10 ($909.61)	6,819.70 ($775.40)	6,259.20 ($711.67)
New	10,628.00 ($1,208.40)	7,439.60 ($845.88)	7,428.40 ($844.61)	6,914.40 ($786.17)
Reno	12,034.43 ($1,368.31)	8,424.10 ($957.82)	6,359.10 ($723.03)	5,799.60 ($659.41)
Senior	10,350.57 ($1,176.86)	7,245.40 ($823.80)	6,476.60 ($736.39)	6,270.00 ($712.90)
Non-Senior	12,013.00 ($1,365.88)	8,409.10 ($956.11)	7,005.60 ($796.54)	6,252.00 ($710.85)

[1]Note: Est = Estimated; Obs = Observed
[2]Note: costs calculated at price of $0.1137/kWh, which was the VA state average for 2015.

[4] Estimated using RESNET approved energy simulation software; REM/Rate - http://www.resnet.us/professional/programs/energy_rating_software

- ✓ Sampled new construction units saved 30% or $363.79 over 1 year and saved 32.4% or $422.23 over 3 years versus standard new construction.
- ✓ Sampled renovation units saved 47.2% or $645.28 over 1 year and saved 51.8% or $708.90 over 3 years versus standard new construction.
- ✓ Sampled senior units saved 37.4% or $440.47 over 1 year and saved 39.4% or $463.96 over 3 years versus standard new construction.
- ✓ Sampled non-senior units saved 41.7% or $569.34 over 1 year and saved 48% or $655.03 over 3 years versus standard new construction.

Energy Use Intensity (EUI) Over 3 Years

- ✓ Over 3 years on average, all building types in the sample are statistically correlated with reduced energy usage. Of these building types, and similar to energy usage findings, new construction has the least significant correlation, suggesting areas for future work in design and construction.
- ✓ Overall, sampled units contain an energy use intensity 20% less than estimated.
- ✓ Sampled new construction units contain an energy use intensity 8.4% less than estimated.
- ✓ Sampled renovated units contain an energy use intensity 26.2% less than estimated.
- ✓ Sampled senior units contain an energy use intensity 17% less than estimated.
- ✓ Sampled non-senior units contain an energy use intensity 21.2% less than estimated.

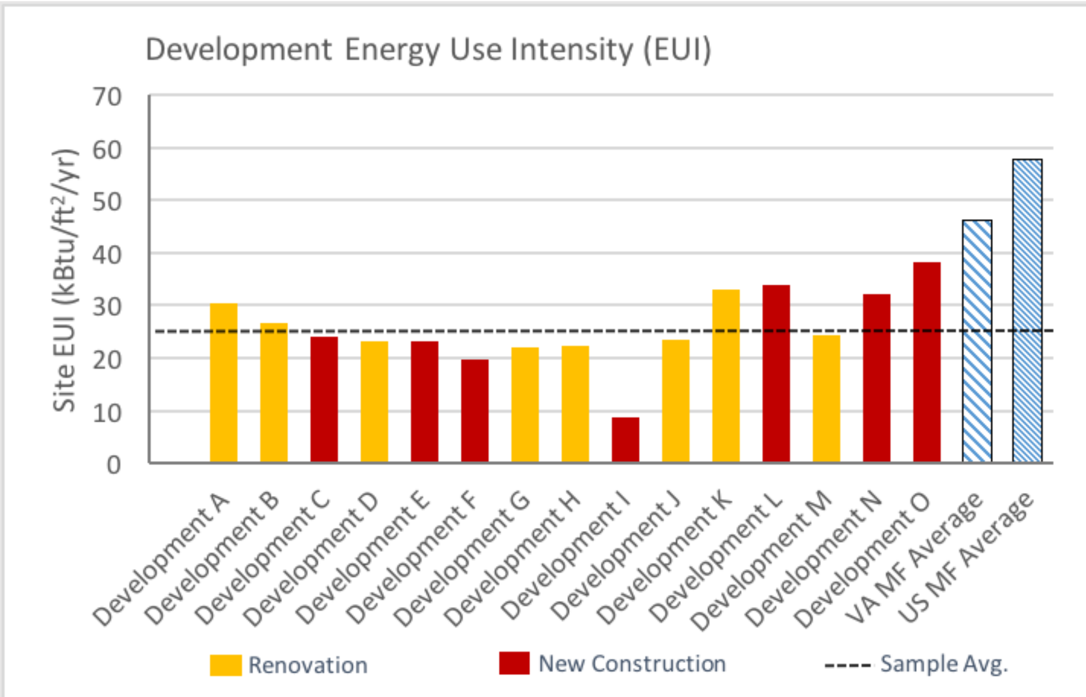
Table 5. EUI summary table

Division	Est. EUI	Obs. EUI	Diff. EUI	*N*	Std Err	*t*	*p*	Upper 95%	Lower 95%
Overall	32.25	25.94	6.31	237	.78	8.11	<0.001**	7.84	-4.78
New	29.75	27.23	2.52	96	1.33	1.89	.031	5.17	-.13
Renovated	33.95	25.05	8.89	141	.88	10.10	<0.001**	10.63	7.15
Senior	34.28	28.42	5.86	89	1.16	5.05	<0.001*	8.16	3.55
Non-Senior	31.03	24.44	6.58	148	1.03	6.36	<0.001**	8.63	4.54

Note: Est = Estimated; Obs = Observed; Diff = Difference; Round-off errors may apply; ** = Significant at 99%.

✓ Across all types of residential units, the ones studied here are more efficient than the national average. Study Y_3 LIHTC units indicate an EUI average that is 55% more efficient[5] than the National average and 43% more efficient than the Virginia average for multifamily rental housing.

Figure 4. Development average site EUI performance from May 2013 to April 2016 by project type.



3YR ENERGY DATA + TECH + BEHAVIOR

✓ Over 3 years, building technology and resident behavior continue to be strongly correlated. Regarding energy use and resident behavior, previous data analysis (Study Y_1) provided quantifiable evidence supporting the hypothesis that "building technology and resident behaviors interact with each other and ultimately affect home energy consumption." Study Y_3 data also indicate that building technology and resident behavior continue to be strongly correlated and significantly affect consumption.

✓ Over 3 years, fewer variables remain significant in reducing energy consumption. Study Y_1 provided quantifiable results that identified four direct correlates between resident behavior and energy use: temperature settings (winter/summer), use of a washer and dryer, and "education/training on building

[5] Energy Information Administration (EIA) 2009 Residential Energy Consumption Survey (RECS) Table CE1.4

systems and energy." Study Y_3 data indicate a longer-term correlation between resident behavior and energy use for use of a washer and dryer, and "education/training on building systems and energy."

- ✓ Over 3 years, resident interaction with technology contains a higher correlation with reduced energy consumption. Previous data analysis (Study Y_1) provided quantifiable results that also identified two indirect correlates (increasing the interaction effect) between technology and behavior: temperature settings specifically during winter combined with knowledge about building systems. Study Y_3 data indicate five indirect correlates between technology and behavior.
- ✓ Over 3 years, as "temperature setting in thermostat during winter" stays at or below 68 degrees, there is a significant decrease in energy usage.
- ✓ Over 3 years, as "season when opening windows" occurs in summer and winter, there is a significant increase in energy usage. Over 3 years, as residents who report "humidity preference" move from low to medium levels it indicates a significant increase in energy usage.
- ✓ Over 3 years, as those who report "frequency of the use of dishwasher" move from low/medium use it indicates a significant increase in energy usage.
- ✓ Finally, data for units reporting "education/training on building systems and energy" indicate a significant decrease in energy usage.

3YR ENERGY DATA + CLIMATE

- ✓ Neither monthly energy use (not normalized) nor EUI (normalized) contained a significant effect due to climate variation across the sample. Study Y_3 data indicate a 3% effect due to climate, which is not a significant correlation (effect) with monthly energy use or energy footprint (EUI) within the sample population. This finding suggests that builder-developers working across the Commonwealth have lower risk of energy cost variability directly or indirectly impacting their developments.
- ✓ New construction units use more monthly energy and have a higher (EUI) than renovated units, similar to overall energy usage.
- ✓ Neither senior nor family units use more monthly energy and family units contain a higher EUI, similar to overall energy usage.
- ✓ Highly efficient housing design, construction and operation can minimize local climate variation effects which will increase energy demand in non-HPH. Findings support anecdotal evidence that recent high performance housing standards are normalizing the effect of local climate variation.

3YR ENERGY DATA + EDUCATION

- ✓ Research suggests that resident education on HPH technologies within their apartment/development is an opportunity for significant energy usage and cost savings. This work continues to find a significant correlation between residents with education on HPH technologies and reduced energy usage (resulting in cost savings and greater housing affordability) versus those without education.
- ✓ Residents with education had a lower average energy usage monthly and annually (over 3 years) by almost 15% (14.8%). Over 3 years, residents in units reporting "education/training on building systems and energy" contain a significantly lower monthly and annual energy usage versus those who report "no education/training on building systems and energy."
- ✓ Residents with education had a lower energy bill by $10.56 per month. Monthly energy use for residents reporting "education/training on building systems and energy" averaged 536 kWh over 3 years and cost $60.95 per month.
- ✓ Residents without education had a higher energy bill. Based on savings for those with education, monthly energy use for residents reporting "no education/training on building systems and energy" averaged 628.9 kWh over 3 years and cost $71.51 per month.
- ✓ Residents reporting education on HPH technologies saved $126.72 per year on average. Annual energy use for residents reporting "education/training on building systems and energy" averaged lower than residents reporting "no education/training on building systems and energy" by 1,113.6 kWh over 3 years.

Table 6: Energy use and cost of energy for residents with and without education

	Energy Use (kWh)	Cost/kWh
W. Education	536.1	$60.95
W/o. Education	628.9	$71.51
Diff. (Monthly)	-92.8	-$10.56
Diff. (Yearly)	-1,113.6	-$126.72
Saving (%)	-14.8%	-$14.8%

Note: costs calculated at price of $0.1137/kWh, which was the VA state average for 2015.

NON-GREEN AND GREEN DEVELOPMENT COSTS

- ✓ Data on construction costs of Virginia LIHTC projects built from 1998 – 2012 support previous research indicating that developer/builder organizations continue to adopt new technology and adjust to associated costs. The difference in the total cost between green and non-green LIHTC developments, is not statistically different across the entire sample of development total costs.

- ✓ Data indicate a higher average total cost for non-green developments of 6.2% or $7.15 per square foot ($ft^2$) (see table 3).
- ✓ Data for LIHTC green developments indicate a lower average cost by 13% or $10.08 per square foot in direct or "hard" costs and a higher average by 6.9% or $2.93 per square foot in indirect and soft costs (see table 7).

Table 7. Development costs: green versus non-green

Average Cost Per ft^2			
	Green	Non-Green	Diff. (± %)
Direct (Hard)	$66.21	$76.29	-13%
Indirect (Soft)	$42.37	$39.44	6.9%
Total	$108.59	$115.74	-6.2%

- ✓ As previously discussed, the sample would need higher resolution data to go beyond the ft^2 level of comparison in this study. Non-green LIHTC developments cost more per square foot but contained smaller total square foot sizing of units and developments since 2008, when green rating systems were integrated into Virginia LIHTC policy, contained a larger footprint.
- ✓ Since green developments occurred primarily after 2008, costs across the entire sample were analyzed in two ways: 1) *without* PPI inflation for non-green developments after 2008 and 2) *with* PPI inflation for non-green developments after 2008. W*ithout* PPI inflation for non-green developments, green developments cost more in 2013 dollars. W*ith* PPI inflation for non-green developments, green developments cost less in 2013 dollars. The resulting difference in cost per square foot between the non-green and the green developments was 6.9% less for green in 2013 dollars. However, none of these differences are statistically significant.

- ✓ Data indicate a higher average soft cost (see Table 8 and Figure 5) in the areas of:
  - professional services;
  - financing;
  - permits and fees;

- developer fees; and
- start-up and reserves.

✓ Data indicate a lower average soft cost in the areas of:

- services;
- bonding fees; and
- pre-development.

✓ Professional services include: Architect, Engineer, Real Estate Agents and Consultants, including Green Building Consultants (see Table 9). Financing refers to costs associated with financing the construction process, including: loan fee, loan interest, legal fees, real estate tax, insurance, bridge loan. Permits and fees are relative to the locality of the construction and refer to local government fees and permanent financing fees. Developer fees refer to allowed overhead costs for the builder-developer organization and start-up and reserves include marketing, rent-up, operating deficit, replacement reserve, furniture and equipment.

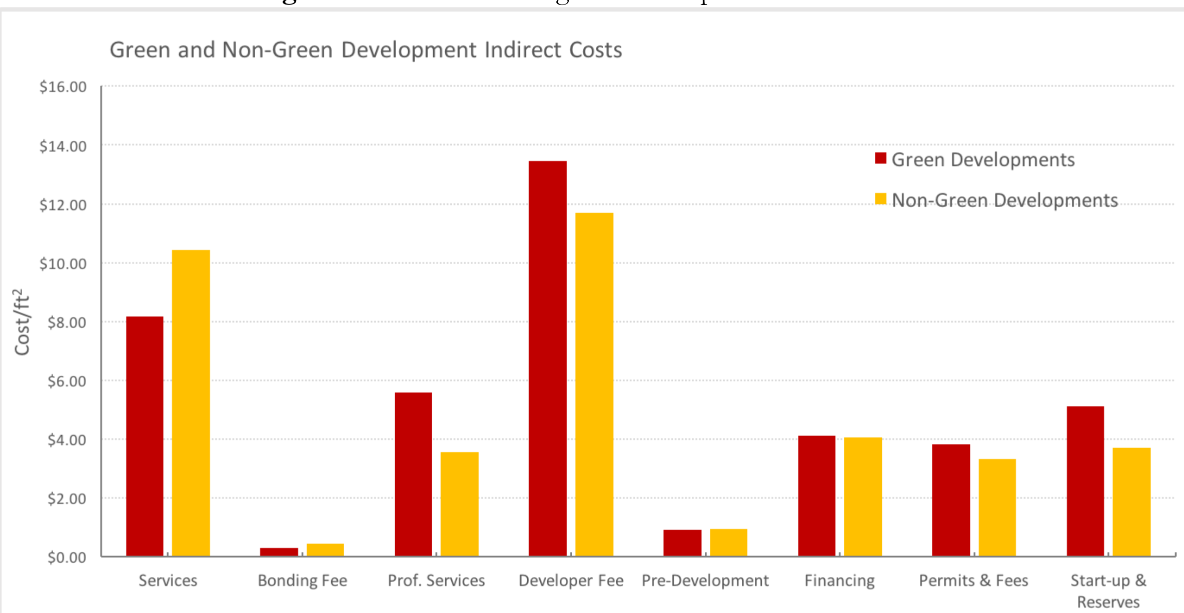
✓ Services contain general contractor services including overhead, profit and general requirements, bonding fees refer to costs associated with performance and bidding bonds and pre-development fees include market study, appraisal, environmental reports, tax credits.

Table 8. Detailed soft costs ($\$/ft^2$): green versus non-green

Soft Cost	Green	Non-Green	Diff (± %)	Sig
Services	$8.16	$10.44	-21%	0.10
Bonding Fee	$0.30	$0.45	-33%	0.41
Prof. Services	$5.59	$3.57	36%	0.13
Pre-Development	$0.93	$0.96	-3%	0.95
Financing	$4.12	$4.07	1.2%	0.51
Permits & Fees	$3.84	$3.34	13%	0.38
Developer Fee	$13.46	$11.69	13%	0.45
Start-up & Reserves	$5.13	$3.72	27%	0.9

- ✓ These results suggest that across time and the entire set of developments sampled (green AND non-green), the average cost per square foot does not reflect a significant statistical difference. Therefore, neither non-green nor green developments deviate significantly enough from the overall average over time to indicate one set of the sample as having a higher cost per square foot. Therefore, over time, green development costs per square foot (especially the hard cost) have diffused into the industry at a similar level to non-green construction developments.

Figure 5. Green and non-green development indirect costs.



- ✓ Literature suggests that technology innovation diffusion must overcome developer-builder resistance for success (McCoy et al. 2012). The result of increased professional services and reduced general contracting (GC) services suggests that risk in this sample of LIHTC green developments is shared across multiple, key stakeholders in the project delivery process. Traditionally, and in the non-green sample, lower professional fees and higher general contracting (GC) services is indicative of risk being carried by the GC more than other stakeholders, which historically generates resistance to new technologies.
- ✓ A detailed analysis of the contribution of green building consultant fees to soft costs was undertaken in Table 9 below. These fees do not appear to be a primary contributor to higher soft costs in the green developments sampled.

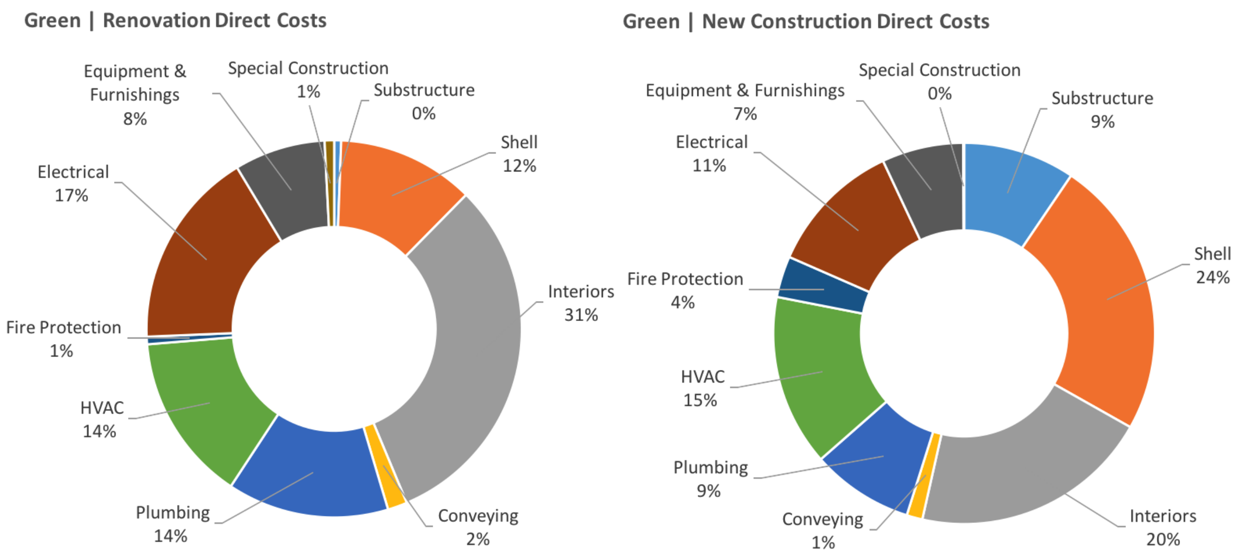
Table 9. Green building consultant fee overview

Unit of Analysis	Green Building Consultant Fee
Percentage of Total Cost	0.38%
Percentage of Indirect Cost	0.93%
Percentage of Professional Services (Indirect Cost)	16.34%
Fee $/ft²	$0.36
Fee $/unit	$ 336.66

ENERGY USE AND DEVELOPMENT COSTS

- ✓ Researchers sought to determine whether there was a positive relationship between green construction costs and energy saved by residents. Construction cost data of the green buildings were analyzed in the context of the magnitude of energy savings yielded by unit over 3 years (Y^3 study). Data modeling did not indicate a significant positive correlation between development costs and energy usage. While the design and construction process often requires a "bottom line" approach that could influence the likelihood of certain processes, technologies or products over others, our analysis does not indicate an influence.
- ✓ Green new construction and renovation development hard costs are driven by their scope of work (Figure 6). Virginia LIHTC Renovation projects do not typically remove interior drywall in the above grade walls, limiting their enclosure improvements (and costs) to airsealing, attic insulation and exterior continuous insulation. Instead renovation projects spend a higher percentage of their hard cost budgets on interiors and system retrofits, while new construction project hard costs are dominated by shell (enclosure) costs.

Figure 6. Green development (renovation and new construction) direct costs distribution.



Conclusion

This report shares findings from a multi-year, mixed-methods study that measured the energy performance of Virginia's green building multifamily housing stock. Over the last ten years, the Virginia Housing Development Authority (VHDA) has utilized green building rating system incentives as a policy vehicle in the Low-Income Housing Tax Credit (LIHTC) program to encourage energy efficiency (EE) in the affordable rental stock in Virginia (Climate Zone 4). The research addresses key issues related to EE and affordable housing through the measurement of actual, unit-level energy use in 237 apartments across 15 developments. Data are used to evaluate the effects of year to year operation, weather and behavior on energy use. Data, analysis and findings focus specifically on facilities constructed and certified to the EarthCraft Multifamily (ECMF) rating system in Virginia, one of the only datasets currently available that allows for this type of inquiry. As a second component of the study, development cost data were analyzed for 24 developments containing 1,351 apartments to compare the cost for building green versus non-green.

The Role of Policy

The findings outlined in this report suggest VHDA's green building incentives in the LIHTC program have been successful in promoting affordable housing development that saves residents on average, 45% on their annual energy costs at little cost difference compared to standard housing. While the authors caution against overgeneralizing the findings beyond this study sample, lessons learned from balancing resident and builder-developer benefits through the use of incentive-based policy and performance-driven program design could contribute to the broader policy conversation currently aimed at reducing energy consumption in the built environment. Recent efforts to promote affordability and reduce energy consumption in Virginia's new and existing housing stock through model building codes and utility demand-side management programs could utilize this work to catalyze conversations regarding the the evaluation of energy-focused mandates and incentives, as well as prescriptive and performance-based policy design.

Moving Forward | Closing the Gap

In 2016, VHDA's Board of Directors approved a change to the LIHTC program that could become a model for closing the energy efficiency information gap introduced earlier in this work. Beginning in 2017, builder-developers can improve their project competitiveness and maximize their green building QAP points by electing to achieve higher levels of certification under a 3rd party-rating system (EarthCraft and/or LEED) and committing to 2 years of benchmarking the performance of their development(s). The demonstrated energy savings afforded through the use of 3rd-party rating systems reduces uncertainty for affordable housing residents, while benchmarking aims to reduce information gaps, lags and risk when builder-developers invest in housing. Leveraging this data will enable stakeholders to make better decisions about the future development, design, construction and operation of affordable housing.

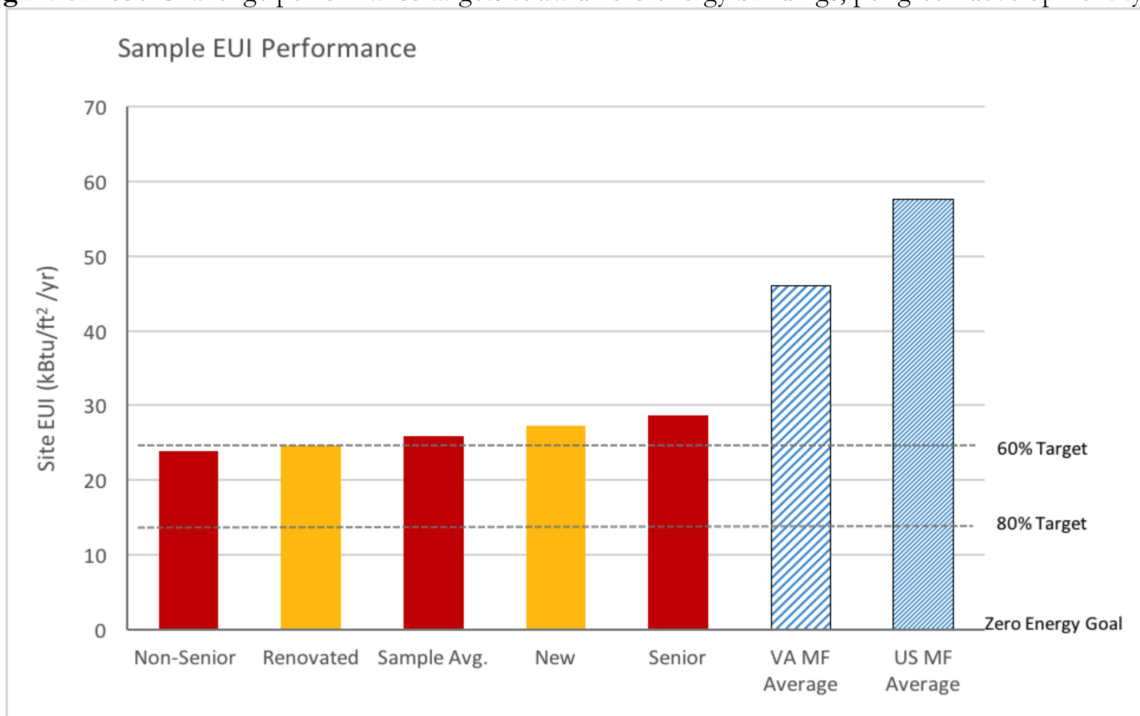
It is important to acknowledge the impact that housing evaluated in this study has on infrastructure and the environment. As utilities are faced with the challenge of providing reliable, affordable energy across an aging grid, energy efficient housing reduces peak load demand and stress on an aging infrastructure compared to standard housing. In the last two years, Virginia utilities have reported multiple peak load events[6,7] during the winter. These events are typically reserved during the height of the summer, late afternoon air conditioning season. Recent work by the Virginia Poverty Law Center (2017) reported that higher utility rates often contain the cost to build new power plants and meet demand. Focusing on energy efficiency programs and education provides a lower-cost alternative to adding infrastructure, while maintaining ageing infrastructure is still a major concern. Further development of energy efficient housing can yield benefits to utilities through reduced peak loads and greenhouse gas emissions. The AEC industry has set aggressive targets (Figure 7) for energy

[6] http://www.richmond.com/business/article_12325e61-ccf1-533b-a631-14f9142b02b7.html

[7] http://www.richmond.com/business/local/dominion-virginia-power-says-power-usage-broke-records-this-summer/article_d003b1ef-3298-5eea-a908-987b765c14f5.html

and greenhouse gas emission reductions over the next ten years. The findings from this study suggest VHDA, LIHTC builder-developers and residents are ahead of non-LIHTC Virginia and national multifamily projects toward reaching these targets.

Figure 7. 2030 Challenge performance targets toward zero energy buildings, per green development type.



Finally, the trend of falling renewable energy prices, specifically the 60% decrease in solar photovoltaic systems over the last 5 years[8] is important to consider. Pairing the reduced risk and favorable economic conditions for energy efficient housing; renewable energy and other intelligent infrastructure technologies present an opportunity to re-envision best practices for utility metering structures in rental housing and public perceptions of affordable housing benefits to society.

Limitations

It is important to recognize the limitations of this work. First, the data, analysis and findings focus specifically the energy use and construction costs of facilities constructed and certified to the EarthCraft Multifamily (ECMF) rating system in Virginia, one of the only datasets currently available that allows for this type of

[8] NREL U.S. Solar Photovoltaic System Cost Benchmark http://www.nrel.gov/docs/fy16osti/66532.pdf

inquiry. Other potential benefits of 3rd party verified, green rating systems were beyond the scope of this project. The energy use analysis focuses on electric use only and energy costs in terms of $/kWh. The analysis excludes utility taxes, tariffs and services fees since the variability in utility fee and municipal tax structures across the state distorts the energy use analysis. The cost data analysis compares non-green and EarthCraft certified-level LIHTC developments that were built spanning a 14 year period. The authors used the PPI to normalize the costs to reduce the impact of the inflation and technology factors since data for more recently constructed non-green LIHTC developments in Virginia was not available due to the majority of builder-developers have elected to pursue a green building certification over the last ten years. Since 2012, developers participating in VHDA's LIHTC program could elect to pursue higher levels of EarthCraft certification (example Gold or Platinum). This work does not consider the impact of developments pursuing higher levels of performance in the context of energy use, cost and/or educational intervention impacts due to the timing of the study and data availability.

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