ENERGY EFFICIENCY IN THE KINGSPORT HOUSING REDEVELOPMENT AUTHORITY (KHRA) RIVERVIEW PLACE: ACTUAL VS. PREDICTED

A Thesis
by
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Abstract

ENERGY EFFICIENCY IN THE KINGSPORT HOUSING AND REDEVELOPMENT AUTHORITY (KHRA) RIVERVIEW PLACE: ACTUAL VS. PREDICTED

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Annual energy costs are rising and threatening the affordability of public housing and are subsequently increasing subsidy payments from the government. Action needs to be taken to reduce energy consumption and to improve the energy efficiency of low-income housing. This is the case with the Kingsport Housing and Redevelopment Authority (KHRA) in Kingsport, Tennessee. In 2010, KHRA completed construction at Riverview Place of 38 energy-efficient housing units. Although designed for energy efficient operation, energy use in some of the units far exceeds projections and results in utility bills for tenants that are much higher than their subsidies cover. The purpose of this study was to determine the underlying factors related to energy consumption in the Riverview Place development. With spending decisions based on grant money received, city financial support, and annual operating and upkeep costs of the development, this study sought to provide recommendations addressing cost-saving energy efficiency measures and programs. To do this, a survey was distributed to the primary tenant of each of the 38 units. The 2013 monthly and annual energy consumption data for each home within Riverview Place was

used to choose six units for building performance testing. These six units were subjected to air leakage testing, including a blower door and duct blaster test. Upon review of the actual energy consumption reported per unit, it was found that KHRA allotted energy subsidies based on projections that did not include use of air conditioning. With an adjusted allotment that included air conditioning, the number of homes that exceeded the utility allowance in July 2013 fell from 30 homes to 19 homes, and in August 2013 it fell from 28 homes to 15 homes. In order to better explain why such a large percentage of tenants exceeded utility allowances in Riverview Place, this study highlighted two major points. First, KHRA should allot utility subsidies that reflect actual tenant behavior; specifically, use of air conditioning in summer months. Second, KHRA should implement education programs for tenants regarding energy efficiency and the need to follow certain energy-efficiency strategies.

Acknowledgments

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CHAPTER 1: INTRODUCTION

Energy consumption and efficiency in subsidized low-income housing is a growing concern, with the US government reportedly spending over five billion dollars a year on operating subsidies for low-income housing units. The majority of funds are sent to local public housing authorities, which allocate around 30% of their total budget to assist tenants with payment of utility bills (Chen & Ma, 2012). Annual energy costs are rising and threatening the affordability of public housing and subsequently increasing subsidy payments from the government. Action needs to be taken to reduce energy consumption and to improve the energy efficiency of low-income housing. The US Department of Housing and Urban Development (HUD) has no mandated standards or guidelines for taking these actions, so the bulk of the work falls to local public housing authorities (Gurian, Langevin & Wen, 2013). This is the case with the Kingsport Housing and Redevelopment Authority (KHRA) in Kingsport, Tennessee.

Statement of the Problem

In 2010, KHRA (Kingsport Housing and Redevelopment Authority) completed construction at Riverview Place of 38 energy-efficient housing units (Figure 1). These units range in type from duplex to single-family homes and range in size from three bedrooms to five bedrooms.

Figure 1. A street view of Riverview Place development.

Although designed for energy efficient operation, energy use in some of the units far exceeds projections and results in utility bills for tenants that are much higher than their subsidies cover. Factors that could contribute to the excess represented on utility bills include individual tenant behavior, building performance measures, size of individual units, and provided appliances. A better understanding is needed about the factors that contribute to this higher-than-projected energy use.

Purpose of the Study

The purpose of this study was to determine the underlying factors related to energy consumption in the Riverview Place development. By analyzing any outliers, or those units that have a wide variance between their actual energy use compared to the modeled/projected energy use, KHRA can determine the best course of action for increasing energy efficiency and lowering energy costs. Building diagnostic research and tenant interviews were conducted in an attempt to identify causes for the variance and to indicate whether tenant education, energy-efficient upgrades, or other strategies would be most effective to increase energy efficiency.

A second aim of the study was to provide KHRA directors with a list of recommendations as they seek to expand upon the neighborhood revitalization model of Riverview Place in other public housing developments within the city of Kingsport. With spending decisions based on grant money received, city financial support, and annual operating and upkeep costs of the development, this study sought to provide recommendations to address cost-saving energy efficiency measures and programs.

Research Questions

1. How energy efficient are the units at KHRA's Riverview Place, based on a comparison of actual energy use and modeled/predicted energy use?
2. When actual energy use is significantly higher or lower than the predicted energy use, what tenant behaviors contribute to this difference?
3. When actual energy use is significantly higher or lower than the predicted energy use, what building performance criteria contribute to this difference?
4. Based on these findings, what recommended actions could be taken to reduce energy use in units using significantly more energy than predicted? If these actions were taken, what would be the subsequent effect on utility payments for the affected units?

Limitations of the Study

This research focused on one development within a single Public Housing Authority (PHA). Expanding the focus to include additional developments or more PHAs would yield added results that are potentially applicable to multiple public housing entities within the region. The inability to compare the Riverview Place development to a similar, recently revitalized neighborhood in the Tri-Cities, Tennessee, region limits the degree to which these findings can be applied elsewhere. In addition, the PHA studied is located in one climate zone, so any building performance criteria noted will only apply to other PHAs in the same climate zone. Furthermore, the study relied on self-reported information from residents about their energy-use behaviors and, as a result, accuracy and objectivity could not be guaranteed, nor can the applicability of this self-reported data to other locations be assumed.

Significance of the Study

The problem of varying levels of energy use across similar housing units has troubled staff members at KHRA since the Riverview Place development opened in 2010. Determining the likely causes of fluctuating levels of energy use between units could significantly benefit KHRA. Also, the study attempted to determine which energy efficiency measures (EEMs) already implemented are performing as predicted and which measures are not, therefore giving KHRA an idea of which EEMs are most effective in terms of actual energy use reductions. Due to the future plans that KHRA has for revitalizing Kingsport city public housing neighborhoods, this study provides KHRA with a baseline comparison for prospective developments in the area of energy efficiency.

CHAPTER 2: REVIEW OF LITERATURE

Energy Use in Public Housing

Energy efficiency in public housing developments is an important topic for researchers, building owners and operators, tenants, and taxpayers. The US Department of Housing and Urban Development (HUD) reported spending over five billion dollars on energy for its assisted housing units in 2008 (Gurian, Langevin & Wen, 2013). Most of that money is allocated to Public Housing Authorities (PHAs), who spend approximately 30% of their allotted budgets on utilities for public housing units within their system (Chen & Ma, 2012). As utility costs, particularly electricity, continue to rise, operating subsidies that the government provides are only expected to increase as well. Improving the energy efficiency of existing and future public housing developments is the best course of action for reducing operating costs and lowering subsidy payments. In 2010, the National Consumer Law Center estimated that a 20% reduction in energy consumption in low-income housing would save at least one billion dollars annually (National Consumer Law Center, 2010). Focusing on how energy is consumed in public housing and determining what energy efficiency upgrades can be accomplished cost-effectively should be a national priority.

Public housing in America was originally structured so that the federal government covered the cost of building housing projects, and the tenant then paid for operating costs (Schwartz, 2010). This system lasted until operating costs began rising faster than tenant incomes were increasing. To mediate the resulting strain on tenants, the federal government established the practice of subsidizing operating costs. Operating subsidies were allocated to housing authorities so that they could cover the tenants' utilities (Schwartz, 2010). The tenants, in return, were expected to pay approximately 30% of their income towards housing costs, regardless of their actual income in comparison with any given area's median income (Global Green USA, 2007; Muri, Oetjen, Pershing, & Wollos, 2011).

Meeting the needs of low-income tenants theoretically worked well within the new system; however, Congress controls the appropriation of subsidies, and these appropriations often fall short of what is needed. In fact, Congress only fully funded public housing operating subsidies ten times between 1980 and 2008 (Schwartz, 2010). The resulting budget deficits faced by PHAs resulted in cutbacks in maintenance and repair. The current need is to reduce operating costs so that subsidy payments will in turn decrease. The greatest opportunity to diminish operating costs is by reducing energy use (Boehland, 2006). Two key factors that affect typical costs are tenant behaviors related to energy consumption and building performance issues related to energy loss.

Tenant Behaviors

A large step in reducing energy use in public housing is to understand tenant behavior. Studies have estimated that tenant behavior accounts for about 30% of the variance in overall heating consumption and 50% in cooling consumption and that if simple behavioral adjustments are made, it is not unreasonable to expect overall energy savings of 10%-20% (Gurian, Langevin, & Wen, 2013). Tenant environmental comfort levels can deviate based on a variety of factors, and this accounts for a large part of the variance in energy use. Fluctuation in energy use coupled with simple behaviors such as proper use of appliances like clothes dryers and ovens, or the preference for open windows over in-house fans, all lead to inconsistencies in energy use in public housing. Poor tenant behavior in the realm of energy efficiency is not necessarily unexpected. For example, tenants can easily save energy in the winter by setting the thermostat to 68° F while they are active within their home and setting it lower during sleeping hours or when away. Turning the thermostat back 10° to 15° for 8 hours can save 5% to 15% a year on heating bills, according to the U.S. Department of Energy (U.S. Department of Energy [USDOE], 2014d). In many cases tenant payments are not affected by their energy consumption, so there is no financial incentive to consume less energy.

Three general categories of behavioral programs are commonly practiced for tenant behavior modification: cognition, calculus, and social interaction. Cognition programs are designed to convey information to a particular audience through media such as billboards or direct mail. Calculus-based programs are designed with benefits for participation, such as financial incentives. Social interaction programs "rely on human desire to be social and to fit in with a group," such as teams or councils (Farley & Mazur-Stommen, 2014, p. 8). Ideal tenant engagement programs would combine elements of each type of program design. A common problem cited for low income housing tenant education programs is the idea of a split incentive program. Due to the already incentivized utility bill, PHAs commonly offer non-monetary incentives. A 2014 study, focusing on behavior modification in 25 different energy efficiency educational programs, found that the programs addressed several energy efficiency behaviors. Figure 2 illustrates the key features of existing program education, including items such as purchasing energy-efficient home appliances, weatherizing doors and windows, and using efficient thermostat settings and light bulbs. The numbers on the right side of the figure represent the number of programs addressing the associated energy efficient behavior.

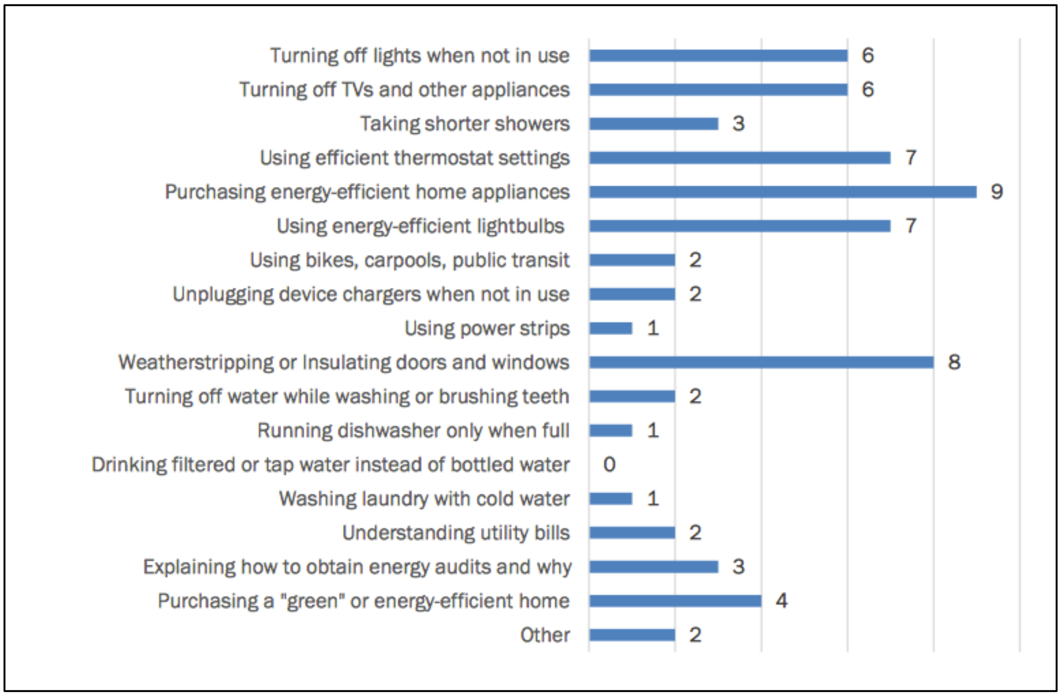


Figure 2. Energy efficient behavior(s) utilized by tenant education programs.

An illustration of a successful tenant behavior program is the Housing Authority of Danbury, Connecticut. The PHA began a Resident Program Fund for improvements within their public housing community. Energy savings were calculated at the end of each year and the money set aside continues to pay for neighborhood resources such as "playground improvements, locked mailboxes, doorbells, permit parking, and new house numbers on the apartments" (Boyle et al., 2012 p. 28). With a focused goal of improving the community, the program keeps motivating residents to continue to be energy efficient.

These examples stress the need for educational programs to teach tenants about the positive, non-financial benefits of increasing energy efficiency, like greater indoor air quality and increased comfort within the home (Muri, Oetjen, Pershing, & Wollos, 2011). Despite the overwhelming ability of energy efficient technologies, tenants still play a large role in a building's energy use. Tenant education and subsequent behavioral adjustments are crucial to long-term energy use reductions; however, at some point, aging infrastructure and building performance issues also need to be addressed (NAHRO Sustainability Working Group, 2012).

Building Performance

PHAs have continuously struggled with the need to replace or renovate aging infrastructure in order to improve building performance. PHAs across the country are dealing with a collective backlog of billions of dollars' worth of unmet capital needs, stemming largely from deferred maintenance due to decreased appropriations for operating subsidies. In addition, federal funding for capital needs decreased nearly 20% from 2004 to 2009 (Schwartz, 2010). PHAs rely on this funding when poor building performance has a higher impact on energy consumption either to replace or renovate older public housing developments.

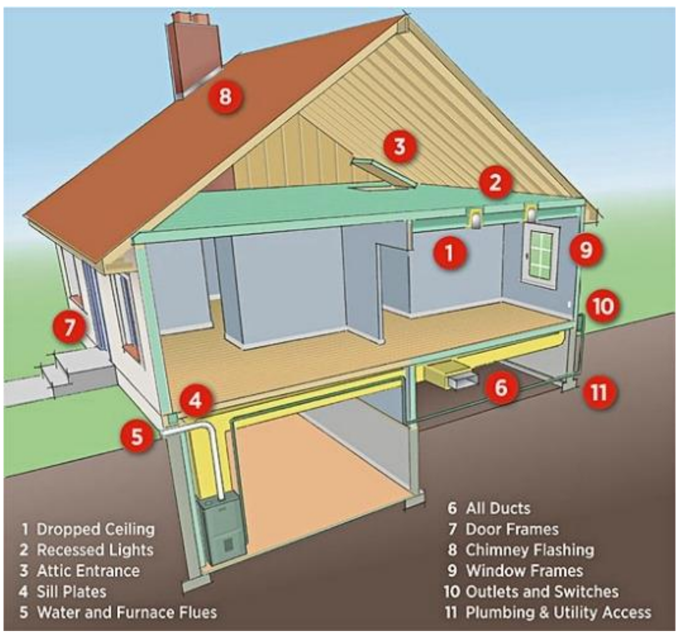


Figure 3. Common air leakage locations.

Air leakage locations in a building's thermal envelope are one of the greatest contributors to energy consumption in a home. Figure 3 shows several locations that are susceptible to air leakage, according to the USDOE (USDOE, 2014c). Even new housing projects can have air leaks around windows and doors that cause heat loss, although more common areas to find significant air leakage are behind knee walls, in plumbing chases, wiring holes, and attic hatches. Gaps or air leaks are responsible for the largest waste of energy in residential buildings, and these problems only grow worse as buildings age (Global Green USA, 2007). In addition to gaps or air leaks in the thermal envelope, leaks in the duct system for a housing unit can prove to be a waste of energy. Sealing ductwork can account for an improvement in the HVAC equipment efficiency of up to 30%, which is monumental considering heating and cooling make up about 56% of the annual energy bill for US residences (Global Green USA, 2007).

Other common contributors to poor efficiency in homes are low quality attic insulation, missing wall insulation, missing floor insulation, deteriorating windows, and wasteful uses of hot water. Common upgrades include the installation of high-performance windows, high efficiency furnaces, and energy-efficient lighting. Making common upgrades such as those listed can be highly effective, typically reducing a building's energy consumption by approximately 30% (Chen & Ma, 2012). For example, in a study performed by the Environmental Protection Agency, improving the documented average of R-13 attic insulation in the south to R-38 and air sealing in the attic and around windows and doors resulted in savings of 11% on a total house utility bill and 20% savings on heating and cooling only (Energy Star, 2014: U.S. Environmental Protection Agency [USEPA], 2014).

Energy Modeling Programs

The origins of building energy modeling can be traced to 1925 when a group of scientists used Response Factor Methods (RFMs) to calculate transient heat flow (International Building Performance Simulation Association, 2012). Later, in 1967, two scientists published a paper titled *Room Thermal Response Factors*, which was a paper in a series that analyzed heat transfer through walls using RFMs (Mitalas & Stephenson, 1967). All of the papers in the series were published in the *American Society of Heating, Refrigerating and Air-Conditioning Engineers* (ASHRAE) *Transactions*, and ASHRAE has remained a vital presence in the development and dissemination of building energy modeling techniques.

One of the first computer-based modeling programs that predicted thermal performance was the National Bureau of Standards Load Determination. Tamami Kasuda, a scientist sponsored by the U.S. Department of Housing and Urban Development, developed the National Bureau of Standards Load Determination program. Kasuda's program relied on Response Factor Methods and was only able to model a single room, but it was a major step toward whole building energy modeling (U.S. National Bureau of Standards, 1971).

The most commonly used energy modeling programs today include EnergyPlus, eQUEST, and TRaNsient SYstems Simulation Program (TRNSYS). EnergyPlus and TRNSYS are funded and developed by the USDOE, James J. Hirsch & Associates developed and funded eQUEST, which was developed at the same time as EnergyPlus. EnergyPlus and eQuest are both whole-building energy simulation programs used by industry professionals (Hirsch, 2012; USDOE, 2014a). The TRNSYS program, on the other hand, focuses on transient systems (as its name implies), and its main applications include solar systems, low energy buildings, heating and cooling systems, and renewable energy systems (University of Wisconsin-Madison, 2013). All three programs are updated by their respective developers, yet each of the programs has distinct advantages and disadvantages. EnergyPlus, for instance, aids in modeling complex systems with more accurate results, but it consumes more time, and its interfaces are more difficult to use (USDOE, 2014a). The eQUEST program is easy to use and quick to produce results that would aid in the decision making process of the design phase, yet it uses DOE-2 software which studies deem less accurate than the newer EnergyPlus software (Hirsch, 2012). The TRNSYS program has an advantage in being a component-based simulation program. It can more accurately model complex and unconventional systems, but it is difficult to use without a vast level of expertise and knowledge (University of Wisconsin Madison, 2013).

Developed in 1994 by Lawrence Berkeley National Laboratory (LBNL) and sponsored by the U.S. DOE is an energy-modeling program called Home Energy Saver™, or HES. HES is the first interactive web-based program designed to help the general public make decisions about energy use in their homes. Like the programs listed above, HES uses engineering models to estimate energy consumption for six major categories: heating, cooling, water heating, large appliances, lighting, and miscellaneous equipment (Lawrence Berkeley National Laboratory, 2014). The site first went online in 1996 and was originally sponsored by the USEPA’s ENERGY STAR program. Essentially, HES offers the user two basic services:

1. A calculation of energy consumption by end use, for the entire household.

2. An estimate of energy bills based on end use consumption with a comparison of consumption to a 'typical' household and subsequent recommendations for bill reduction. (Mills, 2008, p. 1)

The goal of HES since the beginning has been to provide consumers with a simple way to use complicated, cutting-edge residential energy calculation tools and energy data. Historically, access to these tools and energy data has been restricted to industry professionals because of the vast knowledge of energy and building technologies required to use such tools and data. HES, using its simplified web-based platform, provides extensive decision support information to accompany analytical results, and it enables users, specifically non-professionals, to obtain energy use and savings estimates based on details about their particular home, climate, and lifestyle. Advantages of HES include its ease of distribution, version control, platform independence, and its ability to locate complicated computational software like DOE-2.2e on a central server that is free to the public rather than having users buy the software and install and administer it on a personal computer (Mills, 2008).

As previously stated, energy modeling is a beneficial strategy for identifying cost-effective measures for improving energy efficiency. Energy modeling programs take parameters received from design teams and give a predicted value for energy efficiency. Anticipated costs, savings, and payback periods can all be calculated using energy modeling programs as well. These calculations allow PHAs to select appropriate energy efficiency measures to include in the design, as well as to plan operating budgets and to anticipate changes in costs over time (Muri, Oetjen, Pershing, & Wollos, 2011). The accuracy of these modeling or simulation programs is a cause of continuous scrutiny, however, and care must be taken when inputting data and when analyzing results. The programs make use of varying formulas for calculating performance effects, which leads to differences in predicted energy usage. Furthermore, these modeling programs cannot take into account all of the factors impacting energy consumption, and projections can sometimes vary widely from actual energy use.

Energy Efficiency Standards and Energy Codes

Several energy efficiency standards and other energy codes exist, but perhaps none is more recognized than the ENERGY STAR efficiency standards and the International Energy Conservation Code. The ENERGY STAR program was developed by the U.S. Environmental Protection Agency in 1992 under the direction of Congress. The mission of the program is to help individuals and businesses save money and to protect the climate through superior energy efficiency. In 2012, ENERGY STAR delivered $24 billion in energy and cost savings to businesses, organizations, and individuals (Energy Star, 2014a). The International Code Council (ICC) is responsible for developing and publishing the International Energy Conservation Code. Established in 1994 as a non-profit organization with the goal of creating a single set of comprehensive and coordinated construction codes, the ICC grew and now develops and publishes 15 different international codes. One of the codes ICC develops is the International Energy Conservation Code (IECC), which is updated every three years. Tennessee has currently adopted the 2006 IECC statewide (International Code Council [ICC], 2014).

U.S. Department of Housing and Urban Development (HUD)

The U.S. Department of Housing and Urban Development is currently run by HUD Secretary Julian Castro and operates with a budget of $46 billion and 8,000 employees. The

Department of Housing and Urban Development Act of 1965 created HUD as a Cabinet-level agency, and HUD'S current mission is to "create strong, sustainable, inclusive communities and quality affordable homes for all" (U.S. Department of Housing and Urban Development [HUD], 2014, paragraph 1).

HUD does not offer many financial incentives to encourage green building and energy efficiency. For example, HUD only offers one incentive point out of a total 100 to 120 points for energy efficiency in its competitive housing grant programs (Government Accountability Office [GAO], 2009). HUD also neglects to specify the use of energy efficient appliances in projects, which was promised in its *Energy Action Plan and Energy Strategy* (HUD Energy Action, 2007). Overall, HUD mandates or recommends very little in regards to energy efficiency, mainly focusing its attention on funding efforts (Chen & Ma, 2012).

One of HUD's largest programs that funds energy efficient developments and renovations is the Green Retrofit Program (GRP). Funded by the American Recovery and Reinvestment Act (ARRA), the GRP is a $250 million program that provides grants and loans to eligible property owners so that they can make energy efficiency and green retrofit improvements, notably upgrades and improvements related to ENERGY STAR qualifications (Muri, Oetjen, Pershing, & Wollos, 2011). Funds can also be used to ensure that energy efficient technologies on the property continue to operate efficiently (U.S. Department of HUD, 2009).

Some of HUD's other programs offer incentives for energy efficiency measures. However, the standard rules for HUD's operating fund actually provide a disincentive to implementing energy efficiency measures due to the typical high costs of implementation or adoption. HUD provides PHAs with funds from their own capital fund, but according to HUD officials, the funds are usually not enough to cover both the up-front cost and the ongoing repair needs of implemented energy efficiency measures (GAO, 2009). In response, many PHAs are exploring energy performance contracting. Energy performance contracting is a process in which PHAs pay an energy services company to identify and finance energy efficiency measures. This process has been quite effective, with 195 energy performance contracts in progress as of 2007, achieving gross savings of about $50 million annually (GAO, 2009).

Public Housing Authorities

Public housing authorities (PHAs) were first established following the creation of HUD in 1965 (U.S. Department of HUD, 2014). HUD funds roughly 3,200 PHAs across the nation using the Public Housing Capital Fund administrated by the Office of Capital Improvements. In 2013, HUD requested $2.07 billion in Public Housing Capital Funds to address capital repair and replacement needs. Additionally, HUD requested $4.524 billion in Public Housing Operating Funds, which was divided among nearly 1.2 million publicly owned affordable housing units. In all, HUD requested $6.59 billion in 2013 for funds that were used to supplement tenants' rent, maintain the housing, and manage public housing programs (U.S. Department of HUD, 2013).

A large portion of HUD'S Public Housing Operating Funds is spent on utilities (electric, water, and sewer). In the three branches of public housing, assisted housing, public housing, and Section 8 vouchers, PHA-paid utilities in public housing totaled $1.43 billion in 2006, a $160 million increase from 2004 (U.S. Department of HUD, 2009; U.S. Department of HUD Energy Task Force, 2008). Furthermore, the vast majority of utility expenditures are spent on energy, specifically electrical. Table 1 shows the PHA-paid energy expenditures for energy in 2010 and 2011. Total electrical expenditures increased from $505 million to $532 million, a 5.4% increase from 2010 to 2011 (U.S. Department of HUD, 2012).

Table 1. *PHA-paid energy expenditures for energy.*

PHA-Paid Energy Expenditures (Electricity, Gas, and Fuel Oil Only)						
Year Reported	2010 Cycle 10		2011 Cycle 11			
	Total Energy Costs (*$ millions)*	Cost per unit-month (PUM)	Total Energy Costs (*$ millions)*	Percent Change	Cost per unit-month (PUM)	Percent Change (PUM)
Total PHA-Paid Utilities	$1,089	$86.84	$1,055	-3.1%	$80.76	-7.0%
Electricity	$505	NA	$532	5.4%	NA	NA
Natural Gas	$344	NA	$302	-12.2%	NA	NA
Fuel Oil	$241	NA	$221	-8.3%	NA	NA

In order to calculate utility allowances for tenants, HUD gives PHAs a wide degree of flexibility in how they develop utility allowances for their housing units. Essentially, HUD gives PHAs a choice between engineering-based methodologies and consumption-based methodologies. With the engineering-based methodology, PHAs use engineering calculations and technical data to estimate reasonable energy and water consumption. The reasonableness of the estimates depends on assumptions in the calculations that are left up to the PHAs. The engineering-based methodology focuses on various end-uses, including space heating, water heating, cooking, lighting, refrigeration, miscellaneous appliances, laundry, air conditioning, and water. The consumption-based methodology has two different approaches that are equally acceptable for PHAs to choose. The first uses a three-year rolling base timeframe, which requires the PHA to collect consumption data for three years, and with each new year's data collection the oldest year of data is removed. This approach requires the PHA to calculate consumption allowances each year. The other approach uses a fixed-database, normalized for weather. A fixed-database of consumption information for a period of 1-3 years is adjusted for the effects of weather using local weather information; and using this approach, the PHA does not need to collect consumption data every year. After choosing an approach, the PHA then needs to develop allowance categories that combine dwelling units according to factors that affect consumption requirements. Allowances are then formulated using the following process dictated by HUD (U.S. Department of HUD, 2014):

1. Collecting the consumption data
2. Grouping the data into allowance categories
3. Cleaning the data and checking the statistical validity of the data sets
4. Determining the "typical" consumption for each allowance category
5. Adjusting the data for any non-allowable end-uses (if such consumption has not already been removed from the data)
6. Converting consumption allowances to dollar allowances. (Section 3)

PHAs are also required by HUD to have certain programs in community service and economic self-sufficiency in place for tenants. HUD's requirements are that tenants with each PHA contribute eight hours of community service or participate in eight hours of economic self-sufficiency programs each month. The requirement can also be met using a combination of hours from both. Community service requirements can be met by serving with any non-profit or public youth or senior organization or volunteering at the PHA, among many other options. Economic self-sufficiency programs that satisfy the requirement include job training programs, job readiness programs, skills training programs, higher education, apprenticeships, budget and credit counseling, and many others (U.S. Department of HUD, 2003). These programs are staples of the occupancy strategy and guidebook developed by HUD in 2003.

KHRA: Riverview Place Development

In 2006, HUD developed an energy strategy intended to address the need for energy conservation and energy efficiency in HUD's own programs. The strategy created a list of 25 planned actions that can be seen in Figure 4. One of the planned actions for the Public and Indian Housing sector of HUD was to build HOPE VI developments to a high level of energy efficiency. This planned action was a key component that led to the Riverview Place development at Kingsport Housing and Redevelopment Authority (U.S. Department of HUD: Energy Task Force, 2008).

HUD's Energy Strategy—Planned Actions

Departmentwide	
1	Provide incentives for energy efficiency in housing financed through HUD's competitive grant programs.
2	Include energy efficiency performance measures in HUD's Annual Performance Plan (APP) and Management Plan.
3	Promote the use of Energy Star products and standards through HUD's new Partnership for Home Energy and Efficiency with DOE and EPA.
4	Provide residents or organizations with training or information on energy efficiency for building or rehabilitating affordable housing.
5	Establish residential energy partnerships with cities, counties, states, and other local partners.
Community Planning and Development	
6	Encourage energy efficiency in HOME- and CDBG-funded new construction and housing rehabilitation projects.
7	Identify opportunities and assist with feasibility analysis for Combined Heat and Power in public or assisted housing.
Public and Indian Housing	
8	Base appliance and product purchases in public housing on Energy Star standards, unless the purchases are not cost effective.
9	Build HOPE VI developments to a high level of energy efficiency.
10	Improve tracking and monitoring of energy efficiency in public housing.
11	Streamline energy performance contracting in public housing.
12	Promote energy conservation in federally assisted housing on Indian tribal lands.
Housing—Single Family	
13	Feature the Energy Efficient Mortgage as a priority loan product.
14	Provide training on how FHA single-family programs can be effectively used to promote energy efficiency.
15	Continue improved tracking, and evaluate performance, of Energy Efficient Mortgages.
Housing—Multifamily	
16	Promote energy efficiency in multifamily-assisted housing and multifamily programs.
17	Continue HUD-DOE multifamily weatherization partnerships.
18	Encourage use of Energy Star new home standards in the design, construction, and refinancing of Section 202 and 811 projects.
19	Develop incentives for energy efficiency through FHA multifamily insurance programs.
20	Explore asset management strategies and guidance for energy efficiency in HUD-subsidized multifamily properties.
21	Support energy efficiency training for multifamily managers and maintenance staff.
Housing—Manufactured Homes	
22	Implement energy efficiency recommendations of the Consensus Committee for HUD-Code (Manufactured) Homes.
Field Policy and Management	
23	Partner with local energy efficiency groups, HUD program offices, and other agencies to educate HUD customers about ways to reduce energy costs.
Policy Development and Research	
24	Conduct energy-related policy analysis and research to support Departmental energy efficiency actions.
Healthy Homes and Lead Hazard Control	
25	Develop a computerized assessment tool for integrated energy and environmental retrofits.

Figure 4. HUD's Planned Actions for Energy Efficiency.

Kingsport Housing and Redevelopment Authority (KHRA) is the local public housing authority for Kingsport, Tennessee (TN), created by the citizens of Kingsport in 1939. As calculated by HUD in 2014, Kingsport, TN, has a median family income of $50,600 (U.S. Department of HUD, 2014). This is comparable to the United States' Census Bureau's reported median family income of $41,111, which represents the median from 2008-2012.

The Census Bureau also reported that the percentage of persons living below the poverty line in Kingsport, TN, was 17.2% (United States Census Bureau, 2014). In order to qualify for public housing in the Kingsport, TN, area, the tenant(s) seeking housing must fall within the acceptable income limits. Table 2 shows the income limits in Kingsport, TN calculated by HUD (HUD User, 2014).

Table 2. *Income Limits for HUD qualifications in Kingsport, Tennessee.*

STATE:TENNESSEE	PROGRAM	1 PERSON	2 PERSON	3 PERSON	4 PERSON	5 PERSON	6 PERSON	7 PERSON	8 PERSON
Kingsport-Bristol-Bristol,	TN-VA MSA								
FY 2014 MFI: 50600	EXTR LOW INCOME	11670	15730	19790	23850	27350	29350	31400	33400
	VERY LOW INCOME	17750	20250	22800	25300	27350	29350	31400	33400
	LOW-INCOME	28350	32400	36450	40500	43750	47000	50250	53500

A board of commissioners directs KHRA, and its mission statement reads as follows:

> We affirm that shelter is a basic human necessity, and we are dedicated to provide decent housing opportunities to those in need in the Greater Kingsport Area. We believe that blighted areas undermine the vibrancy of our community; and therefore, we are committed to acting as a catalyst for successful redevelopment efforts in the community. (KHRA, 2014, para. 1)

To achieve this mission, KHRA owns and operates 529 units of traditional public housing across six developments in the Kingsport area. These developments include Robert E. Lee Apartments, Frank L. Cloud Apartments, Dogwood Terrace, Holly Hills Apartments, Tiffany Court, and Riverview Place. Additionally, KHRA administers a Housing Choice Voucher Program in the City of Kingsport and in Sullivan, Hawkins, Washington, Unicoi, Greene, and Johnson Counties, with a baseline of 1,242 units.

In 2006, KHRA received an $11.9 million HUD HOPE VI Revitalization Grant. The HOPE VI program, also know as the Urban Revitalization Demonstration (URD) program, was created in 1993, but it originated in 1989 when Congress created the National

Commission on Severely Distressed Public Housing and charged the Commission with the eradication of severely distressed public housing by the year 2000 (U.S. Department of HUD, 2014). HOPE VI funds may be used for capital costs of demolition, major reconstruction, rehabilitation, and other physical improvements; the provision of replacement housing; management improvements; planning and technical assistance; and the provision of supportive services.

KHRA's HOPE VI project was to transform the aging 92-unit Riverview Apartments development into a vibrant, mixed-income, mixed-tenure affordable housing development. An added emphasis was placed on the revitalization of the surrounding community. The proposal included the demolition of the original 92 units and the rebuilding of 116 units to be distributed in the following manner (KHRA, 2014):

- 54 off-site units of elderly/disabled housing
- 24 off-site single family homes in the historic Sherwood/Hiwassee neighborhood of Kingsport
- 38 energy-efficient public housing units on the original site of Riverview

Armstrong Construction completed the 38 energy-efficient units, designed by Cain, Rash, West Architects, Inc., on the original site of Riverview in 2010 (Lane, 2010).

In 2011, all 38 units at Riverview Place were part of an energy efficiency study conducted by Accu-Spec Inspection Services for KHRA. Accu-Spec was paid via KHRA's remaining money from the HOPE VI grant used to develop the neighborhood. All 38 units were subjected to blower door testing, before improvements were made to each of the units, with the goal being the improvement of energy efficiency. Following final improvements, five of the previous 38 homes were subject to a post-round of blower door testing. Common problems identified included air infiltration at recessed lights, bathroom ventilation fans, electrical panels, and attic accesses. Figures 5 through 7 show infrared pictures of some of the common problems (Accu-Spec Inspection Services, Inc., 2011).

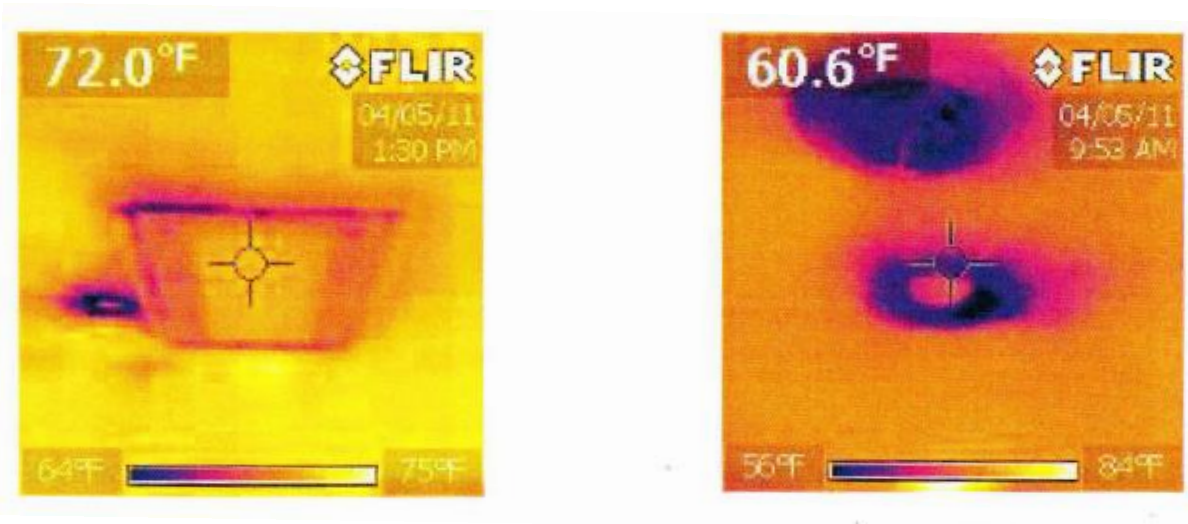


Figure 5. Infiltration around attic access door and recessed light. The blue areas show air infiltration as areas of colder temperature (note temperature range at bottom of photos).

Figure 6. Infiltration around electrical panels installed on exterior walls.

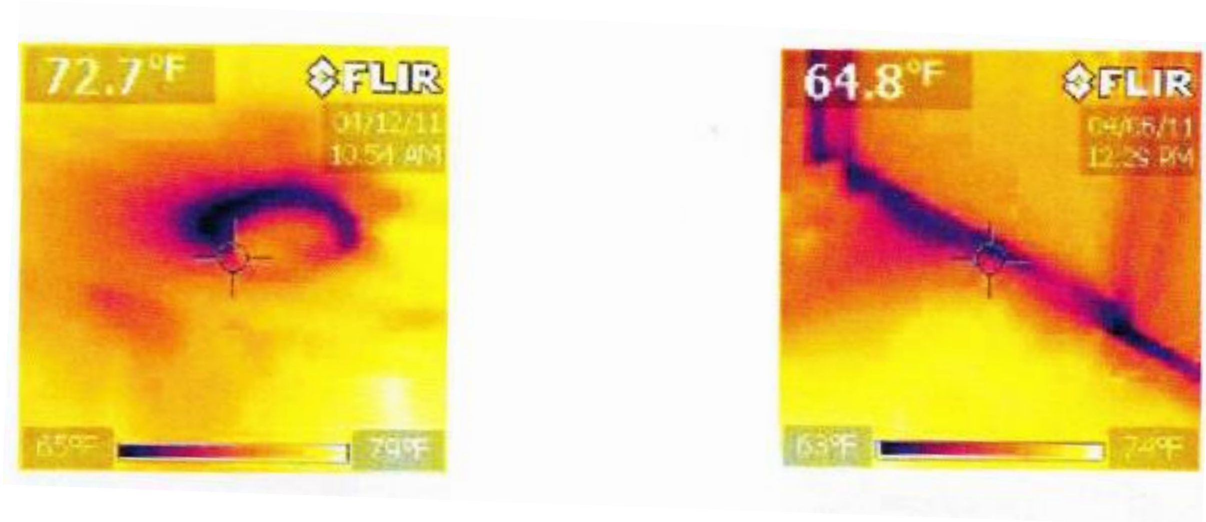


Figure 7. Infiltration around recessed light and attic access door.

Following the energy efficiency study in 2011, Accu-Spec Inspection Services was paid almost $40,000 to make the most common improvements that were needed in each home. Despite this, actual energy consumption by tenants, specifically electrical, still exceeded the KHRA’s allotment in 2012-2013 and in the early half of 2014.

CHAPTER 3: RESEARCH METHODOLOGY

KHRA's Riverview Place development was the subject for this case study and the focus of this research paper. The Riverview Place development consists of 38 energy-efficient housing units, primarily composed of varying layouts of single family, two-story detached houses and multi-family, single-story duplexes. This case study considered several layouts of both types of housing units in its design. Each unit in the study was analyzed in terms of building performance and the residents' energy-consumption behavior.

Sampling Strategy

A purposeful sampling strategy was used for this case study. The focus of the research was on building performance and tenant behavior in relation to energy consumption and efficiency, so an "energy efficient" public housing development to which the researcher was granted wide access was chosen. Armstrong Construction in Kingsport, TN, constructed the Riverview Place development in 2009-2010. Although proclaimed as energy efficient, the units were not built to any nationally recognized standard for enhanced energy efficiency, such as ENERGY STAR. Additionally, analysis of the building's blueprints indicated they did not go above and beyond Tennessee's Energy Code, which follows the 2006 International Energy Conservation Code (IECC) (USDOE, 2014b).

In addition to the actual homes in the Riverview Place development, the sample for this study included representatives from the KHRA (as owners/operators) and the tenants of the homes within the subdivision. Access to the tenants was approved and facilitated by officials at the KHRA.

A survey was distributed to the primary tenant of each of the 38 units by a program coordinator from KHRA. Of the 38 surveys distributed, 20 surveys were returned and analyzed. The 2013 monthly and annual energy consumption data for each home within Riverview Place was used to narrow down the 20 participating housing units and tenants to a group of six units and tenants chosen for building performance testing. These units represented low, average, and high levels of energy consumption.

Data Collection Procedures

Tenant Surveys

Initially, a survey was developed and distributed (see Appendix A). The survey was based on a prior study conducted by Jared Langevin of Drexel University (Gurian, Langevin & Wen, 2013). Langevin used a semi-structured interview with PHA residents to evaluate residents' behaviors regarding energy and to study the relationship of resident behaviors and reducing energy consumption in low-income public housing.

Survey design.

The survey used for the current study was comprised of four sections:

1. Background information: Included questions about the age and gender of the responder, the type of building lived in, the amount of time they've lived in the PHA, and the amount of time they spend in their home on weekdays and weekends.

2. General quality and comfort assessment: Included questions regarding general comfort and environmental satisfaction, including factors such as temperature, humidity, air quality, and noise.
3. Energy use habits: Included questions about heating and cooling equipment, lighting, and how that equipment is used; what residents do to adapt to interior conditions passively; and how often residents cook and watch TV.
4. Energy costs, knowledge, and willingness to conserve: Included questions about utility bills and any fluctuation in cost across the four seasons, and whether residents are already doing or are interested in pursuing 14 energy conservation measures that are relevant to residential efficiency efforts (Gurian, Langevin & Wen, 2013).

The surveys were administered to the residents of each of the 38 units in Riverview Place by a program coordinator from KHRA. Twenty surveys were returned complete from the original 38, resulting in a response rate of 53%. The survey's intent was to aid in characterizing residents' energy behaviors. By surveying the residents on the topics above and scoring their responses, the researcher was able to compare each resident's energy behaviors with the actual reported energy usage of the unit.

Scoring.

In order to score the residents' responses on the survey and to assign each resident a total score relating to energy behavior, a scoring rubric based on the work of Jared Langevin was created (Gurian, Langevin & Wen, 2013). The rubric assigned a score of 1, 2, 3, or 4 to each answer given, depending on the question (Appendix B). For example, a question asking if the tenant uses a personal space heater in the winter would be answered with either a Yes or No. In this case, the yes would be worth two points on the rubric, and the no only one.

The lower the score, the more energy efficient the residents' behavior. Each survey was scored using the rubric, and the total of each section's score was recorded, along with the combined total score. The lowest possible, median possible, and highest possible scores were also totaled and noted for each individual section and the entire survey.

Building Performance Engineering (BPE) Protocol

One of the major aspects of building performance is air leakage. Air leakage can increase heating and cooling costs over 30%, and mitigating air leakage can be very difficult (Southface Energy Institute, 2013). A building's air barrier is the primary component designed to control air leakage, and the air barrier provides several benefits to the building's occupants. The main benefits of air leakage control are energy savings, increased comfort, protection of the building insulation's thermal integrity, reduction of direct cooling or heating by outdoor air, and avoidance of moisture migration into building cavities (Dorsi & Krigger, 2004). Any problems with the air barrier in a building can disrupt the thermal boundary and contribute to comfort, health, and safety problems (Building Performance Engineering, 2012).

Finding problems with the air barrier, particularly in hidden locations, can be quite difficult. It was not until blower door testing units were developed and implemented that finding hidden air leaks became much easier. Blower doors use variable speed fans to pressurize or depressurize a building, which makes it easier to feel/test for air infiltration, and when a blower door is used in conjunction with a digital manometer, the relative leakiness of a building can be measured. Common terms in building performance testing for air leakage include air changes per hour at 50 Pascals, or ACH50; cubic feet per minute at 50 Pascals, or

CFM50; cubic feet per minute at 25 Pascals, or CFM25; and natural air changes per hour, or NACH.

Unit testing: Blower door and duct blaster testing.

Based on the energy data gathered by KHRA, six units were selected for testing. The units were chosen based on one full year of electricity consumption in relation to the average electricity consumption of the 20 units from which tenants had returned surveys. The 20 units had an average annual consumption of 16,771 kWh per unit. In order to test an average range of consumption values, one unit was chosen that had an annual kWh consumption near the development average, one unit was chosen that had below-average annual kWh consumption, and one unit was selected that had above-average annual kWh consumption. Also, KHRA specifically requested that three other units be added to the testing. The units selected and their individual kWh consumptions can be seen in Table 3. The same testing protocol was followed for each unit.

Table 3. *Selection of Six Units for Building Performance Testing*

KwH		Consumption													
Address	Street	July	August	September	October	November	December	January	February	March	April	May	June	Total	Avg. Annual kWh Consumption
212	Carver	1728	1560	1381	939	1421	2016	2096	1900	1852	1238	997	1165	18293	16,771
240	Carver	1758	1846	1838	1352	1734	2679	2576	2498	2499	2101	2157	2454	25492	16,771
1019	Douglass	1999	1688	1067	854	2212	3059	3125	3258	3261	2651	2119	2366	27659	16,771
238	Louis	2,398	1,919	2,287	1,905	2,390	2,576	2,787	2,089	2,029	1,378	970	1,110	23,838	16,771
1029	MLK, Jr	535	415	509	526	870	1,278	1,248	1,200	1,263	847	585	598	9,874	16,771
336	Wheatley	1,682	1,445	1,435	866	1,266	1,879	2,006	1,821	1,632	1,102	741	1,009	16,884	16,771
Total		10,100	8,873	8,517	6,442	9,893	13,487	13,838	12,766	12,536	9,317	7,569	8,702	122,040	
Average		1,683	1,479	1,420	1,074	1,649	2,248	2,306	2,128	2,089	1,553	1,262	1,450	20,340	

Due to the absence of combustion appliances, fireplaces, and attached garages, the prerequisite of worst-case depressurization and carbon monoxide testing was not needed. The data collection testing protocol began with each unit being set to natural conditions, meaning each unit was set up to minimize driving forces like wind, mechanical fans, and stack effect on the home. To do this all mechanical fans were turned off including the heating and cooling system, clothes dryers, kitchen exhaust fans, bathroom exhaust fans, and ceiling fans. Additionally, all exterior doors and windows were closed and locked, all interior doors were opened, all dampers were closed, and the blower door fan (after it was set up) was covered. After setting up the house for natural conditions, the manometer was calibrated to the testing conditions, which essentially zeros out any existing pressures in the house at the time of baseline (Figure 8). To perform the baseline function, the researcher presses baseline on the manometer, and then start. After 30 to 60 seconds, or when the number appearing on Channel A remains steady for several seconds, the baseline was entered and recorded (Building Performance Engineering, 2012).

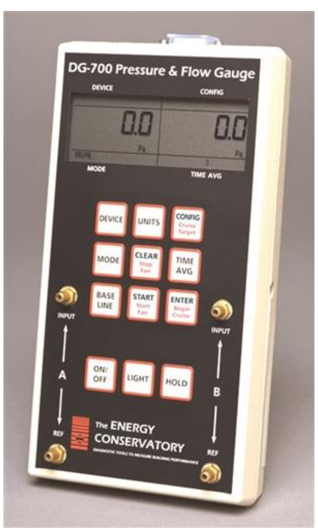


Figure 8. Hand-held manometer showing calibration to test conditions.

This same pre-testing protocol was repeated in each unit before the research team performed the actual building performance tests. Once each house had been set up and the baseline was recorded, the team proceeded with an untaped blower door test, a taped blower door test, and a duct blaster test.

Untaped blower door test.

The first test conducted on each unit was an untaped blower door test. The test was called an "untaped" blower door test because in the testing sequence both an untaped blower door test and a taped blower door test were performed. This sequence of tests allowed the researcher to make a rough estimate of the total duct leakage in the house. The untaped blower door test is also the basis for the air changes per hour calculation.

Typically, while one researcher set up the house for natural conditions, the other installed the blower door apparatus in the front entry door. The blower door apparatus includes a frame; flexible, airtight fabric large enough to fill an empty doorway; a variable speed fan with interchangeable rings and a controller; and hoses for attaching the manometer to the outdoors and to the fan (Figure 9). Once the blower door was set up in the entry door, the HVAC system's filter was removed, the house was set to natural conditions, and a baseline was established, the untaped blower test was ready to be conducted.

Figure 9. Blower door mock set-up.

To conduct the test, one hose was extended from the A Reference of the manometer to the outside, and one hose was extended from the A Input of the manometer to the blower door's fan. Care was taken to ensure that the hose extending to the outside was free of water, debris, and off to one side so as not to be affected by the fan. The manometer was then turned on and the mode was set to PR/FL@50, the device was set to Blower Door 3 (BD 3), and the manometer was configured for the ring setup of the blower door fan. All rings were removed from the blower door fan except for the A ring and the fan was slowly brought up to speed so that the reading on the A Channel of the manometer was -25 Pascal (Pa). Once a pressure of -25 Pa was reached, one member of the research team would walk around the home, ensuring that everything was fine with the natural conditions setup of the home. After the walkthrough, the fan speed was slowly adjusted to reach -50 Pa on the A Channel. The CFM@50 was then recorded from the B Channel of the manometer. At the conclusion of the untaped blower door test, the research team proceeded to the second test in sequence, the taped blower door test (Building Performance Engineering, 2012; The Energy Conservatory, 2012; The Energy Conservatory, 2014).

Taped blower door test.

A taped blower door test was also performed so that the researcher could make a very quick rough estimate of duct leakage before setting up duct blaster testing by subtracting the taped test from the untaped test (Dorsi & Krigger, 2004). The taped test is inherently less accurate than duct blaster testing, but it aided the process for the researcher. To set up for the taped blower door test, all the supply and return registers were sealed with tape to determine the air leakage through the building envelope. The testing protocol for the taped blower door test was the same as for the untaped blower door test. The only changes made were to accommodate "LOW" readings when trying to record the CFM@50 in the two duplexes tested. When this happened, the fan was turned off and Ring B was installed. The manometer was configured to Ring B and the fan was turned on and slowly brought back to speed. Once the fan reached the speed where the A Channel on the manometer read -50 Pa, the CFM@50 was then recorded from the B Channel. The final measurement concluded the blower door phase of testing, but before the supply and return registers were untaped, the research team moved on to the final test, the duct blaster (Building Performance Engineering, 2012; The Energy Conservatory, 2012).

Duct blaster.

The duct blaster test was the final building performance test conducted in each unit. The test was set up to measure the total leakage of the duct system, meaning the blower door was not used during this phase of testing. To conduct the test, the registers were left sealed from the taped blower door testing and a pressure relief to the outside was opened near the space where the duct blaster was positioned. Before attaching the duct blaster to the main return of the HVAC system, the flow conditioner was inserted. Then the duct blaster was attached with the fan exhaust facing the return. A hose was run from the A Input on the manometer to the furthest accessible register, and a hose was run from the B Input to the fan. Ring 3 was installed and the manometer was calibrated for testing (Figure 10). The mode was set to PR/FL@25; the device was set to the duct blaster DBB; and the manometer was configured for Ring 3, A3.

Figure 10. Duct blaster mock set-up.

Once set-up was complete, the fan speed was slowly raised until the manometer read -25 Pa in the A Channel. When the pressure was reached, the CFM25 measurement was recorded from the B Channel (Building Performance Engineering, 2012; The Energy Conservatory, 2014). This concluded building performance testing in each of the duplex units because they only had one HVAC system. However, in each of the other two-story, single-family units, a second duct blaster test had to be conducted because the houses were built with two separate HVAC systems, one serving each floor of the unit. In these cases, once the initial duct blaster test was finished on the lower level, the process was repeated on the upper level of each home.

Energy Use Data

Energy data was acquired from KHRA in two forms. First, electrical consumption data was acquired that showed each of Riverview Place's units and its associated electrical consumption from July 2012 to January 2014. Second, a report from Goodwin & Associates, LLC was acquired that showed the original *predicted* electrical consumption per month for each of the five different housing unit styles used in Riverview Place. Goodwin & Associates, LLC is an energy audit and conservation-consulting firm based in Ball Ground, Georgia. The "Utility Allowance Study" they conducted for KHRA proposed allowances on an annual and monthly basis for each unit type at Riverview Place (Goodwin and Associates, 2010). The utility allowances were based on all building-related requirements, including lighting, refrigeration, television, stereo, washing machines, small appliances, space heating, domestic hot water, and cooking. The allowances were also based on accepted engineering heat loss/gain calculation methods. These methods recognized the thermal design characteristics of each unit type and the estimates reflected energy need variations required for the unit structure's major systems and orientation of each building type. KHRA requested additional data for air conditioning, which was provided, but under HUD regulations at the time KHRA was not obligated to provide an allowance for air conditioning. Furthermore, the charge per kWh mandated by the electrical provider, American Electric

Power, was detailed in the report by Goodwin & Associates as being 0.07463 dollars per kWh. KHRA used the data from Goodwin & Associates to set monthly consumption allowances in kWh and dollars for electricity at each of the units in Riverview Place. The calculations provided by Goodwin & Associates served as a comparison for the independent energy model prepared in the current study.

Home Energy Saver™.

Home Energy Saver™ was the first Internet-based tool for calculating energy use in residential buildings. It was developed and is currently maintained by the Lawrence Berkeley National Laboratory, with sponsorship from the USDOE. Students and researchers periodically use the program as a tool for analyzing residential energy performance issues, and it was selected as the energy-modeling program for this study. Home Energy Saver™ makes many of its calculations, including heating and cooling consumption, using the DOE-2.2e building simulation program developed by the USDOE (Lawrence Berkeley National Labratory, 2014).

Home Energy Saver™ was chosen for this study because it is a free web-based program and KHRA could implement the use of this program in the future without the need to hire a professional or pay any licensing fees. Each of the six units subjected to building performance testing were entered into the HES program using the simple inputs. The simple inputs were used in lieu of the detailed units for two primary reasons. First, a study completed at Appalachian State University in 2011 demonstrated that the difference in accuracy using default calculations, or those inputs not required during simple inputs, and programs requiring more detailed inputs was found to differ by only 3.6% (King, 2011). Also, the simple inputs were used to mimic what was assumed any layperson at KHRA would be able to operate without extensive guidance. Table 4 specifies the differences between simple and detailed inputs in HES.

Table 4. *Comparison of "Simple Inputs" level in HES vs. "Detailed Inputs" level (Mills, 2008).*

Major End-Use	**Simple Inputs Level**	**Detailed Inputs Level**
Heating and Cooling	City with similar climate House construction year Conditioned floor area Stories above ground level Orientation Foundation type Ceiling/floor/wall insulation Heating/cooling equipment Window area (each side of house) Number of occupants in age groups (also affects water heating)	Approximately 80 additional questions about house shape & size; exterior shading; air-tightness; foundation & floor; walls; doors & windows; skylights; attic & roof; ducts & boiler pipes; thermostat details; heating & cooling equipment (efficiency, vintage, etc.)
Water Heating	Water heater fuel	Eight additional questions about temperature settings, water heater location and specifics, etc.
Major Appliances	Number of refrigerators (1-3) Number of freezers (0-2) Presence of clothes washer	Specific details about the refrigerators and freezers specified in the simple level; 8 questions about cooking and your dishwasher; 5 questions about clothes washers/dryers; 8 questions about hot tubs, spas and pumps
Lighting	No questions	Two levels – 1st asks for the number of fixtures/room, energy consumption/fixture defaulted based on TPU study, 2nd asks for detains on the number of bulbs, bulb type, total wattage and usage for each fixture.
Small Appliances	No questions	Roughly 50 questions about entertainment, home office, misc. kitchen appliances and other appliances.

The simple inputs cover two major sections: (1) building design and (2) appliances and equipment. These sections, coupled with the general inputs at the front of the program pertaining to energy prices and climate zones, provided enough data for the results from these units to be compared to the actual energy data for each unit from July 2012 to January 2014 and to the predicted energy use values calculated by Goodwin & Associates.

The basic information needed for an energy model in Home Energy Saver™ included:

- Number of stories above ground
- Square feet of conditioned area
- Type of foundation
- Insulation levels for floors, walls, ceilings, and roof
- Airtightness/Air leakage prevention details
- Window type and window area
- Appliance information, including heating and cooling equipment and thermal distribution

After simple data input, the results for each of the six tested units were recorded and grouped with the relevant energy data collected previously (Lawrence Berkeley National Labratory, 2014).

CHAPTER 4: RESEARCH FINDINGS

Tenant Survey Research Findings

The tenant surveys were scored based on a scoring rubric (Appendix B) taken from a study by Jared Langevin from Drexel University. The resulting scores for each respondent can be found in Table 5. The numbers in the left-hand column of each section of the table represent each of the 20 residents who responded to the survey. The numbers in the right-hand column of each section represent the score for that section of the survey for each surveyed respondent. These numbers were derived using a scoring rubric shown in Appendix B.

Table 5. *Breakdown of Tenant Survey Responses and Scores*

Scoring Index per Survey Section									
Possible Points for Background Information		Possible Points for General Qaulity and Comfort Assessment		Possible Points for Energy Use Habits		Possible Points for Energy Costs, Knowledge, Willingness		Total Possible Points in Survey	
Lowest:	3	Lowest:	5	Lowest:	17	Lowest:	15	Lowest:	40
Median:	5	Median:	10	Median:	42	Median:	38	Median:	95
Highest:	8	Highest:	15	Highest:	60	Highest:	60	Highest:	143

Survey Breakdown									
Background Information		General Quality and Comfort Assessment		Energy Use Habits		Energy Costs, Knowledge, Willingness		Total Survey Scores	
Survey	Score	Survey	Score	Survey	Score	Survey	Score	Survey	Score
1	4	1	5	1	24	1	19	1	52
2	5	2	8	2	33	2	30	2	76
3	6	3	7	3	41	3	32	3	86
4	4	4	5	4	37	4	33	4	79
5	6	5	9	5	40	5	33	5	88
6	4	6	7	6	40	6	26	6	77
7	5	7	7	7	37	7	28	7	77
8	5	8	9	8	33	8	28	8	75
9	6	9	9	9	35	9	28	9	78
10	6	10	5	10	38	10	25	10	74
11	7	11	5	11	33	11	22	11	67
12	4	12	6	12	30	12	21	12	61
13	3	13	8	13	28	13	33	13	72
14	7	14	9	14	32	14	27	14	75
15	7	15	5	15	38	15	14	15	64
16	6	16	7	16	34	16	20	16	69
17	6	17	8	17	52	17	39	17	105
18	4	18	5	18	26	18	17	18	54
19	5	19	9	19	39	19	25	19	78
20	6	20	5	20	36	20	30	20	77
Avg. Score:	5.3	Avg. Score:	6.9	Avg. Score:	35.3	Avg. Score:	26.5	Avg. Score:	74.2
Low Score:	3	Low Score:	5	Low Score:	24	Low Score:	14	Low Score:	52
High Score:	7	High Score:	9	High Score:	52	High Score:	39	High Score:	105

All respondents to the survey reported better general quality and comfort than the median score of 10 for the section. Additionally, all but one tenant reported energy use habits below the median score of 42 for that section, essentially reporting that all but one tenant was moderately efficient with their energy use. However, when asked "In a typical month, do you usually pay an excess electric bill to KHRA?" 70% of tenants participating in the survey answered "yes." All surveyed tenants use heating and cooling. In the winter months, 20% of surveyed participants reported never adjusting their thermostat for heating and 25% reported using personal heaters in addition to their heat pump. Half of those surveyed stated that they never switch off their thermostat during the winter months, even if they are away. In the summer, 65% of respondents stated that they never turned off their thermostats when leaving the house.

Regarding lighting, most tenants turned off their lights when leaving the house, but 60% of residents stated that they only sometimes or never turned off the lights when leaving the room. Additionally, 60% of surveyed tenants reported that they do not turn off the television when they are not watching it. Outside the scope of multiple choice questioning, in the comments section, three survey respondents reported that they noticed problems with the level of insulation and air sealing in their homes, specifically in the laundry room and living room.

Building Performance Research Findings

Each of the six houses were tested according to the Building Performance Engineering protocol for infiltration and total duct leakage was compared to the minimum values necessary to qualify as an ENERGY STAR home based on ENERGY STAR Qualified Homes, Version 3.1 (Rev. 02) National Program Requirements (USEPA, 2014).

Additionally, the results of the tests were compared to the 2006 International Energy Conservation Code, Tennessee's current energy code, and to the 2012 International Energy Conservation Code (IECC) (ICC, 2006; ICC, 2012). The 2006 IECC requires a specific leakage area of 0.00036 which was converted to an ACH50 of 7. The results from each test are detailed for each house in the sections that follow but related data on unit types and size can be found in Table 6 (for expanded results see Appendix D).

Table 6. *Building Performance Related Characteristics Of Six Tested Units*

Building Performance Related Data					
Identifier:	1029 MLK	**Identifier:**	336 Wheatley	**Identifier:**	238 Louis
Model:	Thompson	**Model:**	Blye	**Model:**	Pierce
1st Floor Area:	1289	**1st Floor Area:**	1046	**1st Floor Area:**	1080
2nd Floor Area:	N/A	**2nd Floor Area:**	425	**2nd Floor Area:**	427
Total Floor Area:	1289	**Total Floor Area:**	1471	**Total Floor Area:**	1507
Ceiling Height:	8	**Ceiling Height:**	8	**Ceiling Height:**	8
Building Volume:	10312	**Building Volume:**	11768	**Building Volume:**	12056
Number of Stories Above Grade:	1	**Number of Stories Above Grade:**	2	**Number of Stories Above Grade:**	2
Location:	Kingsport, TN	**Location:**	Kingsport, TN	**Location:**	Kingsport, TN
Identifier:	212 Carver	**Identifier:**	1019 Douglass	**Identifier:**	240 Carver
Model:	Cunningham	**Model:**	Banner	**Model:**	Dobbins
1st Floor Area:	1028	**1st Floor Area:**	1289	**1st Floor Area:**	1028
2nd Floor Area:	532	**2nd Floor Area:**	N/A	**2nd Floor Area:**	532
Total Floor Area:	1560	**Total Floor Area:**	1289	**Total Floor Area:**	1560
Ceiling Height:	8	**Ceiling Height:**	8	**Ceiling Height:**	8
Building Volume:	12480	**Building Volume:**	10312	**Building Volume:**	12480
Number of Stories Above Grade:	2	**Number of Stories Above Grade:**	1	**Number of Stories Above Grade:**	2
Location:	Kingsport, TN	**Location:**	Kingsport, TN	**Location:**	Kingsport, TN

As can be seen in Table 6, the six units tested were of various sizes, ranging from the smallest duplex unit at 1289 sq. ft. to the largest single-family unit at 1560 sq. ft. The identifier is just the address of each unit and it was used for the sole purpose of identifying each of the tested units. Also, although it appears that some of the units tested are identical, each unit is actually a different model. Some of the models are the same size in terms of square footage and building volume; however, the number and size of windows and the interior layout varies.

Table 7. *Untaped Blower Door Test Results*

1029 MLK		**336 Wheatley**		**212 Carver**	
Untaped Blower Door Test		Untaped Blower Door Test		Untaped Blower Door Test	
CFM@50:	929	CFM@50:	1568	CFM@50:	1051
ACH@50:	5.41	ACH@50:	7.99	ACH@50:	5.05
NACH:	0.25	NACH:	0.46	NACH:	0.29
1019 Douglass		**238 Louis**		**240 Carver**	
Untaped Blower Door Test		Untaped Blower Door Test		Untaped Blower Door Test	
CFM@50:	796	CFM@50:	1472	CFM@50:	1171
ACH@50:	4.63	ACH@50:	7.33	ACH@50:	5.63
NACH:	0.22	NACH:	0.43	NACH:	0.33

Each of the tested units' untaped blower door test results were compared to ENERGY STAR requirements and to IECC requirements. In order to qualify as an ENERGY STAR home, the current infiltration rate not to be exceeded in climate zone 4 is 3 ACH50 (USEPA, 2014). None of the tested units came in at or under the required 3 ACH50, as can be seen in Table 7. The average amount by which each unit exceeded the ENERGY STAR standard was 3 ACH50. In addition, each of the units' results was compared to Tennessee's current energy code, the 2006 IECC, as well as to the more energy-efficient 2012 IECC. The air infiltration rate in the 2006 IECC is listed as not exceeding 7 ACH50, and two of the units failed to meet this requirement during the untaped blower door testing (ICC, 2006). The 336

Wheatley unit, 7.99 ACH50, and the 238 Louis unit, 7.33 ACH50, failed to meet the requirement, exceeding by .99 and .33 ACH50. The other four units met the code requirement by an average 1.82 ACH50. When the units were compared to the 2012 IECC, which has the same ACH50 requirement as the current ENERGY STAR standard (3 ACH50 for climate zone 4), the same result was seen in comparison to the ENERGY STAR standard (ICC, 2012).

The NACH values for each of the units were also calculated by dividing the ACH50 by the relevant N-factor for each unit. These values are included in Table 4, along with the CFM50 measurement. The average NACH was calculated to be .33 NACH, and the average CFM50 was calculated as 1164.5 CFM50. Additionally, 240 Carver and 1029 MLK underwent blower door testing in 2011 when KHRA hired Accu-Spec Inspection Services to conduct an energy efficiency study. These two units were the only comparable units from the current study that were included in a post-test by Accu-Spec. Accu-Spec's results from those two units are included in Tables 8 and 9, and both units currently show improvements in energy consumption compared to previous testing.

Table 8. *Accu-Spec's Blower Door Data from 2011 at 240 Carver Alongside Current Study Results*

Date:	April 28, 2011	Rating No.:	1144878
Building Name:	240 Carver StreFINAL	Rating Org.:	Accu-Spec Inspection Services
Owner's Name:	KHRA	Phone No.:	865-453-9965
Property:	240 Carver Street	Rater's Name:	Tom Maides
Address:	Kingsport, TN 37660	Rater's No.:	4803
Builder's Name:	N/A		
Weather Site:	Bristol, TN	Rating Type:	Confirmed Rating
File Name:	240 Carver Street - Dobbins - FINAL BS.blg	Rating Date:	4-5-11

Whole House Infiltration

Blower door test		
	Heating	Cooling
Natural ACH:	0.32	0.22
ACH @ 50 Pascals:	6.25	6.25
CFM @ 25 Pascals:	855	855
CFM @ 50 Pascals:	1342	1342
Eff. Leakage Area: [sq.in]	73.7	73.7
Specific Leakage Area:	0.00032	0.00032
ELA/100 sf shell: [sq.in]	1.84	1.84

Current Study Results 2014

240 Carver	
Untaped Blower Door Test	
CFM@50:	1171
ACH@50:	5.63
NACH:	0.33

Table 9. *Accu-Spec's Blower Door Data from 2011 at 1029 MLK alongside Current Study Results*

Date:	April 29, 2011	Rating No.:	1144895
Building Name:	1029 Martin LutFINAL	Rating Org.:	Accu-Spec Inspection Services
Owner's Name:	KHRA	Phone No.:	865-453-9965
Property:	1029 Martin Luther King	Rater's Name:	Tom Maides
Address:	Kingsport, TN 37660	Rater's No.:	4803
Builder's Name:	n/a		
Weather Site:	Bristol, TN	Rating Type:	Confirmed Rating
File Name:	1029 Martin Luther King - Thompson Dplx - FINA	Rating Date:	4-12-11

Whole House Infiltration

Blower door test		
	Heating	Cooling
Natural ACH:	0.21	0.15
ACH @ 50 Pascals:	5.66	5.66
CFM @ 25 Pascals:	593	593
CFM @ 50 Pascals:	930	930
Eff. Leakage Area: [sq.in]	51.1	51.1
Specific Leakage Area:	0.00029	0.00029
ELA/100 sf shell: [sq.in]	1.54	1.54

Current Study Results 2014

1029 MLK	
Untaped Blower Door Test	
CFM@50:	929
ACH@50:	5.41
NACH:	0.25

Table 10. *Taped Blower Door Test Results*

1029 MLK		**336 Wheatley**		**212 Carver**	
Taped Blower Door Test		Taped Blower Door Test		Taped Blower Door Test	
CFM@50:	916	CFM@50:	1438	CFM@50:	960
ACH@50:	5.33	ACH@50:	7.33	ACH@50:	4.62
NACH:	0.25	NACH:	0.43	NACH:	0.27
1019 Douglass		**238 Louis**		**240 Carver**	
Taped Blower Door Test		Taped Blower Door Test		Taped Blower Door Test	
CFM@50:	711	CFM@50:	1309	CFM@50:	1017
ACH@50:	4.14	ACH@50:	6.51	ACH@50:	4.89
NACH:	0.19	NACH:	0.38	NACH:	0.28

The taped blower door test results (Table 10) were also compared to the same ENERGY STAR, 2006 IECC, and 2012 IECC standards. These results were indicative of losses specific to the building envelope and gave the researcher a clearer picture of whether losses in each unit were more prevalent in the duct system or the building envelope. The results, when compared with the three standards used previously, yielded very similar results; however, the 238 Louis unit passed the 2006 IECC code requirement of 7 ACH50 when taking the taped blower door test measurement (ICC, 2006; ICC, 2012; USEPA, 2014).

Table 11. *Duct Blaster Results With ENERGY STAR/2012 IECC Target Totals*

1029 MLK				**336 Wheatley**				**238 Louis**			
1st Floor Duct Blaster		2nd Floor Duct Blaster		1st Floor Duct Blaster		2nd Floor Duct Blaster		1st Floor Duct Blaster		2nd Floor Duct Blaster	
CFM@25:	71	CFM@25:	N/A	CFM@25:	101	CFM@25:	39	CFM@25:	94	CFM@25:	72
Target Total:	51.56	Target Total:	N/A	Target Total:	41.84	Target Total:	17	Target Total:	43.2	Target Total:	17.08
212 Carver				**1019 Douglass**				**240 Carver**			
1st Floor Duct Blaster		2nd Floor Duct Blaster		1st Floor Duct Blaster		2nd Floor Duct Blaster		1st Floor Duct Blaster		2nd Floor Duct Blaster	
CFM@25:	86	CFM@25:	67	CFM@25:	86	CFM@25:	N/A	CFM@25:	69	CFM@25:	143
Target Total:	41.12	Target Total:	21.28	Target Total:	51.56	Target Total:	N/A	Target Total:	41.12	Target Total:	21.28

Building performance testing concluded with duct blaster testing in each of the six units. Table 11 shows the results of tests on the first and, if applicable, second floor systems and the target total duct leakage representing the maximum value that cannot be exceeded to obtain ENERGY STAR certification and/or to meet the 2012 IECC code requirement. The testing showed that none of the units had duct systems that met the total duct leakage requirement of ≤ 4 CFM25 per 100 sq. ft. required by both the current ENERGY STAR standards and the 2012 IECC, with an average total system leakage over the target total of 48 CFM25. Table 12 shows the same duct blaster tests compared against the 2006 IECC requirement of total duct leakage ≤ 9 CFM25 per 100 sq. ft.

Table 12. *Duct Blaster Results With 2006 IECC Target Totals*

1029 MLK		336 Wheatley		238 Louis	
1st Floor Duct Blaster	2nd Floor Duct Blaster	1st Floor Duct Blaster	2nd Floor Duct Blaster	1st Floor Duct Blaster	2nd Floor Duct Blaster
CFM@25: 71	CFM@25: N/A	CFM@25: 101	CFM@25: 39	CFM@25: 94	CFM@25: 72
Target Total: 116.01	Target Total: N/A	Target Total: 94.14	Target Total: 38.25	Target Total: 97.2	Target Total: 38.43
212 Carver		**1019 Douglass**		**240 Carver**	
1st Floor Duct Blaster	2nd Floor Duct Blaster	1st Floor Duct Blaster	2nd Floor Duct Blaster	1st Floor Duct Blaster	2nd Floor Duct Blaster
CFM@25: 86	CFM@25: 67	CFM@25: 86	CFM@25: N/A	CFM@25: 69	CFM@25: 143
Target Total: 92.52	Target Total: 47.88	Target Total: 116.01	Target Total: N/A	Target Total: 92.52	Target Total: 47.88

In all but one case, the first floor duct system passed the 2006 IECC requirement, and the second floor system failed. The first floor systems tests reported values that ranged from 69 CFM23 to 101 CFM25, and the applicable second floor tests ranged from 39 CFM25 to 143 CFM25. The exception was the case of the 336 Wheatley unit, which failed to meet the requirement for the first floor system with a 101 CFM25. However, the 336 Wheatley unit had the best performing second floor system at 39 CFM25. The notable outlier was the second floor test at 240 Carver, which measured 143 CFM25, when the target total for the 2006 IECC is 47.88 CFM25, this coming after the first floor system test revealed the best performance of the entire tested unit group with a measurement of 69 CFM25 (ICC, 2006; ICC, 2012; USEPA, 2014).

Energy Use Data Research Findings

The two sources of energy data from KHRA—the electricity consumption data from July 2012 to January 2014 and the predicted utility allowances from Goodwin & Associates were compared to evaluate the energy efficiency of the homes in their current state in relation to their modeled/predicted energy consumption. This gave the researcher a more accurate picture of each home's target energy consumption and predicted energy consumption.

In the reported period of July 2013 to January 2014, shown in Table 13, an average of 29 homes per month out of the 38 total exceeded the allotted utility allowance. During the months of December and January of the same reported period, all 38 homes exceeded their utility allowance, and in January 2014, 55% of these homes exceeded the allowance by over 1,000 kWh. However, the utility allowances currently used by KHRA do not take into account air conditioning, only heating.

Table 13. *July 2013 – January 2014, Comparison of Actual kWh Consumption to Calculated Allowances – Chosen by KHRA*

		kWh							Allowance							kWh Over Allowance							Percentage Over Allotted
Address	Street	July	August	September	October	November	December	January	July	August	September	October	November	December	January	July	August	September	October	November	December	January	Amount
204	Carver	698	549	578	701	1,068	1,607	1,840	675	672	676	784	908	1,044	1,094	23	0	0	0	160	563	746	25.49%
209	Carver	1,205	1,020	1,144	952	1,227	1,929	2,983	890	887	897	1,052	1,231	1,424	1,496	315	133	247	0	0	505	1,487	34.11%
212	Carver	1,141	1,988	1,805	1,250	1,429	2,339	2,890	927	924	932	1,076	1,241	1,419	1,486	214	1,064	873	174	188	920	1,404	60.42%
213	Carver	1,131	981	1,030	763	1,412	2,701	3,614	908	905	914	1,061	1,230	1,413	1,481	223	76	116	0	182	1,288	2,133	50.78%
216	Carver	1,663	1,709	1,605	1,188	920	2,004	2,396	890	887	897	1,052	1,231	1,424	1,496	773	822	708	136	0	580	900	49.75%
220	Carver	1,041	1,261	1,653	1,648	1,441	1,531	2,456	890	887	897	1,052	1,231	1,424	1,496	151	374	756	596	210	107	960	40.04%
224	Carver	1,003	1,007	1,014	1,013	1,450	2,359	2,362	895	892	901	1,046	1,213	1,394	1,462	108	115	113	0	237	965	900	31.24%
228	Carver	1,610	1,313	1,551	1,206	1,383	2,327	2,539	927	924	932	1,076	1,241	1,419	1,486	683	389	619	130	142	908	1,053	49.02%
232	Carver	1,717	2,018	1,694	937	1,058	2,409	2,957	908	905	914	1,061	1,230	1,413	1,481	809	1,113	780	0	0	996	1,476	65.39%
236	Carver	1,014	692	1,281	1,033	1,306	1,719	2,206	927	924	932	1,076	1,241	1,419	1,486	87	0	349	0	65	300	720	19.00%
237	Carver	1,601	1,182	1,282	1,107	1,354	1,985	2,284	927	924	932	1,076	1,241	1,419	1,486	674	258	350	31	113	566	798	34.85%
240	Carver	1,683	2,129	2,090	1,327	1,575	2,631	2,882	927	924	932	1,076	1,241	1,419	1,486	756	1,205	1,158	251	334	1,212	1,396	78.85%
241	Carver	1,511	1,306	1,511	1,024	1,181	2,208	2,544	890	887	897	1,052	1,231	1,424	1,496	621	419	614	0	0	784	1,048	44.26%
248	Carver	931	761	794	622	1,139	1,748	1,918	675	672	676	784	908	1,044	1,094	256	89	118	0	231	704	824	37.96%
1011	Douglass	600	508	640	366	875	1,372	1,698	675	672	676	784	908	1,044	1,094	0	0	0	0	0	328	604	15.92%
1015	Douglass	1,469	1,268	1,451	1,080	1,458	2,261	2,503	675	672	676	784	908	1,044	1,094	794	596	775	296	550	1,217	1,409	96.31%
1019	Douglass	2,172	2,032	2,211	1,837	2,200	3,757	3,781	675	672	676	784	908	1,044	1,094	1,497	1,360	1,535	1,053	1,292	2,713	2,687	207.36%
1023	Douglass	1,365	1,011	1,056	737	1,157	2,007	2,092	675	672	676	784	908	1,044	1,094	690	339	380	0	249	963	998	61.83%
1027	Douglass	1,153	695	1,373	945	870	1,442	1,671	675	672	676	784	908	1,044	1,094	478	23	697	161	0	398	577	39.88%
1031	Douglass	623	500	566	513	932	1,657	1,805	675	672	676	784	908	1,044	1,094	0	0	0	0	24	613	711	23.03%
206	Louis	1,002	850	825	704	1,085	1,569	1,937	675	672	676	784	908	1,044	1,094	327	178	149	0	177	525	843	37.57%
214	Louis	1,672	1,364	1,615	1,025	1,368	2,182	2,844	927	924	932	1,076	1,241	1,419	1,486	745	440	683	0	127	763	1,358	51.42%
218	Louis	1,301	1,199	1,288	961	1,380	2,361	3,000	890	887	897	1,052	1,231	1,424	1,496	411	312	391	0	149	937	1,504	47.02%
222	Louis	1,768	1,467	1,097	874	1,660	2,738	3,169	895	892	901	1,046	1,213	1,394	1,462	873	575	196	0	447	1,344	1,707	65.90%
226	Louis	1,056	1,165	1,001	611	1,631	2,527	3,375	908	905	914	1,061	1,230	1,413	1,481	148	260	87	0	401	1,114	1,894	49.34%
230	Louis	335	301	901	841	1,204	1,969	2,744	927	924	932	1,076	1,241	1,419	1,486	0	0	0	0	0	550	1,258	22.59%
234	Louis	1,334	1,135	1,212	742	1,426	2,470	2,896	890	887	897	1,052	1,231	1,424	1,496	444	248	315	0	195	1,046	1,400	46.31%
238	Louis	1,020	1,002	951	928	1,123	2,455	3,314	908	905	914	1,061	1,230	1,413	1,481	112	97	37	0	0	1,042	1,833	39.45%
242	Louis	1,276	650	1,551	980	1,066	1,884	2,051	895	892	901	1,046	1,213	1,394	1,462	381	0	650	0	0	490	589	27.04%
245	Louis	682	633	819	559	917	1,529	2,209	890	887	897	1,052	1,231	1,424	1,496	0	0	0	0	0	105	713	10.38%
1009	MLK, Jr	862	824	1,123	868	1,177	2,055	2,358	675	672	676	784	908	1,044	1,094	187	152	447	84	269	1,011	1,264	58.33%
1013	MLK, Jr	1,048	1,079	1,097	863	952	1,615	1,812	675	672	676	784	908	1,044	1,094	373	407	421	79	44	571	718	44.64%
1017	MLK, Jr	551	520	579	524	982	1,540	1,803	675	672	676	784	908	1,044	1,094	0	0	0	0	74	496	709	21.85%
1021	MLK, Jr	343	733	766	986	1,162	1,843	2,113	675	672	676	784	908	1,044	1,094	0	61	90	202	254	799	1,019	41.43%
1025	MLK, Jr	528	583	615	408	708	1,208	1,427	675	672	676	784	908	1,044	1,094	0	0	0	0	0	164	333	8.49%
1029	MLK, Jr	538	586	673	725	1,065	1,881	2,247	675	672	676	784	908	1,044	1,094	0	0	0	0	157	837	1,153	36.68%
336	Wheatley	1,008	1,118	1,276	773	1,117	1,929	2,665	890	887	897	1,052	1,231	1,424	1,496	118	231	379	0	0	505	1,169	30.49%
340	Wheatley	1,589	1,676	1,724	1,295	1,408	2,570	3,012	927	924	932	1,076	1,241	1,419	1,486	662	752	792	219	167	1,151	1,526	65.82%
	Total:	43,244	40,815	45,442	34,916	46,866	78,318	94,397							Total:	13,933	12,088	14,825	3,412	6,438	30,080	43,821	Average % Over Allotted
	Average:	1,138	1,074	1,196	919	1,233	2,061	2,484							Average:	367	318	390	90	169	792	1,153	46.59%

Number of Units Exceeding Allowance							
Total/Month:	30	28	30	13	26	38	38
Average Number of Units Exceeding Allowance/Month:				29			

Goodwin & Associates also prepared a utility allowance for Riverview Place using added kWh hours during the affected months of April-October, reflecting use of air conditioning (Table 14). Comparing the same reported energy use values from KHRA to the utility allowance including air conditioning provided by Goodwin & Associates lowered the average of homes exceeding their utility allowance from 29 to 25 homes. The most prominent change came during the months July through September. The number of homes exceeding the utility allowance in July fell from 30 homes to 19 homes, and in August it fell from 28 homes to 15 homes exceeding the allowance. Additionally, prior to comparing the reported energy use to the utility allowance with air conditioning, in July 40% of homes exceeded the utility allowance by more than 600 kWh. However, after the change, only 3% of homes exceeded the utility allowance by more than 600 kWh.

Table 14. *July 2013 - January 2014 kWh Consumption Over Calculated Allowance with Air Conditioning – Provided by Goodwin & Associates*

		Allowance Including Air Conditioning Values							kWh Over Allowance							
Address	Street	July	August	September	October	November	December	January	July	August	September	October	November	December	January	% Over Allowance with AC
204	Carver	923	887	768	803	908	1,044	1,094	0	0	0	0	160	563	746	22.86%
209	Carver	1,231	1,183	1,024	1,078	1,231	1,424	1,496	0	0	120	0	0	505	1,487	24.37%
212	Carver	1,242	1,197	1,049	1,100	1,241	1,419	1,486	0	791	756	150	188	920	1,404	48.19%
213	Carver	1,236	1,189	1,036	1,086	1,230	1,413	1,481	0	0	0	0	182	1,288	2,133	41.55%
216	Carver	1,231	1,183	1,024	1,078	1,231	1,424	1,496	432	526	581	110	0	580	900	36.10%
220	Carver	1,231	1,183	1,024	1,078	1,231	1,424	1,496	0	78	629	570	210	107	960	29.47%
224	Carver	1,223	1,176	1,023	1,071	1,213	1,394	1,462	0	0	0	0	237	965	900	24.55%
228	Carver	1,242	1,197	1,049	1,100	1,241	1,419	1,486	368	116	502	106	142	908	1,053	36.58%
232	Carver	1,236	1,189	1,036	1,086	1,230	1,413	1,481	481	829	658	0	0	996	1,476	51.21%
236	Carver	1,242	1,197	1,049	1,100	1,241	1,419	1,486	0	0	232	0	65	300	720	15.08%
237	Carver	1,242	1,197	1,049	1,100	1,241	1,419	1,486	359	0	233	7	113	566	798	23.77%
240	Carver	1,242	1,197	1,049	1,100	1,241	1,419	1,486	441	932	1,041	227	334	1,212	1,396	63.92%
241	Carver	1,231	1,183	1,024	1,078	1,231	1,424	1,496	280	123	487	0	0	784	1,048	31.41%
248	Carver	923	887	768	803	908	1,044	1,094	8	0	26	0	231	704	824	27.90%
1011	Douglass	923	887	768	803	908	1,044	1,094	0	0	0	0	0	328	604	14.50%
1015	Douglass	923	887	768	803	908	1,044	1,094	546	381	683	277	550	1,217	1,409	78.78%
1019	Douglass	923	887	768	803	908	1,044	1,094	1,249	1,145	1,443	1,034	1,292	2,713	2,687	179.91%
1023	Douglass	923	887	768	803	908	1,044	1,094	442	124	288	0	249	963	998	47.67%
1027	Douglass	923	887	768	803	908	1,044	1,094	230	0	605	142	0	398	577	30.37%
1031	Douglass	923	887	768	803	908	1,044	1,094	0	0	0	0	24	613	711	20.97%
206	Louis	923	887	768	803	908	1,044	1,094	79	0	57	0	177	525	843	26.16%
214	Louis	1,242	1,197	1,049	1,100	1,241	1,419	1,486	430	167	566	0	127	763	1,358	39.05%
218	Louis	1,231	1,183	1,024	1,078	1,231	1,424	1,496	70	16	264	0	149	937	1,504	33.92%
222	Louis	1,223	1,176	1,023	1,071	1,213	1,394	1,462	545	291	74	0	447	1,344	1,707	51.48%
226	Louis	1,236	1,189	1,036	1,086	1,230	1,413	1,481	0	0	0	0	401	1,114	1,894	39.31%
230	Louis	1,242	1,197	1,049	1,100	1,241	1,419	1,486	0	0	0	0	0	550	1,258	20.70%
234	Louis	1,231	1,183	1,024	1,078	1,231	1,424	1,496	103	0	188	0	195	1,046	1,400	33.83%
238	Louis	1,236	1,189	1,036	1,086	1,230	1,413	1,481	0	0	0	0	0	1,042	1,833	33.16%
242	Louis	1,223	1,176	1,023	1,071	1,213	1,394	1,462	53	0	528	0	0	490	589	19.39%
245	Louis	1,231	1,183	1,024	1,078	1,231	1,424	1,496	0	0	0	0	0	105	713	9.44%
1009	MLK, Jr	923	887	768	803	908	1,044	1,094	0	0	355	65	269	1,011	1,264	46.12%
1013	MLK, Jr	923	887	768	803	908	1,044	1,094	125	192	329	60	44	571	718	31.73%
1017	MLK, Jr	923	887	768	803	908	1,044	1,094	0	0	0	0	74	496	709	19.90%
1021	MLK, Jr	923	887	768	803	908	1,044	1,094	0	0	0	183	254	799	1,019	35.09%
1025	MLK, Jr	923	887	768	803	908	1,044	1,094	0	0	0	0	0	164	333	7.73%
1029	MLK, Jr	923	887	768	803	908	1,044	1,094	0	0	0	0	157	837	1,153	33.41%
336	Wheatley	1,231	1,183	1,024	1,078	1,231	1,424	1,496	0	0	252	0	0	505	1,169	22.22%
340	Wheatley	1,242	1,197	1,049	1,100	1,241	1,419	1,486	347	479	675	195	167	1,151	1,526	51.98%
								Totals:	6,588	6,190	11,572	3,126	6,438	30,080	43,821	Average % Over Allotted
								Averages:	173.37	162.89	304.53	82.26	169.42	791.58	1,153.18	36.94%
								Number of Units Exceeding Allowance								
								Total/Month:	19	15	25	13	26	38	38	
								Average Number of Units Exceeding Allowance/Month:					25			

Similarly, the annual data reported from July 2012 to June 2013, found in Appendix C, showed that an average of 32 of the 38 homes exceeded their annual utility allowance, and when comparing the data to the utility allowance with air conditioning, the average was 30 of 38 homes, and the exceeding amounts were much smaller when using the utility allowance with air conditioning (Goodwin and Associates, 2010).

The data show the kWh over the calculated allowance without air conditioning for the last full year of data from July 2012 to June 2013. The average amount of kWh over allowance is reported for each month, with December and January having the highest averages at 636 kWh and 594kWh, respectively. May and October had the lowest averages of 169 kWh and 91 kWh. In addition, the percentage of kWh over the allotted amount was also calculated. The average percentage over the allotted kWh was 42.43% without the air conditioning values, and 36.13% with the air conditioning values.

The data from July 2012 to June 2013 were also used to determine the total annual amount in dollars paid by the tenants of the six chosen units for testing. The annual allotment for each of the units was calculated using the total annual allotment without air conditioning, which varied from 9,937 kWh to 13,598 kWh, and the rate per kWh, which was reported as .084387 cents per kWh. These values were multiplied to derive the cost of the annual allotment. The annual allotment was then multiplied by the percentage of kWh consumption over the allowance, which permitted the total annual amount paid by the tenant for kWh consumption over the allotment to be determined. The results for the six units showed that the costs to the tenants for the excess kWh consumption ranged from $83.29 to $1,495.51 annually (Table 15).

Table 15. *2012-2013 Annual Amount Paid by Tenant for Excess Consumption*

Unit Identifier	kWh Total Annual Allotment	Rate $/kWh	Cost of Annual Allottment	Percentage Over Allotted kWh Amount	Total Annual Amount Paid by Tenant for Excess
240 Carver	13,598	$0.084387	$1,147.49	87.47%	$1,003.70
212 Carver	13,598	$0.084387	$1,147.49	35.53%	$407.76
1019 Douglass	9,937	$0.084387	$838.55	178.34%	$1,495.51
238 Louis	13,435	$0.084387	$1,133.74	77.43%	$877.88
1029 MLK	9,937	$0.084387	$838.55	9.93%	$83.29
336 Wheatley	13,369	$0.084387	$1,128.17	29.15%	$328.86

Home Energy Saver™ Findings

Each of the six homes on which building performance testing was conducted were also evaluated using Home Energy Saver™ (HES). These modeled findings were calculated in an attempt to verify the original predicted energy use calculations performed by Goodwin & Associates, and to identify key areas in which upgrades would have the most benefit. Table 16 shows the HES modeled annual energy consumption compared to both the current annual utility allowance and the annual utility allowance with air conditioning predicted by Goodwin & Associates.

Table 16. *Home Energy Saver™ Calculations of Annual kWh Consumption (Modeled)*

1029 MLK		336 Wheatley		238 Louis	
Model: Thompson	SQ FT: 1289	Model: Blye	SQ FT: 1471	Model: Pierce	SQ FT: 1507
HES Annual Kwh Consumption		HES Annual Kwh Consumption		HES Annual Kwh Consumption	
HES Predicted:	12,453	HES Predicted:	13,779	HES Predicted:	13,985
Curently Allotted:	9,937	Curently Allotted:	13,370	Curently Allotted:	13,436
Percent Difference:	25%	Percent Difference:	3%	Percent Difference:	4%
Allotted & Air Conditioning:	10,720	Allotted & Air Conditioning:	14,447	Allotted & Air Conditioning:	14,470
Percent Difference:	16%	Percent Difference:	-5%	Percent Difference:	-3%
212 Carver		**1019 Douglass**		**240 Carver**	
Model: Cunningham	SQ FT: 1560	Model: Banner	SQ FT: 1289	Model: Dobbins	SQ FT: 1560
HES Annual Kwh Consumption		HES Annual Kwh Consumption		HES Annual Kwh Consumption	
HES Predicted:	13,926	HES Predicted:	12,453	HES Predicted:	14,072
Curently Allotted:	13,598	Curently Allotted:	9,937	Curently Allotted:	13,598
Percent Difference:	2%	Percent Difference:	25%	Percent Difference:	3%
Allotted & Air Conditioning:	14,592	Allotted & Air Conditioning:	10,720	Allotted & Air Conditioning:	14,592
Percent Difference:	-5%	Percent Difference:	16%	Percent Difference:	-4%

Energy use in the four detached, single-family houses was very close to previously predicted values, only differing by a maximum of 4% from the annual utility allowance, and -5% from the annual utility allowance with air conditioning. The multi-family duplexes differed much more from the predicted values with a mean variance of 25% higher usage than the annual utility allowance and 16% from the annual utility allowance with air conditioning.

The yearly energy costs for six key areas in energy consumption are predicted by HES and reported as the total yearly energy cost for the house. HES then recommends a varying degree of upgrades to the six key areas, and recalculates the total yearly energy cost based on predicted upgrades. Table 17 shows the key areas determined by HES that would benefit the most from upgrades. The yearly energy costs for 336 Wheatley, which was the closet unit tested to the average kWh consumption of all units, are shown, both for the existing home and with upgrades.

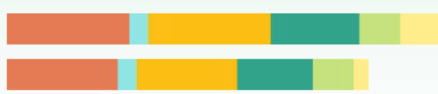
Table 17. *HES predicted yearly energy costs for 336 Wheatley.*

YEARLY ENERGY COSTS

Providing more details will make your results more accurate.

Existing Home $1,034

With Upgrades $855



	Total	Heating	Cooling	Hot Water	Large Appliances	Small Appliances	Lighting
Existing Home	$1,034	$287	$45	$288	$209	$97	$108
With Upgrades	$855	$257	$45	$238	$180	$97	$38
Savings	**$179**	**$30**	**$0**	**$50**	**$29**	**$0**	**$70**

Important Note: These are initial estimates only, and results may vary. If the owner has not already done so, we strongly recommend that they retain a professional energy auditor to develop a detailed work scope and budget for improving the home. We also recommend the Home Performance with ENERGY STAR program when considering home improvements.

The yearly energy cost of 336 Wheatley was reported as $1,034 in comparison to the cost of the allotted kWh (without air conditioning values), which was $1,128.17 (thus, HES estimated with 92% accuracy). HES recommended various upgrades to lower the yearly energy costs to $855, a savings of $179. The three most significant upgrades were suggested in lighting ($70), hot water ($50), and heating ($30). All of these changes are detailed in Table 18, along with a recommended large appliance upgrade. The recommended upgrade with the most savings potential was transitioning from incandescent lighting to compact fluorescent lighting (CFL). This upgrade had an added cost of $88 but a payback period of two years, and a return on investment of 33%. The hot water heater was also suggested for an upgrade, specifically upgrading to an ENERGY STAR-rated water heater. A water heater upgrade of this type was predicted to add a cost of $90 and result in a payback period of three years with a return on investment of 39%.

Table 18. *HES-recommended detailed upgrades for 336 Wheatley.*

Lights (Incandescent to CFL)

Economic Benefits:	
Estimate Yearly Bill Savings:	$38
Estimated Lifetime Energy Savings:	$456
Estimated Added Cost:	$88
Maximum Price for 10 Year Payback:	$380
Return on Investment:	33%
Upgrade Pays for Itself in:	2 years

Water Heater (ENERGY STAR)

Economic Benefits:	
Estimate Yearly Bill Savings:	$35
Estimated Lifetime Energy Savings:	$420
Estimated Added Cost:	$90
Maximum Price for 10 Year Payback:	$350
Return on Investment:	39%
Upgrade Pays for Itself in:	3 years

Thermostat (Programmable)

Economic Benefits:	
Estimate Yearly Bill Savings:	$31
Estimated Lifetime Energy Savings:	$372
Estimated Added Cost:	$85
Maximum Price for 10 Year Payback:	$310
Return on Investment:	36%
Upgrade Pays for Itself in:	3 years

Clothes Washer (ENERGY STAR)

Economic Benefits:	
Estimate Yearly Bill Savings:	$28
Estimated Lifetime Energy Savings:	$336
Estimated Added Cost:	$90
Maximum Price for 10 Year Payback:	$280
Return on Investment:	30%
Upgrade Pays for Itself in:	3 years

CHAPTER 5: DISCUSSION AND CONCLUSIONS

Discussion

Tenant Behavior

This study has demonstrated the effect of tenant behavior and building performance on energy consumption, with specific regard to excess energy consumption in the Riverview Place development. In the tenant survey, the respondents reported a lower total score than the median score possible for the survey; however, the survey did not get into the details of specific behaviors such as heating the unit with the windows open. The survey did capture general energy consumption behaviors of tenants. For instance, the summer was the primary time tenants reported paying KHRA for excess kWh consumption. Additionally, 79% of tenants reported paying KHRA for excess kWh consumption in the spring, as did 93% of tenants in the fall and winter. The large portion of tenants paying for excess in the fall and winter relates to the fact that 85% of tenants reported that they either do not, or only occasionally, adjust their thermostats for heating, and that 50% of tenants never turn off their thermostats, even if they leave their unit. Also, 25% of tenants reported using personal space heaters in addition to the heating unit for the house.

Building Performance

One of the first factors to measure when studying energy consumption is building size (square footage). However, in the six-unit sample studied, size did not identify as a prominent factor in energy consumption. This led to the analysis and comparison of the code compliant construction of the development with ENERGY STAR standards and updated energy codes. It is clear that the development was built to comply with the 2006 IECC, which is the current statewide Tennessee energy code. The average untaped blower door test value of 6.01 ACH50 leaves room for a 49.9% improvement in air leakage should ENERGY STAR or the 2012 IECC be the minimum standard (maximum infiltration: 3 ACH50). Comparably, when observing the data for the first-floor duct systems in the six tested units, achieving the minimum ENERGY STAR and 2012 IECC goal of ≤ 4 CFM25 per 100 sq. ft. would result in a 52.9% improvement over the current first-floor systems. Furthermore, the current study's comparison to the building performance tests performed by Accu-Spec Inspection Services in 2011 helps confirm the existing development's use of the 2006 IECC as a baseline and helps to highlight the additional modifications that would be needed to meet the 2012 IECC requirements or the ENERGY STAR standard.

Energy Use

Perhaps the most significant finding of the study was that the current energy subsidy does not include any allotment for air conditioning. The most recent reported data from July 2013 to January 2014 shows that the tenants in all 38 units exceeded the energy subsidy, which was based on projected consumption *without* air conditioning, by an average of 46.59%. By simply basing the energy subsidy on the Goodwin & Associates projection that included air conditioning, the percentage of units that exceed their allotment would be reduced to 36.94%. This still represents a significant percentage of tenants who pay for overages, but it brings the subsidies they are allotted more in line with actual practice.

Home Energy Saver™ modeling recommended other improvements aimed at reducing energy consumption and saving money on energy bills. The four suggested upgrades were:

1. Replace incandescent lighting (specified in Riverview Place blueprints) with compact fluorescent lighting.
2. Replace water heaters (the A.O. Smith DEL-50 model specified in blueprints is not ENERGY STAR certified) with ENERGY STAR rated water heaters.
3. Replace thermostats with programmable thermostats.
4. Replace clothes washers (not provided with unit; hook-ups only) with ENERGY STAR rated clothes washers.

HES calculated that making the suggested changes would result in energy savings of $179 per year, with a payback period of no longer than three years for each of the upgrades. Obviously, any upgrade would be dependent on the ability of the KHRA or the tenant to pay for the modification, but lower-cost upgrades should be considered as a starting point.

Implications and Recommendations

The following section represents the second aim of the study and is presented in the form of recommendations to the Kingsport Housing and Redevelopment Authority. These recommendations span all three aspects of the Riverview Place development that were studied: tenant behavior, building performance, and energy use.

Tenant Behavior

Recommendation 1. Develop a tenant education program aimed at improving energy efficient behavior that is comprehensive enough to sustain long-term adoption of such behaviors. Address issues such as turning the lights off when leaving the room (60% of survey respondents reported only sometimes or never turning the lights off when leaving the room), turning the television off while not watching it (60% of surveyed tenants reported leaving the television on while not watching it), and adjusting the thermostat to save energy (turning the thermostat back 10° to 15° for 8 hours can save 5% to 15% a year on heating bills). Behavioral adjustments can result in 10-15% energy savings if significant follow-up efforts are made to ensure that tenants are accepting and applying what they learn. Due to KHRA's already existing tenant self-sufficiency programs, based on HUD's requirements, implementing an efficiency program would be possible.

Building Performance

Recommendation 2. Select an energy efficiency standard or updated energy code early on in the design process and ensure that it is achieved during the construction process with routine inspections. Meeting the code minimum 2006 IECC criteria results in a home that is roughly half as efficient as a home meeting the minimum requirements for ENERGY STAR or the 2012 IECC. Choose a standard that is achievable with the available degree of funding and support, and commit to it.

Recommendation 3. Replace all incandescent lighting with compact florescent lighting (CFL). Replacing incandescent lighting with CFLs is the best-suggested upgrade based on the completed energy modeling, and the lowest-cost modification.

Recommendation 4. Replace all non-ENERGY STAR appliances with ENERGY STAR rated appliances. The two clearest examples in the Riverview Place development are the water heaters and clothes washers. The water heater specified in the plans is not ENERGY STAR rated; and because no clothes washer is provided with the units, only a hook-up, tenants are free to install a clothes washer of their choice. Letting tenants install their own clothes washers reduces the control that KHRA has over energy consumption.

Recommendation 5. Replace thermostats with programmable thermostats. Programmable thermostats are a good way to indirectly control the heating and cooling in each unit without having to lock a traditional thermostat at a set temperature, and the programmable thermostat can “learn” to turn the thermostat down 10° to 15° during typical sleeping hours, which can save 5% to 15% a year on heating bills.

Energy Use

Recommendation 6. Use the kWh allowance provided by Goodwin & Associates that reflects the use of air conditioning as the basis for calculating energy allotments. Simply by using the allowance that relates most directly to actual tenant behavior, the average kWh overages can be reduced nearly 10%.

Conclusion

This study has demonstrated the importance of pursuing a holistic approach to achieving energy efficiency in public housing and the need for tenant energy efficient behavioral programs to be enacted. The Kingsport Housing and Redevelopment Authority’s goal of providing energy efficient public housing is commendable and can be achieved if the right steps are followed. The responsibility initially lies with KHRA, to adopt and achieve a defined level of energy efficiency from a building performance perspective, but subsequently the tenants must take responsibility for their behavior and commit to using energy efficiently in daily life. This can be facilitated through a well-designed tenant education program.

Future Studies

Future studies would benefit from building performance testing and energy auditing with the intent on obtaining a HERS score. HERS scores would provide a more up-to-date comparison for determining energy efficiency. Further research on the heating and cooling systems, specifically the systems' design and efficiency, would provide information on what percentage of excess energy consumption is due to heating and cooling each month. Such information could perhaps point to faulty equipment, which would have a significant impact on energy consumption. Finally, a future study that focuses more specifically on tenant behaviors and levels of understanding about energy consumption could provide the basis for a targeted tenant education program that could be implemented by the KHRA and by similar public housing authorities.

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APPENDIX A

KHRA Occupant Survey

Occupant Survey

Unit #:________

Kingsport Housing and Redevelopment Authority
Appalachian State University
12.01.13

Introduction:
We'd like to thank you for agreeing to participate in this occupant survey for the Kingsport Housing and Redevelopment Authority (KHRA). The purpose of this survey is to assess the performance of the KHRA Riverview Place development in terms of its occupants' levels of comfort and satisfaction with their interior living environments. In addition, your responses will help the KHRA identify new opportunities for saving energy at its properties while ensuring that the impacts of these energy saving measures on residents are well understood. The survey will be completed in a questionnaire format, and should take no longer than thirty minutes. Your participation is voluntary, and you may stop at any time. Your responses are confidential: while we will summarize general results for KHRA, we will not provide KHRA with information about who told us what.

By completing the survey you are agreeing to participate in the study.

I. BACKGROUND INFORMATION

Gender: ◯ Male ◯ Female

Age: ◯ 20-30yrs ◯ 31-40yrs ◯ 41-50yrs ◯ 51-60yrs ◯ 61-70yrs ◯ 71-80yrs ◯ 81-90yrs ◯ 91+

1. What type of building do you live in? (Please check one)
◯ Detached House ◯ Multi-family Duplex

2. How long have you lived in the Riverview Place development? (Please check one)
◯ Less than 1 year ◯ 1 – 3 years ◯ 3+ years

3. How much active time (not sleeping or out of the house) do you normally spend in your house on a typical weekday? (Please check one)
◯ 0-4 hours ◯ 5-9 hours ◯ 10-14 hours ◯ 15-19 hours ◯ 20-24 hours

4. How much active time (not sleeping or out of the house) do you normally spend in your house on a typical weekend? (Please check one)
◯ 0-4 hours ◯ 5-9 hours ◯ 10-14 hours ◯ 15-19 hours ◯ 20-24 hours

II. GENERAL QUALITY & COMFORT ASSESSMENT

1. How would you rate the overall comfort level of your home? (Please check one)
◯ Comfortable ◯ Sometimes Comfortable ◯ Uncomfortable

2. How is the temperature? (Please check one)
◯ Comfortable ◯ Sometimes Comfortable ◯ Uncomfortable

3. How is the humidity/moisture level in your home? (Please check one)
◯ Comfortable ◯ Sometimes Humid ◯ Humid

4. How is the air freshness/quality in your house? (Please check one)
◯ Good ◯ Sometimes Good ◯ Bad

5. How noisy are the appliances in your home (dishwasher, air conditioner, refrigerator, heat pump, water heater etc.) (Please check one)
◯ Quiet ◯ Sometimes Quiet ◯ Noisy

6. If you rated any of the above as unsatisfactory, is there a time of day or season when the problem is particularly bad? (Check all that apply)

	Morning	Afternoon	Night	Spring	Summer	Fall	Winter
Temperature	◯	◯	◯	◯	◯	◯	◯
Humidity/Moisture	◯	◯	◯	◯	◯	◯	◯
Air Quality	◯	◯	◯	◯	◯	◯	◯
Noise	◯	◯	◯	◯	◯	◯	◯

Please use this space to talk about any problems you have with temperature, humidity, air quality, and noise. Why do you think you may have these problems?

____

____

____

III. ENERGY USE HABITS

1. Do you use a thermostat to control the *heating* in your house? (Please check one)
◯ Yes ◯ No

2. If Yes, what temperature is typical? (Please check one)
◯ Below 60°F ◯ 60°F-80°F ◯ Above 80°F

3. If Yes, how frequently do you adjust the thermostat? (Please check one)
◯ Never ◯ Occasional Adjustment ◯ Frequent Adjustment

4. If Yes, do you ever switch off the thermostat? (Please check one)
◯ No ◯ Only when I'm away ◯ Always when not in use

5. Do you use a personal space heater to control the heating in your house? (Please check one)
◯ Yes ◯ No

6. If Yes, how frequently do you use the heater? (Check all that apply)
◯ Every day in the winter
◯ Every time I am cold regardless of the season
◯ Every time the HVAC is heating

7. Do you use a thermostat to control the *cooling* in your house? (Please check one)
◯ Yes ◯ No

8. **What temperature is typical? (Please check one)**
○ Below 60°F ○ 60°F-80°F ○ Above 80°F

9. **How frequently do you adjust the thermostat? (Please check one)**
○ Never ○ Occasional Adjustment ○ Frequent Adjustment

10. **Do you ever switch off the thermostat? (Please check one)**
○ No ○ Only when I'm away ○ Always when not in use

11. **Do you use an air conditioner to control the cooling in your house? (Please check one)**
○ Yes ○ No

12. **If Yes, how frequently do you use the air conditioner? (Check all that apply)**
○ Every day in the summer
○ Every time I am hot regardless of the season
○ Every time the HVAC is cooling

13. **Do you use fans to help cool your home? (Please check one)**
○ Yes ○ No

14. **If Yes, what type of fan do you use? (Please check one)**
○ Overhead Fan ○ Personal Fan

15. **When do you usually turn your fan on/off? (Please check one)**
○ I turn it on and run it all day when it's hot
○ I turn it on when the HVAC is cooling
○ I turn it on instead of running the air conditioner for the house

16. **Do you have any problems with any of your heating or cooling equipment? Please list any problems you may have.**

____

____

____

17. **How many hours during the day do you typically have your lights on? (Please check one)**
○ 0-4 hours ○ 5-9 hours ○ 10+ hours

18. **Does light from the sun affect when you turn on lights? (Please check one)**
○ Yes, I only turn lights on when it is dark outside
○ No, I use lights no matter if it is light or dark outside

19. **Do you turn off your lights when you leave your house? (Please check one)**
○ Yes ○ Sometimes ○ No

20. **Do you turn off your lights when you leave the room? (Please check one)**
○ Yes ○ Sometimes ○ No

21. **Do you have any blinds or shades on your windows? (Please check one)**
○ Yes ○ No

22. If Yes, are your blinds typically up or down depending on the time of day? (Please check all that apply)

	Morning	Afternoon	Night
Blinds/Shades Up	◯	◯	◯
Blinds/Shades Down	◯	◯	◯

23. Do you have any problems with any of your lighting equipment? Please list any problems you may have.

____

____

____

24. What other methods do you commonly use to adjust your comfort level inside your home? (Please check all that apply)

◯ I put on warm clothes when it's cold
◯ I put on lighter clothes when it's hot
◯ I switch rooms when one becomes uncomfortable
◯ I open windows when it's hot
◯ I open windows when it's cool

Other/s:

____

____

____

25. In a typical week, how many meals do you cook at home? (Please check one)

◯ Less than 5 ◯ 5-10 ◯ 11 or more

26. How many times a week do you use your stove? (Please check one)

◯ Less than 5 ◯ 5-10 ◯ 11 or more

27. How many times a week do you use your microwave? (Please check one)

◯ Less than 5 ◯ 5-10 ◯ 11 or more

28. How many times a week do you use your oven? (Please check one)

◯ Less than 5 ◯ 5-10 ◯ 11 or more

29. On a typical day, how many hours is your TV on? (Please check one)

◯ Less than 3 ◯ 3-6 ◯ 7 or more

30. Do you often leave the TV on while doing something else? (Please check one)

◯ Yes ◯ No

IV. ENERGY COSTS, KNOWLEDGE, & WILLINGNESS

1. In a typical month, do you usually pay an excess electric bill to KHRA? (Please check one)

◯ Yes ◯ No

2. If you answered Yes to question 1 what is the average amount per month that you pay in each season? (Please check one for each season)

	$1 - $20	$21 - $40	$41 - $60	$60+
Spring	○	○	○	○
Summer	○	○	○	○
Fall	○	○	○	○
Winter	○	○	○	○

3. Listed in the table below are several technologies and daily habits to reduce energy costs. Of these ways, please indicate whether you already do them, you don't do them but would like to, or that you have no interest in doing them. (Please check all that apply)

	I already do/have this.	I don't do/have this but would like to.	I don't have any interest in doing/having this.
Energy saving light bulbs	○	○	○
Pre-set thermostat	○	○	○
Wear warmer clothes in winter	○	○	○
Wear lighter clothes in summer	○	○	○
Switching off lights when not in room	○	○	○
Energy saving appliances	○	○	○
Energy saver computer settings	○	○	○
Low flow shower heads	○	○	○
Window fans	○	○	○
Keep windows closed with AC	○	○	○
Weatherize exterior (caulk air gaps, add insulation)	○	○	○
Put blinds down in summer	○	○	○
Reset thermostat at night or when out of home	○	○	○
Learn more about energy use	○	○	○

APPENDIX B

Survey Scoring Rubric

Survey Scoring Rubric

Background Information				
Type of Building	1 Multi-Family Duplex	2 Detached House		
Active Time in Home (Weekday)	1 0-9 hrs	2 10-14 hrs	3 15-24 hrs	
Active Time in Home (Weekend)	1 0-9 hrs	2 10-14 hrs	3 15-24 hrs	
			Section Total:	
General Quality and Comfort Assessment				
Comfort Level	1 Comfortable	2 Sometimes Comfortable	3 Uncomfortable	
Temperature	1 Comfortable	2 Sometimes Comfortable	3 Uncomfortable	
Humidity/Moisture Level	1 Comfortable	2 Sometimes Humid	3 Humid	
Air Quality	1 Good	2 Sometimes Good	3 Bad	
Noise	1 Quiet	2 Sometimes Quiet	3 Noisy	
			Section Total:	
Energy Use Habits				
Set Temperature (Heating)	1 Below 60	2 60-80	3 Above 80	
Adjust Thermostat (Heating)	1 Never	2 Occasionally	3 Frequently	
Turn off thermostat (Heating)	3 No	2 Only when away	1 Always when not in use	
Personal Heater	1 No	2 Yes		
Set Temperature (Cooling)	3 Below 60	2 60-80	1 Above 80	
Adjust Thermostat (Cooling)	1 Never	2 Occasionally	3 Frequently	
Turn off thermostat (Cooling)	3 No	2 Only when away	1 Always when not in use	
Added Air Conditioner	1 No	2 Yes		
Air conditioner frequency	1 Everyday in Summer	1 Everytime tenant is hot	1 Everytime the HVAC is cooling	
Fans	1 No	2 Yes		
Type of Fan	1 Overhead	2 Personal		
Use of fan	3 Turn it on and run it all day	2 Turn it on when HVAC is cooling	1 Turn it on in lieu of AC	
Light Usage	1 0-4 hrs	2 5-9 hrs	3 10+ hrs	
Does sunlight affect usage?	1 Yes	2 No		
Turn off lights when leaving house?	1 Yes	2 Sometimes	3 No	
Turn off lights when leaving room?	1 Yes	2 Sometimes	3 No	
Blinds or shades?	1 Yes	2 No		
Adjusting Comfort Level	Detract total number of replies			
Meals cooked at home	1 Less than 5	2 5-10	3 11 or more	
Stove	1 Less than 5	2 5-10	3 11 or more	
Microwave	1 Less than 5	2 5-10	3 11 or more	
Oven	1 Less than 5	2 5-10	3 11 or more	
TV	1 Less than 3	2 3-6	3 11 or more	
Energy Costs, Knowledge, Willingness				
Pay excess to KHRA	1 No	2 Yes		
Spring	1 1-20	2 21-40	3 41-60	4 60+
Summer	1 1-20	2 21-40	3 41-60	4 60+
Fall	1 1-20	2 21-40	3 41-60	4 60+
Winter	1 1-20	2 21-40	3 41-60	4 60+
ECM	x1 Already doing	x2 Interested in	x3 No interest	

APPENDIX C

Comparison of Energy Allowances With and Without Air Conditioning

Table 19. *July 2012 - June 2013, kWh Over Allowances, without Air Conditioning*

Address	Street	kWh Over Allowance												Percentage Over Allotted Amount
		July	August	September	October	November	December	January	February	March	April	May	June	
204	Carver	118	0	30	0	0	320	220	256	447	137	0	0	15.38%
209	Carver	529	211	31	0	0	133	178	238	380	214	65	509	18.61%
212	Carver	801	636	449	0	180	597	610	533	599	155	28	244	35.53%
213	Carver	340	75	203	0	157	823	1,011	1,111	1,085	338	0	0	38.28%
216	Carver	264	27	46	0	92	901	713	649	661	457	586	906	39.66%
220	Carver	779	365	371	0	89	533	352	430	580	323	0	466	32.07%
224	Carver	116	0	129	0	175	471	483	542	658	169	74	247	23.13%
228	Carver	1,126	681	749	244	171	596	302	540	490	306	256	816	46.16%
232	Carver	697	746	943	330	463	715	1,104	1,327	1,013	469	402	677	66.14%
236	Carver	877	518	607	0	110	43	790	673	904	253	0	176	36.41%
237	Carver	844	603	162	0	0	346	125	387	152	50	0	486	23.20%
240	Carver	831	922	906	276	493	1,260	1,090	1,131	1,246	1,018	1,188	1,533	87.47%
241	Carver	546	74	10	0	0	474	562	522	415	274	136	532	26.52%
248	Carver	445	215	248	0	217	577	455	403	536	263	32	208	36.22%
1011	Douglass	0	22	9	0	57	347	315	287	486	38	0	0	15.71%
1015	Douglass	1,116	960	1,277	218	642	1,145	891	855	972	844	649	640	102.74%
1019	Douglass	1,324	1,016	391	70	1,304	2,015	2,031	2,254	2,343	1,862	1,415	1,697	178.34%
1023	Douglass	943	158	207	0	270	927	547	471	650	356	324	491	53.78%
1027	Douglass	397	278	353	0	61	407	338	414	499	95	4	382	32.48%
1031	Douglass	0	8	0	0	71	365	335	371	381	86	0	0	16.27%
206	Louis	522	349	283	24	301	983	1,252	1,145	1,241	659	212	282	72.99%
214	Louis	1,246	813	998	287	326	766	698	664	588	346	204	622	55.58%
218	Louis	754	594	612	46	206	544	198	0	456	208	65	464	31.02%
222	Louis	1,012	508	481	85	308	548	566	448	474	271	92	883	42.84%
226	Louis	139	137	0	0	0	303	583	488	434	63	0	78	16.56%
230	Louis	905	413	454	0	308	935	779	755	701	266	50	150	42.04%
234	Louis	825	469	598	65	358	826	569	493	701	83	3	420	40.47%
238	Louis	1,490	1,014	1,373	844	1,160	1,163	1,306	730	787	310	18	208	77.43%
242	Louis	552	475	558	0	51	545	468	371	430	203	0	396	30.56%
245	Louis	103	0	0	0	0	0	0	45	0	0	0	0	1.11%
1009	MLK, Jr	501	388	536	305	425	867	819	693	876	349	153	434	63.86%
1013	MLK, Jr	640	365	436	36	117	412	354	376	436	247	0	343	37.86%
1017	MLK, Jr	0	0	0	0	35	375	316	302	416	158	0	0	16.12%
1021	MLK, Jr	384	657	1,111	404	290	662	301	222	330	21	0	0	44.10%
1025	MLK, Jr	217	0	0	0	0	477	340	262	338	19	0	0	16.63%
1029	MLK, Jr	0	0	0	0	0	234	154	196	345	58	0	0	9.93%
336	Wheatley	792	558	538	0	35	455	510	454	388	42	0	125	29.15%
340	Wheatley	938	738	772	227	423	1,059	894	631	854	514	454	647	59.94%
	Total:	23,113	14,993	15,871	3,461	8,895	24,149	22,559	21,669	24,292	11,524	6,410	15,062	Average % Over Allotted
	Average:	608	395	418	91	234	636	594	570	639	303	169	396	42.43%
Number of Units Exceeding Allowance														
Total/Month:		34	32	32	15	30	37	37	37	37	37	22	29	
Average Number of Units Exceeding Allowance/Month:					32									

Table 20. *July 2012 - June 2013, kWh Over Allowances with Air Conditioning*

Address	Street	kWh Over Allowance												Percentage Over Allotted Amount
		July	August	September	October	November	December	January	February	March	April	May	June	
204	Carver	0	0	0	0	0	320	220	256	447	137	0	0	13.13%
209	Carver	188	0	0	0	0	133	178	238	380	214	65	509	13.45%
212	Carver	486	363	332	0	180	597	610	533	599	155	28	244	28.81%
213	Carver	12	0	81	0	157	823	1,011	1,111	1,085	338	0	0	32.53%
216	Carver	0	0	0	0	92	901	713	649	661	457	586	906	35.07%
220	Carver	438	69	244	0	89	533	352	430	580	323	0	466	24.89%
224	Carver	0	0	7	0	175	471	483	542	658	169	74	247	20.17%
228	Carver	811	408	632	220	171	596	302	540	490	306	256	816	38.72%
232	Carver	369	462	821	305	463	715	1,104	1,327	1,013	469	402	677	57.26%
236	Carver	562	245	490	0	110	43	790	673	904	253	0	176	29.64%
237	Carver	529	330	45	0	0	346	125	387	152	50	0	486	17.10%
240	Carver	516	649	789	252	493	1,260	1,090	1,131	1,246	1,018	1,188	1,533	77.93%
241	Carver	205	0	0	0	0	474	562	522	415	274	136	532	22.04%
248	Carver	197	0	156	0	217	577	455	403	536	263	32	208	28.96%
1011	Douglass	0	0	0	0	57	347	315	287	486	38	0	0	14.56%
1015	Douglass	868	745	1,185	199	642	1,145	891	855	972	844	649	640	91.67%
1019	Douglass	1,076	801	299	51	1,304	2,015	2,031	2,254	2,343	1,862	1,415	1,697	163.14%
1023	Douglass	695	0	115	0	270	927	547	471	650	356	324	491	46.10%
1027	Douglass	149	63	261	0	61	407	338	414	499	95	4	382	25.43%
1031	Douglass	0	0	0	0	71	365	335	371	381	86	0	0	15.31%
206	Louis	274	134	191	5	301	983	1,252	1,145	1,241	659	212	282	63.54%
214	Louis	931	540	881	263	326	766	698	664	588	346	204	622	47.67%
218	Louis	413	298	485	20	206	544	198	0	456	208	65	464	23.71%
222	Louis	684	224	359	60	308	548	566	448	474	271	92	883	35.10%
226	Louis	0	0	0	0	0	303	583	488	434	63	0	78	13.73%
230	Louis	590	140	337	0	308	935	779	755	701	266	50	150	34.98%
234	Louis	484	173	471	39	358	826	569	493	701	83	3	420	32.63%
238	Louis	1,162	730	1,251	819	1,160	1,163	1,306	730	787	310	18	208	67.94%
242	Louis	224	191	436	0	51	545	468	371	430	203	0	396	23.67%
245	Louis	0	0	0	0	0	0	0	45	0	0	0	0	0.32%
1009	MLK, Jr	253	173	444	286	425	867	819	693	876	349	153	434	54.91%
1013	MLK, Jr	392	150	344	17	117	412	354	376	436	247	0	343	30.33%
1017	MLK, Jr	0	0	0	0	35	375	316	302	416	158	0	0	15.24%
1021	MLK, Jr	136	442	1,019	385	290	662	301	222	330	21	0	0	36.23%
1025	MLK, Jr	0	0	0	0	0	477	340	262	338	19	0	0	13.66%
1029	MLK, Jr	0	0	0	0	0	234	154	196	345	58	0	0	9.39%
336	Wheatley	451	262	411	0	35	455	510	454	388	42	0	125	22.13%
340	Wheatley	623	465	655	203	423	1,059	894	631	854	514	454	647	51.80%
	Total:	13,718	8,057	12,741	3,124	8,895	24,149	22,559	21,669	24,292	11,524	6,410	15,062	Average % Over Allotted
	Average:	361	212	335	82	234	636	594	570	639	303	169	396	36.13%
		Number of Units Exceeding Allowance												
Total/Month:		28	23	27	15	30	37	37	37	37	37	22	29	
Average Number of Units Exceeding Allowance/Month:					30									

APPENDIX D

Expanded Building Performance Data

Building Performance Data

House Number	House Type	Area (sq.ft)*	Blower Door - Untaped	Units	Blower Door - Taped	Units	First Floor Duct Blaster	Units	Second Floor Duct Blaster	Units
1029 MLK	Thompson (Dup	1289	929	CFM@50	916	CFM@50	71	CFM@25	N/A	CFM@25
336 Wheatley	Blye	1471	1568	CFM@50	1438	CFM@50	101	CFM@25	39	CFM@25
238 Louis	Pierce	1507	1472	CFM@50	1309	CFM@50	94	CFM@25	72	CFM@25
212 Carver	Cunningham	1560	1051	CFM@50	960	CFM@50	86	CFM@25	67	CFM@25
1019 Douglas	Banner (Duplex)	1289	796	CFM@50	711	CFM@50	86	CFM@25	N/A	CFM@25
240 Carver	Dobbins	1560	1171	CFM@50	1017	CFM@50	69	CFM@25	143	CFM@25
Averages:		1446	1164.5	CFM@50	1058.5	CFM@50	84.5	CFM@25	80.25	CFM@25

Blower Door: CFM@50 -> ACH@50

House Number	House Type	Area (sq.ft)	Ceiling Height (ft)	Building Volume (ft3)	Blower Door - Untaped	Units	Untaped ACH50 Calculation	Units	Blower Door - Taped	Units	Taped ACH50 Calculation	Units
1029 MLK	Thompson (Dup	1289	8	10312	929	CFM@50	5.41	ACH@50	916	CFM@50	5.33	ACH@50
336 Wheatley	Blye	1471	8	11768	1568	CFM@50	7.99	ACH@50	1438	CFM@50	7.33	ACH@50
238 Louis	Pierce	1507	8	12056	1472	CFM@50	7.33	ACH@50	1309	CFM@50	6.51	ACH@50
212 Carver	Cunningham	1560	8	12480	1051	CFM@50	5.05	ACH@50	960	CFM@50	4.62	ACH@50
1019 Douglas	Banner (Duplex)	1289	8	10312	796	CFM@50	4.63	ACH@50	711	CFM@50	4.14	ACH@50
240 Carver	Dobbins	1560	8	12480	1171	CFM@50	5.63	ACH@50	1017	CFM@50	4.89	ACH@50
Averages:				11568	1164.5	CFM@50	6.01	ACH@50	1058.5	CFM@50	5.47	ACH@50

Blower Door: ACH@50 -> NACH

House Number	House Type	LBL Factor (Adj.)*	Untaped ACH50 Calculation	Units	Untaped NACH Calculation	Units	Taped ACH50 Calculation	Units	Taped NACH Calculation	Units
1029 MLK	Thompson (Dup	21.5	5.41	ACH@50	0.25	NACH	5.33	ACH@50	0.25	NACH
336 Wheatley	Blye	17.2	7.99	ACH@50	0.46	NACH	7.33	ACH@50	0.43	NACH
238 Louis	Pierce	17.2	7.33	ACH@50	0.43	NACH	6.51	ACH@50	0.38	NACH
212 Carver	Cunningham	17.2	5.05	ACH@50	0.29	NACH	4.62	ACH@50	0.27	NACH
1019 Douglas	Banner (Duplex)	21.5	4.63	ACH@50	0.22	NACH	4.14	ACH@50	0.19	NACH
240 Carver	Dobbins	17.2	5.63	ACH@50	0.33	NACH	4.89	ACH@50	0.28	NACH
Averages:			6.01	ACH@50	0.33	NACH	5.47	ACH@50	0.30	NACH

*Riverview Place blueprint drawings (BPI, 2012)

Vita

Sean McNeil Collins was born in Johnson City, Tennessee, in 1990. After completing his schoolwork at University High School in Johnson City in 2008, Sean was accepted into the Roan Scholars Leadership Program at East Tennessee State University in Johnson City, Tennessee. During the spring of 2010, he studied abroad in Palmerston North, New Zealand, where he attended Massey University. Sean obtained his Bachelor of Science with a major in Exercise Science from East Tennessee State University in May 2012. In September 2012, he entered the Graduate School of Appalachian State University to pursue a Masters of Science degree in Technology, with concentrations in Building Science and Sustainable Design & Construction.