

ENERGY MODELING OF JAILS: A CASE STUDY OF WATAUGA COUNTY
DETENTION FACILITY

A Thesis
by
ALEXANDRA BOSTWICK LOWRIE

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ALEXANDRA BOSTWICK LOWRIE
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APPROVED BY:

Ok-Youn Yu
Chairperson, Thesis Committee

Jeff Tiller
Member, Thesis Committee

Jeff Holcomb
Member, Thesis Committee

Marie Hoepfl
Member, Thesis Committee

Brian Raichle
Chairperson, Department of Sustainable Technology & the Built Environment

Max C. Poole
Dean, Cratis D. Williams School of Graduate Studies

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Abstract

ENERGY MODELING OF JAILS: A CASE STUDY OF WATAUGA COUNTY DETENTION FACILITY

Alexandra Bostwick Lowrie
B.S., North Carolina State University
M.S., Appalachian State University

Chairperson: Dr. Ok-Youn Yu

Jails are local detention facilities that house inmates serving short sentences and awaiting trial. There are approximately 3,200 jails across the U.S. housing over 700,000 people daily. Detention facilities have a considerable utility demand; in 2011 North Carolina prisons spent \$48 million on energy and water utility bills. One reason for the high energy and water bills is the aging building stock of detention facilities. However, the constant need for electricity, heating, and ventilation create the possibility of significant savings from retrofits.

In order to realize these savings, substantial capital expenditure is required for appropriate projects. Typically, the allocation of scarce capital is determined by creating an energy model to evaluate the potential savings. Though there is a large amount of high-level statistics, there is little information about the detailed energy flows need for energy modeling. Additionally, few modeling programs have detention facility default settings.

The purpose of this study is to identify and quantify the energy flows of a detention facility to the level that they accurately characterize a representative jail. The representative jail

selected for this project is Watauga County Detention Facility which houses 106 inmates and was last renovated in 2004. This housing capacity and age make Watauga County Detention Facility a jail of medium size and age for the State of North Carolina. The jail will be modeled in two energy modeling programs and those models will then be used to evaluate retrofit options.

It is hoped that this study will provide insight into how a detention facility can be accurately modeled, with specific information about the appropriateness of the software evaluated. The model will also be used to provide Watauga County Detention Facility with a recommendation for retrofit options.

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CHAPTER 1: INTRODUCTION

Statement of the Problem

Jails are locally administered confinement facilities designed to house a variety of individuals including those immediately arrested, those awaiting trial, and those sentenced to a period of incarceration by the courts (United States Bureau of Justice Statistics [USBJS], n.d.). There are approximately 3,200 jail and detention facilities in the U.S. (USBJS, 2011) housing over 700,000 inmates on a daily basis (Sourcebook of Criminal Justice Statistics Online, 2011). These numbers mirror an increase in the U.S. prison population rate of nearly 400% since 1983 (Mauer, 2006). Jails and prisons have considerable energy and water utility demands. For example, North Carolina prisons spent more than \$48 million for energy and water bills in 2011 (North Carolina Office of State Budget and Management, 2011). From 2008 to 2010, North Carolina prisons have consumed over 2 billion BTUs per year (586,000 kWh/yr) with an average annual consumption per inmate of 52 million BTUs (15,300 kWh) (North Carolina Office of State Budget and Management, 2011). In North Carolina, as in many states, jail construction and operation are primarily funded by the local jurisdiction and may represent a significant expenditure for local governments. The high energy consumption of detention facilities is largely due to the age of building stock and equipment. Safety and security demand construction methods and materials which are not easily insulated. However, factors such as the continuous need for electricity and heat, ventilation, and self-contained laundry create the possibility for facility retrofits which could result in substantial energy savings.

Purpose of the Study

These potential energy savings can only be realized through capital expenditures on appropriate facility projects. Typically, project prioritization of scarce capital would be based on energy modeling of the facility in question. Even though a great deal of macro-level data exists, such as overall energy consumption per inmate and per gross square foot, detailed facility level data and associated models are not evident in the literature. In addition, common energy modeling tools do not have default models for jail or prison facilities. The main purpose of this study was to assess modeling tools and determine how to accurately quantify the various energy flows through a jail facility. To verify the modeling tools, a case study was conducted using energy data collected from the Watauga County Detention Center in Boone, NC. The study compared the building level energy models to facility specific data and to each other, in order to determine how to create an accurate energy model of a jail. By providing more accurate modeling tools, this study can improve jails' ability to determine the viability of specific energy efficiency upgrades.

Research Questions

This study examined five primary research questions:

1. How much energy does Watauga County Detention Facility, a jail of medium size and age, use?
2. How can these energy flows be modeled in eQuest and Integrated Environmental Solutions (IES) Virtual Environment energy modeling tools?
3. Which energy modeling tool more accurately quantifies the energy flows in Watauga County Detention Facility and why is it more accurate?
4. What are the comparative advantages of each energy modeling program?
5. Do the models have similar estimated savings for various energy efficiency upgrades?

Limitations of the Study

The study focused on Watauga County Detention Facility which includes the jail and sheriffs' office. The building can house up to 106 inmates and was last renovated in 2004. This age and capacity result in the classification of medium size and medium age for a jail, which will make this project applicable to the numerous facilities of similar age and size. Another important factor is that Watauga County Detention Facility does not have a kitchen and gets its meals from the local hospital. This is considered an acceptable limitation since many jails get their meals from separate facilities.

Watauga County is located in ASHRAE climate zone five, which stretches from coast to coast across the United States (United States Department of Energy [USDOE] Office of Energy Efficiency and Renewable Energy, 2017a). Some information, such as heating and cooling loads, are climate dependent and will be different in other climate zones. In addition, only climate appropriate energy saving upgrades were evaluated.

Significance of the Study

This study shows how jails can be modeled accurately using energy simulation tools. This increase in knowledge will improve the ability to model detention facilities and quantify the energy savings available through certain investments in equipment and buildings. Using energy modeling to select appropriate facility investments has the potential to reduce costs for local governments and taxpayers.

CHAPTER 2: REVIEW OF LITERATURE

Green Building Movement

The history of green building starts with the use of passive solar practices dating back thousands of years. (Barber, 2012) For example, Roman bathhouses were heated by the sun entering south facing windows and heating the pools of water. The Anasazi Native Americans built their settlements on south facing cliffs such that the overhangs blocked the high summer sun, but let in the light from the low winter sun (see Figure 1).



Figure 1. Anasazi Native American cliff dwellings from US National Parks.

Green building continued with other notable achievements like the Victorian era green houses and solar water heating at the beginning of the 20th century (Barber, 2012).

The modern green building movement in the United States picked up in the 1970's (Cassidy, 2003). The OPEC oil embargo combined with the fledgling environmental movement

to direct attention to where we get energy from and how efficiently it is used. The United States Department of Energy (USDOE) and the Solar Energy Research Institute (now National Renewable Energy Laboratories or NREL) were created to address these concerns on a national level (Cassidy, 2003). However, public opinion became less favorable after the famous “put on a sweater” speech made by then-President Jimmy Carter in the late 1970s. Americans felt that energy efficiency should not come at the cost of being comfortable in their own homes (Biello, 2010). The removal of the solar panels from the White House roof in 1986 sent a clear message to the American people that renewable energy was no longer a national priority. At the beginning of the 1990s, the political climate shifted again leading to the Greening of the White House Initiative (Cassidy, 2003). The USEPA and USDOE started the ENERGY STAR program in 1992 and the US Green Building Council (USGBC) was founded a year later. Once more the green building movement was growing, helped along by ever-increasing oil prices in the late 1990s to early 2010s as illustrated in Figure 2 (MacroTrends, 2016).



Figure 2. Oil price from 1950 to 2016 (MacroTrends, 2016)

During that time, the USGBC launched the Leadership in Energy and Environmental Design (LEED) program. The easy-to-use points system was a key factor in the adoption of LEED across the building industry. Another crucial attribute of LEED was the attention to indoor environmental quality, making it clear that energy efficiency goals should no longer come at the cost of occupant comfort (Cassidy, 2003). The green building movement started with homes and offices, but has grown to include many other sectors including jails and prisons.

Overview of Jails

Jails are locally operated facilities that hold inmates who are awaiting trial or sentencing and those who have sentences of less than a year. Jails are different from prisons because they do not house long term prisoners and inmates come and go frequently creating a more dynamic environment (USBJS, n.d.). Jails come in many sizes, from over a thousand inmates to less than fifty. Watauga County jail has a rated capacity of 106 inmates (North Carolina Jail Administrators’ Association, 2017), making it a medium sized jail (American Jail Association, 2017).

Table 1. *American Jail Association Size Classification*

Number of Inmates	American Jail Association Size Classification
1-49	Small
50-249	Medium
250-999	Large
1,000+	Mega

Detention facilities are long term investments expected to last decades. As of 2003, approximately 88% of North Carolina’s prisons were built before 1990 (Heyer, 2003). The North Carolina Department of Public Safety (2012) reported that ten prisons have closed

between 2003 and 2012, leaving about 75% of North Carolina Jails being built before 1990. These facilities have been in operation for over 25 years and in some cases facilities are expected to last 50 years or more (Johnson, 2014). Among these aging buildings is Watauga County Detention Facility, having areas dating back to the creation of Watauga Prison in the 1930s (North Carolina Department of Correction, 1999).

Security is a high concern in detention facilities and often dictates architectural choices. Inmate housing is often arranged in blocks of cells, with or without an enclosed common area, and these usually have adjacent spaces for surveillance (George, 2008). Frequently, several cell blocks are attached to one another via corridors or shared administration areas. This can make detention facilities irregular or oddly shaped (see Figure 3) when compared to traditional rectangular office buildings.



Figure 3. House of Corrections (left) and Philadelphia Industrial Correctional Center (right) (Philadelphia Department of Prisons, n.d.)

There are three common cell layouts: Auburn, Pennsylvania, and Pods. Auburn layouts have a central corridor with two rows of cells facing one another. This can lead to aggressive behavior since inmates on one side of the hall can see and interact with inmates on the other side. The Pennsylvania system eliminates the inmates' interaction by having two rows of cells in the center of the building facing outward (Clark 1999).

Another advantage of the Pennsylvania system is that inmates are not housed along the perimeter, allowing windows to be included to introduce natural light. Diagrams of these systems can be seen in Figure 4. The pod system has cells along the perimeter with a common area in the center for the inmates to share, as shown in Figure 5.

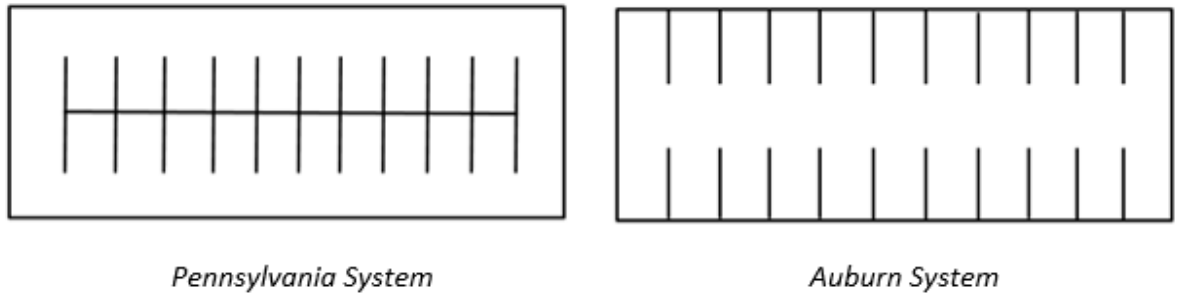


Figure 4. Pennsylvania system cell layout (left) and Auburn cell layout (right)

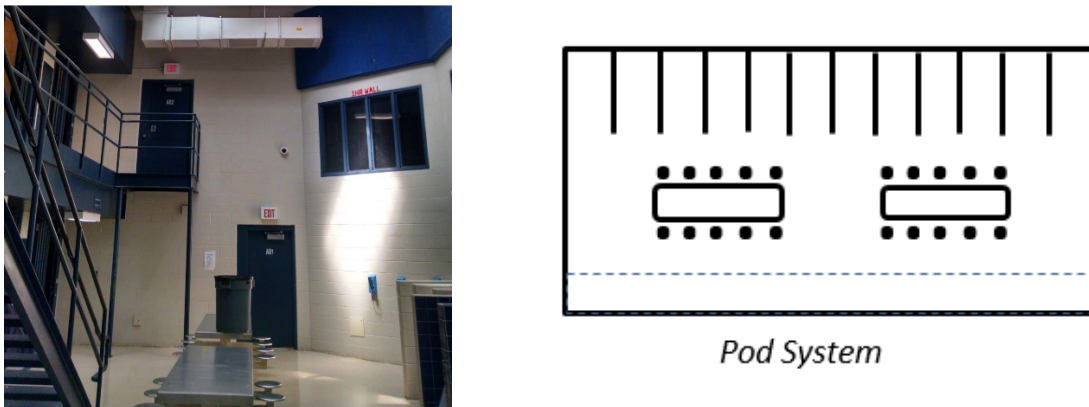


Figure 5. Pod layout picture (left) with diagram (right)

Inmates in pods are usually observed through glass, while the Auburn and Pennsylvania systems require a guard to make rounds (Clark 1999).

The current U.S. jail population is approximately 744,600 inmates (USBJS, 2016). The number of inmates in jail has increased by almost 400% since 1980 (Sourcebook of Criminal

Justice Statistics Online, 2011). This increase is caused by several factors including mandatory incarceration for certain crimes, longer sentences, and inmates being transferred to jails from overcrowded federal and state prisons (Kerle & Wallenstein, 2008). Because of the dramatic increase in the jail population in a relatively short period of time, many facilities have renovated or made additions to existing buildings.

As the number, size, and population of jails grow, the more resources they consume. The volatility of energy prices, shifts in climate patterns, and increasing demand for resources in other sectors all make it desirable to control and reduce the use of resources in detention facilities.

Green Jail Initiatives

There are many initiatives to reduce energy consumption of detention facilities and maximize efficiency. As of 2012, the California Department of Corrections and Rehabilitation had approved the installation of 25 Megawatts of photovoltaic capacity (California Department of Corrections and Rehabilitation [CDCR], 2012). In North Carolina, a strategic energy management plan outlined goals of 20% energy reduction by 2010 (Majernik, 2011). Although the 20% reduction goal was not reached in the 2010 fiscal year, the North Carolina Department of Corrections decreased energy consumption per gross square feet by 5% compared to the 2004 baseline (Majernik, 2011). Other programs, such as Ohio Department of Rehabilitation and Correction's Three-Year Sustainability Plan, focused on moderately reducing resource use and dramatically cutting waste (Ohio Department of Rehabilitation and Correction, 2012). Although there is quite a variety of approaches used to improve jail efficiency, including conserving resources and energy generation, one tool that has not been widely studied in jails is energy modeling.

Challenges of Energy Modeling for Jails

Jails provide a special challenge for energy modelers for several reasons. First, the resources involved cost money and require paperwork. A program has to be selected, a modeler has to be paid, and access to the facility plans must be granted. This is a lot of work for facilities, which are historically understaffed and resource restricted. Second, the jail setting is atypical for a commercial building; operation hours, usage schedules, and architectural elements all require extra attention when defining a jail. Because, jails are regulated to have certain lighting, heating, cooling, and ventilation requirements, the modeler must be familiar with these requirements or the model will not accurately reflect the building's energy consumption. Setting the schedules properly is also crucial because jails narrowly define the occupant movement and behavior of inmates, officers, and visitors. The residential aspect of jails is unusual as well; instead of the occupants leaving during the day for work, school, or recreational activities, they reside there twenty-four hours a day. In addition, the jail environment includes highly specialized lighting and plumbing fixtures that are difficult to incorporate into the model, such as the combined hand-wash/water-fountain/commode shown in Figure 6.



Figure 6. Combined hand-wash/water-fountain/commode

Another challenge in any detention setting is modeling delinquent behaviors such as excessive toilet flushing. A few trouble makers can change water use patterns, particularly in small facilities with high turnover. Third, most energy modeling programs have no preset category for detention facilities, therefore virtually all model information has to be gathered and inputted by the modeler without mistakes. While the energy modeling process for jails is a lot of work, the use of complex simulation algorithms allows for an unprecedented ability to consider multiple options simultaneously with little uncertainty and minimal up-front investment.

Overview of Energy Modeling

Building energy modeling uses physics based calculations of building energy consumption (USDOE Office of Energy Efficiency and Renewable Energy, 2017b). The goals of energy modeling are usually to design an energy efficient building or to determine the energy savings available for a retrofit project (USDOE Office of Energy Efficiency and Renewable Energy, 2017b). Energy modeling programs require information about the building geometry, its mechanical systems, its location, and use patterns (Paradis, 2010). This information is used to calculate the building's loads or energy requirements. The program will then calculate the energy use of the building, usually hour by hour for a year. It uses energy balancing equations to determine how much energy enters or leaves the building from the surrounding environment. The program references the user's description of the building and how it is used to determine when heating, cooling, and various other processes are occurring (Paradis, 2010). The accuracy of energy modeling is a hotly debated issue for several reasons. First, the inherent assumptions of some programs are inaccurate (Elizabeth Ratner¹, personal communication, June 15, 2016). Second, some programs are difficult to use properly and require substantial double checking and

¹ Elizabeth Ratner models buildings in IES for Little Diversified Architectural Consulting

adjustments to yield an accurate result. At times the required attention to detail is too much for some users. Third, energy modeling does not model real life; it models only what you have inputted into the program (Megan Tosh², personal communication, June 13, 2016). That means that you cannot guarantee a model for next year's energy consumption will be 100% accurate since you cannot input next year's weather. It also means that programs with few inputs are usually less accurate than programs with many inputs. Most energy modelers consider an error of 10% or less acceptable and an error of 5% or less very good when comparing a model to actual building energy use (Megan Tosh, personal communication, June 13, 2016).

Programs Used

The programs used in this study were Integrated Environmental Solutions (IES) Virtual Environment (VE) and eQuest. Both programs are well established and regularly updated; the versions I used in this study were IES VE 2015 and eQuest 3.65.

Both of these programs have a powerful graphical user interface which presents the user with input screens and can display the models in 3D (Attia, Beltrán, DeHerde, & Hensen, 2009). They also have the capability to display results in graphical formats. These features are essential when inputting information, double checking building geometry, and interpreting simulation results (Attia et al., 2009).

Though these programs are quite good, each has a few weaknesses. IES VE has only a limited amount of tutorials which are shallow in nature (Oy, Korhonen, & Laine, 2008). Another drawback of IES VE is the cost; eQuest is free, but IES VE can cost a few hundred dollars per computer. eQuest has its own limits; it cannot perform daylighting analysis and its HVAC options are very restricted (Crawley, Hand, Kummert, & Griffith, 2008).

² Megan Tosh works for IES providing training in IES VE for professional users

Calibration of Energy Models

Many energy models are calibrated to control for uncertainties in building materials, HVAC performance, and occupant behavior (Sun, Hong, Taylor-Lange, & Piette, 2015). This is usually done by determining what variables have uncertainty, then using a program to vary the uncertain parameters within specified limits until they yield a model that best correlates to the known energy use of the building (Heoa, Augenbroeb, Grazianoc, Muehleisenc, & Guzowskic, 2015). However, the uncertainty of jail parameters is dramatically reduced due to federal, state, and local oversight. This comes in the form of energy and building codes, regulatory standards for the living conditions of inmates, and procedural standards for jail operation and maintenance. In Watauga County Detention Facility, the consistent number of inmates, as well as the above parameters, were deemed sufficient to constrain the energy model. Therefore, calibration via optimization algorithms was not performed. Other facilities may still require calibration.

CHAPTER 3: RESEARCH METHODS

The energy use of Watauga County Detention Facility (WCDF) was estimated by reviewing utility bills for electricity, propane, and water usage. This energy consumption information was used (along with building plans) to model Watauga County Jail using eQuest and IES VE energy simulation tools. The results of energy modeling were compared to the actual energy consumption of the facility to determine which tool gave a more accurate prediction. Next, the models were compared to each other to identify what assumptions and considerations were included in the more accurate model.

Data Collection Procedures

Utility bills were used to compare energy models to actual building performance. These were obtained from the Watauga County Maintenance Office. The Watauga County Maintenance Office also provided building plans that included information about building shape, size, and materials. These plans also had mechanical and electrical specifications necessary to represent the building's HVAC, lighting, and plumbing systems. Hourly weather data files to be used in energy simulations were created from information provided by the Appalachian State University Physical Plant.

Data Gathered

Electricity

Electricity use was separated into calendar months by taking the average daily usage for the billing period and multiplying by the number of days in the calendar month, as shown in

Tables 2 and 3. This was deemed accurate since the billing periods are short; one average day should be fairly similar to another day in the period.

Table 2. *Electric Utility Bills for Watauga County Detention Facility in 2012*

Billing Start	Billing End	Cost (\$)	Energy	Unit	Average Use/Day	Unit Cost (\$/kWh)
01/23/2013	02/21/2013	5,790	76,880	kWh	2,651	.0753
12/19/2012	01/23/2013	4,421	73,600	kWh	2,102	.0601
11/19/2012	12/19/2012	4,709	60,400	kWh	2,013	.0780
10/22/2012	11/19/2012	4,621	58,560	kWh	2,091	.0789
09/24/2012	10/22/2012	4,515	56,320	kWh	2,011	.0802
08/22/2012	09/24/2012	5,599	73,040	kWh	2,213	.0767
07/23/2012	08/22/2012	5,470	70,240	kWh	2,341	.0779
06/22/2012	07/23/2012	5,706	73,520	kWh	2,371	.0776
05/21/2012	06/22/2012	5,527	71,120	kWh	2,222	.0777
04/23/2012	05/21/2012	4,727	59,280	kWh	2,117	.0798
03/22/2012	04/23/2012	5,073	65,520	kWh	2,047	.0774
02/22/2012	03/22/2012	4,761	60,320	kWh	2,080	.0789
01/24/2012	02/22/2012	4,791	60,720	kWh	2,093	.0789
12/22/2011	01/24/2012	4,755	71,120	kWh	2,155	.0669

Note: The unit cost of electricity varies slightly from month to month due to the regressive rate structure that is dependent on energy use per peak demand.

Table 3. *Electricity Use by Calendar Month for Watauga County Detention Facility in 2012*

Month	Usage (kWh)
Jan	66,380
Feb	60,623
Mar	64,188
Apr	61,912
May	66,685
Jun	67,868
Jul	73,278
Aug	71,429
Sep	65,189
Oct	63,074
Nov	61,884
Dec	63,488

Example Calculation: January 2012

Bill 1:

$$2155.15 \frac{kWh}{day} * 24 \text{ January days in Billing Period} = 51723.60 \text{ kWh}$$

Bill 2:

$$2093.79 \frac{kWh}{day} * 7 \text{ January days in Biling Period} = 14656.53 \text{ kWh}$$

January 2012 Total

$$51723.60 \text{ kWh in Bill 1} + 14656.53 \text{ kWh in Bill 2} = 66380.13 \text{ kWh in January}$$

Propane

Due to the long billing periods (see Table 4), multiplying the number of days in a month by the average usage per day was not considered a valid way to determine monthly usage. Instead, monthly propane use was calculated by looking up the number of heating degree days (HDD) in the billing period and the number of HDD in each month or partial month of the billing period, as shown in Table 5. The HDD for the month or part month was divided by the total HDD in the billing period to get the proportion of propane use for the month in that billing period (see Table 6). That ratio was then multiplied by usage to get the number of gallons used in that calendar month, as shown in Table 7.

Table 4. *Propane Utility Bills for Watauga County Detention Facility in 2012*

Billing Start	Billing End	Cost	Use	Unit	Use/day	Unit Cost	Days
12/11/2012	01/24/2013	2601	2,147	Gal	48.79	1.21	44
10/19/2012	12/11/2012	1999	1,868	Gal	35.24	1.07	53
09/04/2012	10/19/2012	563	284	Gal	6.31	1.98	45
06/01/2012	09/04/2012	484	391	Gal	4.11	1.24	95
03/21/2012	06/01/2012	538	443	Gal	6.15	1.21	72
02/20/2012	03/21/2012	1253	760	Gal	25.33	1.65	30
01/20/2012	02/20/2012	2246	1,368	Gal	44.12	1.64	31
12/22/2011	01/20/2012	2170	1,342	Gal	46.27	1.62	29

Table 5. *Heating Degree Days, by Billing Period*

Billing Period	HDD
12/11/2012 - 01/24/2013	1213
10/19/2012 - 12/11/2012	1211
09/04/2012 - 10/19/2012	425
06/01/2012 - 09/04/2012	115
03/21/2012 - 06/01/2012	582
02/20/2012 - 03/21/2012	554
01/20/2012 - 02/20/2012	817
12/22/2011 - 01/20/2012	853

Note: From Weather Underground, 2012

To prevent double counting days the periods were assumed to begin the day after the previous billing period ended.

2012 was a leap year.

Table 6. *Monthly Heating Degree Days, by Billing Period*

Billing Period	Month	Number HDD
12/11/2012 – 01/24/2013	Dec 12 2012 – Dec 31 2012	603
10/19/2012 - 12/11/2012	Dec 1 2012 – Dec 11 2012	225
	Nov 1 2012 – Nov 30 2012	762
	Oct 20 2012 – Oct 31 2012	224
09/04/2012 - 10/19/2012	Oct 1 2012 – Oct 19 2012	265
	Sep 5 2012 – Sep 30 2012	160
06/01/2012 - 09/04/2012	Sep 1 2012 – Sep 4 2012	0
	Aug 1 2012 - Aug 31 2012	28
	Jul 1 2012 – Jul 31 2012	8
	Jun 2 2012 – Jun 30 2012	79
03/21/2012 - 06/01/2012	Jun 1 2012	6
	May 1 2012 – May 31 2012	134
	Apr 1 2012 – Apr 30 2012	345
	Mar 22 2012 – Mar 31 2012	97
02/20/2012 - 03/21/2012	Mar 1 2012 – Mar 21 2012	349
	Feb 21 2012 – Feb 29 2012	205
01/20/2012 - 02/20/2012	Feb 1 2012 – Feb 20 2012	547
	Jan 21 2012 – Jan 31 2012	270
12/22/2011 - 01/20/2012	Jan 1 2012 – Jan 20 2012	609

Note: Information from Weather Underground, 2012

Example Calculation for January 2012

Formula:

$$\frac{\text{Jan HDD in billing period}}{\text{HDD in billing period}} * \text{usage in billing period} = \text{usage in Jan in bill}$$

Bill 1: 12/22/2011 - 01/20/2012

$$\frac{609 \text{ HDD Jan}}{853 \text{ HDD Bill}} * 1341.90 \text{ gal} = 958.05 \frac{\text{gal}}{\text{Jan bill 1}}$$

Bill 2: 01/20/2012 - 02/20/2012

$$\frac{270 \text{ HDD Jan}}{817 \text{ HDD Bill}} * 1367.70 \text{ gal} = 451.99 \frac{\text{gal}}{\text{Jan bill 2}}$$

January 2012 Total:

$$958.05 \frac{\text{gal}}{\text{Jan bill 1}} + 451.99 \frac{\text{gal}}{\text{Jan bill 2}} = 1410.04 \frac{\text{gal}}{\text{Jan}}$$

Table 7. *Propane Usage by Calendar Month for Watauga County Detention Facility in 2012*

Month	Propane Use (gal)	Propane Use (MMBtu)
January 2012	1,410	128.78
February 2012	1,197	109.32
March 2012	553	50.47
April 2012	263	23.98
May 2012	102	9.31
June 2012	273	24.93
July 2012	34	3.07
August 2012	95	8.69
September 2012	107	9.77
October 2012	523	47.73
November 2012	1,175	107.34
December 2012	1,414	129.16
Total 2012	7,145	652.57

Note: The energy content of a gallon of propane is estimated to be 91,333 Btu/gal (United States Energy Information Administration, 2017).

Weather data was gathered by the Appalachian State University Physical Plant. This information was separated to get two datasets: a Typical Meteorological Year 3 (TMY 3) and an Actual Meteorological Year 2012 (AMY 2012). A TMY file is an average of several years and is good for general building modeling for comparisons. An AMY file is an actual year of weather information and would be used to compare an energy model's output to actual historical utility bills for model validation. A model that is within 10% of the actual usage is considered valid; within 5% is considered very accurate. The TMY and AMY files were compiled into .epw and .bin weather file formats for use in IES VE and eQuest, respectively.

Energy Modeling - General Procedures

Energy modeling tools are used for a number of reasons including, but not limited to, evaluating new construction projects, deep or shallow retrofits, and troubleshooting complex building systems. In this study, we were evaluating retrofit scenarios. In order to do this we had to first define the energy flows of the building.

Energy flows for the facility can be divided into three main categories: internal gains, energy lost to (or gained from) the external environment, and energy added to maintain thermal set points. Sources of internal gains include heat given off from lights, computers, and other equipment, as well as heat given off by the occupants of the building. The internal gains were modeled by entering an amount of energy and a variation profile for each internal gain.

The energy lost or gained from the environment is calculated by the hour, using each program's internal algorithms. These algorithms account for conduction, convection, and radiation heat transfer. The user provides the thermal characteristics of the building materials, the internal gains, and the external environment data (weather file) for the program to use in its calculations.

The HVAC system consumes energy to condition the spaces to the desired thermal set points. The user specifies the HVAC system type, set points, controls, and efficiency to provide the program with the necessary data to perform these energy calculations.

The user can view these energy flows after performing a simulation. IES VE has a large number of very detailed energy flows, while eQuest has more general outputs.

eQuest

Navigating eQuest and IES VE are very different experiences; eQuest deliberately guides the user while IES VE allows more independence. eQuest has a home screen from which the user can click into and edit building envelopes, loads, and equipment. When the user enters a building shell, she is taken through a series of screens where she inputs information. Nearly all information is entered by typing or using drop-down menus. Once all the screens are filled, the user knows that the section is complete. This is useful for new users because it insures that they do not leave anything out.

The shape of the building is defined using coordinates on a grid. The shape must be created in a counterclockwise direction. Identifying the locations of buildings relative to each other can be done in several ways, but the easiest is to do so via coordinates. This option allows the user to select to origin of the grid where she will define the building shape. Window and door types and locations are defined on a later screen.

The building envelope is defined using drop-down menus. Each option has a material type and thickness. The selection is fairly good; however, in some cases the user may have to select by equivalent R-value if the material is not available in the desired thickness. Each assembly will have structural, insulating, and finish components. This means that some characteristics, like air barriers and air gaps, have to be left out.

It is also easy to create internal loads, like lighting. The user is presented with a screen with several different types of internal loads and can select the appropriate ones by clicking the checkboxes to the left of them. This will create a screen for each load selected in which the user can edit the load. There are two components to the load: intensity and schedule. Intensity is the level or amount of energy use per square foot. The schedule defines how much of the load is on at any given time. In eQuest, the load intensity and the minimum and maximum percent in use can be changed, but the shape of the use profile cannot.

The HVAC system is also defined using a series of screens. The program allows the user to decide what type of heating and cooling systems are in place, what fuel is used, and the equipment efficiencies and sizes. In the size options, the user may select Auto-Size, which will have the software size the system for the user.

After simulation is done, the “view summary of results” button will take the user to a report that breaks down monthly energy consumption by usage category.

IES VE

IES VE does not guide the user. Instead, the user is free to create and edit her model in whatever order she likes. There is a main tool bar along the top of the screen and along the left side of the screen there are modules. When a user clicks on a module, a tool ribbon appears under the main tool bar. The tool ribbons are module-specific and have a large variety of functions that may be useful to the user. Because of the less rigid structure of the program, the user can define a building characteristic in multiple locations within the program. This can be confusing for new users. For the most part, a user will rely on the ModelIT module to create the building shape, the ApacheHVAC module to define the space conditioning and ventilation system, and the Building Template Manager Tool to define loads, building materials, and usage profiles.

To define the shape of a building in IES VE, the user draws the building on an adjustable grid in the ModelIT module. The footprint can be edited by dragging the vertices on the grid or by defining the locations of the vertices in a table. IES VE requires these points to be created in order, but does not require the points be defined in a counterclockwise manner like eQuest does. Windows and doors are drawn on the wall in which they reside. Window and door types are defined in the Building Template Manager tool.

IES VE allows the user to either use preset building assemblies or to create a custom assembly layer by layer. To do so, the user copies the materials from an extensive database and pastes them into layers. The user then defines the thickness of the layers and saves the template. It will then be available to apply to the building.

The intensity, minimum and maximum percentages, and the profile shapes can all be edited to the user's liking, but the profiles must already exist before they can be assigned. All of this is done in the Building Template Manager.

The HVAC system can be created using the ApacheHVAC module. The user selects the type of system from an extensive list. A schematic diagram of the system will then appear on screen to be edited. This can be done by selecting each component and typing the desired changes into the correct field. The user can also insert additional components by selecting a piece of equipment from the top ribbon and placing it in the schematic diagram. Set points and schedules can be adjusted from ApacheHVAC or the Building Template Manager. To auto-size the system, the user can select Auto-Size as the size then click the run load calculations button on the top ribbon. A menu will appear which has options to calculate room loads and assign load parameters. Calculating room loads must be done before calculating system loads. This sizes the system and sends that information to the simulator.

To simulate in IES VE, the user goes to ApacheSym and clicks dynamic simulation. She then defines how she wants the simulation done, usually in VistaPro and linked to SunCast and the HVAC system. The simulate button should then be clicked. The user will then be able to choose which variables to look at and how to view them. Because there are dozens of variables and several ways to view them, it can take the user a while to get used to the VistaPro interface.

Energy Modeling – Specific Procedures

A driving motivation for this project was to make energy modeling easy and accessible to county energy managers. The specific goal was to make the process simple enough that an employee familiar with the operation of the detention facility and who has access to building plans could make an acceptable energy model. Therefore, some building information was left out in order to streamline this process and to avoid common errors and known bugs.

Building Characteristics

The figures referred to in this section were taken from the architectural drawings and the research team's photographs of Watauga County Detention Facility.

Building footprint

Size. The gross square footage of the jail is approximately 38,599 square feet. Due to the automatic rounding in eQuest the square footage in that model was only 38,038 square feet. IES VE calculates the net square footage instead of the gross square footage. The interior square footage of the IES model was 37,159 square feet.

Shape/layout. The shapes of the buildings are shown in Figure 7. Building A contains the jail administration, the pod style housing, and the control tower. Building B has single cells only. Building C is the sheriffs' wing. Building D contains Emergency Management Services. The dining hall was not modeled since the space is not conditioned and is not connected to electricity.

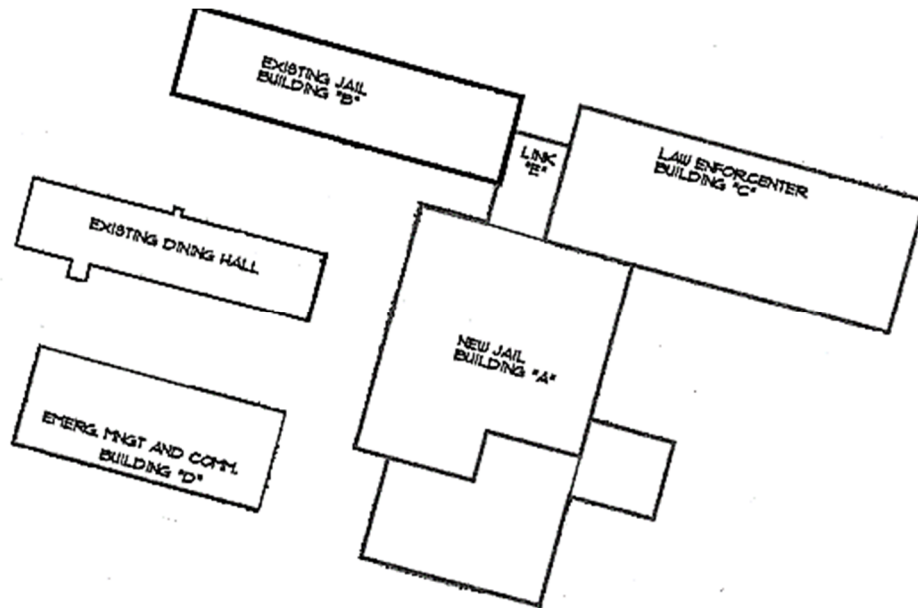


Figure 7. Layout of Watauga County Detention Facility

Orientation. The site is oriented approximately NNE. This orientation was inputted into both eQuest and IES VE as shown in Figure 8.

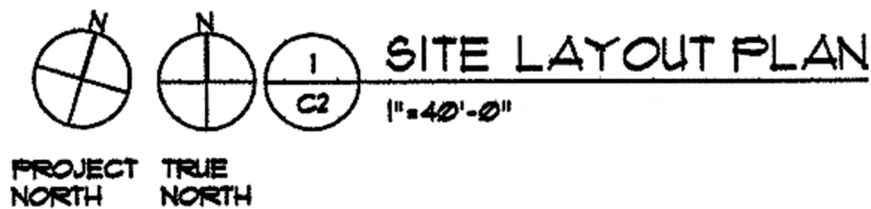


Figure 8. Site orientation from C2.

Zoning. Each level of the jail was modeled as its own floor, even though the pods are two-story units. This is because it may be difficult for a user with limited experience to connect spaces between floors.

Due to difficulty in adding floors at different heights, the eQuest model had the sheriff's wing level with the second floor of building A and building B. This created five zones: Building D (EMS), the first floor of building A, the second floor of building A, building B, and building C.

In IES VE, it is easier to model building shells at various heights, but zones cannot include spaces on more than one floor. There are four zones in the IES model: Building D (EMS), the first floor of building A, the second floor of building A and building B (single cells), and building C (sheriff's wing).

Building envelope.

Building materials and construction types were found in the architectural plans and inputted into eQuest and IES VE with as much accuracy as the programs allow.

Exterior walls. From interior to exterior the walls are made from 5/8" gypsum board, 8" reinforced solid grouted CMU, 2" polyisocyanurate, air barrier, air gap, and 4" CMU masonry or accent brick (see Figure 9). eQuest uses a drop-down menu to select insulation and structural components; it was not able to model the air barrier, air gap, or gypsum board. In IES VE all layers were modeled.

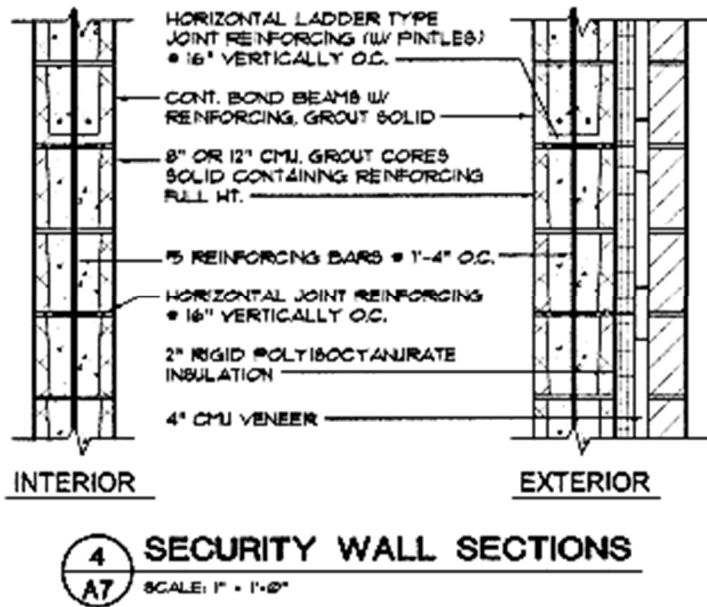


Figure 9. Labeled wall sections from A7.

The internal walls were not modeled due to both the time it would take to input them and also to avoid geometry errors. Errors are particularly prevalent when a wall is drawn and then deleted and redrawn. Unless the user is performing a daylighting analysis, it was deemed unnecessary to include internal walls and partitions. Daylighting analysis was not done because artificial lighting is mandatory in North Carolina (North Carolina Administrative Code, 2014).

Windows. The exterior windows are double-paned, with a 1/2 inch air gap. The inside surface is clear and the outside glass is gray tinted. Both panes of glass are 1/4 inch thick, as seen in Figure 10.

In eQUEST windows were modeled as double clear, since it was the closest available option to clear and gray tint. IES VE was able to model the windows accurately since the program allows the user to construct windows layer by layer. Both modeling programs have preset thermal and optical values for various glass types. eQuest does not show the solar heat

gain coefficient, U-factor, or visual transmittance. IES VE gives a U-value of 0.4911 and visible light transmittance of 0.76 for this double pane window.



G16

Figure 10. Labeled typical window section from A12.

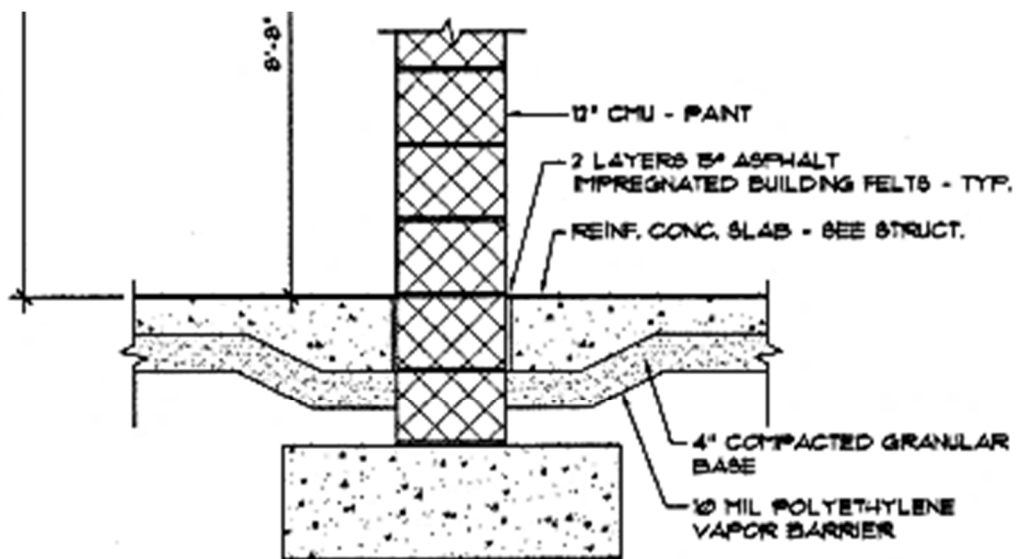


Figure 11. Window in Building B.

Building B has older windows with an operable center pane, as shown in Figure 11. These were simplified as clear, quarter-inch thick, single pane windows in both programs. ISE VE gives a U-factor of 1.0026 for a single pane of glass.

Doors. The doors were modeled as hollow 18-gage steel with polystyrene cores. Although the building plan does not specify core type, polystyrene was assumed because it would have a better fire rating than polyurethane. The U-factor of the door is 0.065 in IES VE. eQuest does not display the U-factor of the door.

Floors. The floors are 4" concrete slab on 4" of crushed rock with a polyethylene vapor barrier (see Figure 12). Internal floor concrete is 6" hollow core with a 2" concrete topping. This was modeled as 4" of concrete in eQuest because only one layer is allowed. IES VE floors were modeled as 4" concrete on top of 4" of chipped stone with a 10mm membrane beneath.

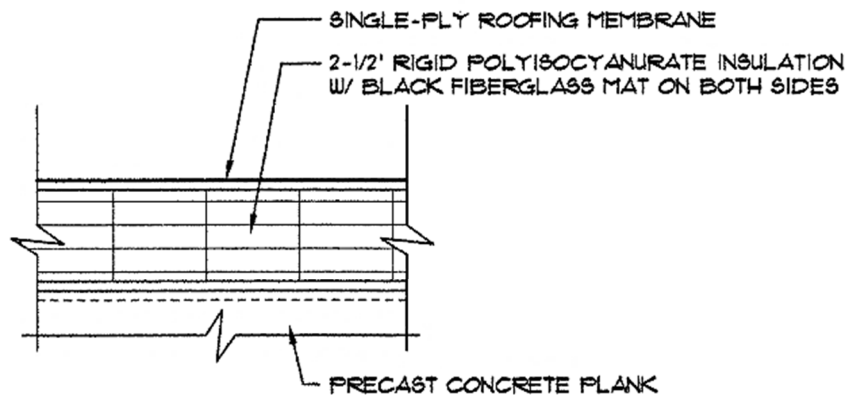


4 WALL SECTION
A8 SCALE: 3/4" = 1'-0"

Figure 12. Partial wall section from A8

Roof. The roof system of the WCDF consists of an 8-inch precast concrete plank covered with 2.5-inch polyisocyanurate insulation, as shown in Figure 13. The insulation has black fiberglass mat on both sides. On top of the insulation there is a white, single-ply roofing membrane.

eQuest allows for the input of a structural component, a layer of insulation, and a surface coating. This allowed for all components except for the fiberglass mats to be modeled. Due to the insulation options in eQuest being limited to whole-inch increments, the roof was modeled with 3" of polyurethane to get the equivalent R-value of 2.5" of polyisocyanurate. In IES VE the roof was constructed layer by layer and included the fiberglass mats.



6 **SINGLE-PLY ROOF SYSTEM**
A25 SCALE: 3" = 1'-0"

Figure 13. Roof system from A25.

Skylights. The Watauga County Detention Facility has twelve dark tinted skylights on the roof of building A (see Figure 14). Skylights were modeled as three-foot by four-foot tinted

domes in both models. The visible light transmittance in IES VE was 0.6 and the U-factor was 1.1588. eQuest does not display thermal or optical properties of skylights.



Figure 14. Skylights on the WCDF

Internal loads.

Lighting. Lighting is provided by T-8 florescent lamps. The North Carolina Administrative Code (NCAC) Title 10A Chapter 14 Subchapter J requires that lighting in cell areas to be 30 foot candles (NCAC, 2014). Typical lighting power density is usually 0.85 W/ft^2 in areas occupied by inmates (Liebel & Brodrick, 2005). The lighting power density in the offices was assumed to be 1 W/ft^2 because that was the current American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) 90.1 standard when the facility was built in 2004 (American Society of Heating, Refrigeration, and Air-Conditioning Engineers [ASHRAE], 2004). Because the lighting stays on in the 24 hour-use offices, security corridors, and jail administration areas, the lighting schedule was set to range from 75% to 100%. In eQuest, the lighting profile shape cannot be edited, but in IES VE, the profile shape was set to be at 100% between 7:00 am and 7:00 pm. The rest of the day the lighting was assumed to be at 75%.

eQuest has the option of adding task lighting, which was used to represent the few desk lamps in office areas. The load was set to $0.2W/ft^2$ and the profiles were edited to range from 0% to 30%.

People. The project estimated that the total building occupation would be around 110 people; approximately 70 inmates, 10 jail staff, 10 EMS staff, and 20 sheriff office employees. The number of inmates was provided by WCDF.

In eQuest, there were preset occupation densities and ventilation rates. Instead of changing the preset ventilation rate and square feet per occupant, the schedule of percentage occupancy was reduced to usual levels for the jail. In the main building, the occupancy was set to 40% while the EMS building was left at 100%. This resulted in 110 people in the eQuest model.

The IES VE model allowed the occupancy to be set by square feet per person. To select the appropriate number of people, the square footage of the building was divided by 110 (the number of occupants). It was determined that the occupancy is 338 square feet per person.

Office Equipment. Office loads (see Table 8) were assumed to be medium-use desktop computers and printers. The number of monitors is mixed with up to four per computer in the EMS building and one per computer in the shared sheriff's office. It was estimated that the average computer in the detention facility would only have one monitor and be used lightly. This type of use is approximately $0.6 W/sq. ft.$ (Wilkins & Hosni, 2011) in an office area, or approximately $0.30 W/sq. ft.$ when averaged over the whole building.

In Watauga County Detention Center, 911, dispatch, and the jail staff remain working throughout the night. The usage profile was set to range from 75% to 100% in both programs to represent lower computer usage at night.

Table 8. *Office Plug Loads* (Wilkins & Hosni, 2011)

Type of Use	Load Factor (W/ft ²)	Description
100% Notebook–Light	0.25	167 ft ² /Workstation, All Notebook Use, 1 Printer per 10, Speakers and Misc.
100% Notebook–Medium	0.33	125 ft ² /Workstation, All Notebook Use, 1 Printer per 10, Speakers and Misc.
50% Notebook–Light	0.40	167 ft ² /Workstation, 50% Notebook/50% Desktop, 1 Printer per 10, Speakers and Misc.
50% Notebook–Medium	0.50	125 ft ² /Workstation, 50% Notebook/50% Desktop, 1 Printer per 10, Speakers and Misc.
100% Desktop–Light	0.60	167 ft ² /Workstation, All Desktop Use, 1 Printer per 10, Speakers and Misc.
100% Desktop–Medium	0.80	125 ft ² /Workstation, All Desktop Use, 1 Printer per 10, Speakers and Misc.
100% Desktop–2 Monitors	1.00	125 ft ² /Workstation, All Desktop Use, 2 Monitors, 1 Printer Per 10, Speakers and Misc.
100% Desktop–Heavy	1.50	85 ft ² /Workstation, All Desktop Use, 2 Monitors, 1 Printer Per 8, Speakers and Misc.
100% Desktop–Full On	2.00	85 ft ² /Workstation, All Desktop Use, 2 Monitors, 1 Printer Per 8, Speakers and Misc., No Diversity

Mechanical equipment

HVAC Equipment. The jail is equipped with 13 packaged roof top units with propane heating and electric cooling (see Figure 15). There is also a Fujitsu unit used to cool the server room in the EMS Building. HVAC sizing was done using the auto-size features in both IES VE and eQuest. This was for the sake of simplicity, since most county employees would not have time needed to investigate the more minute details of their facility’s HVAC system.



Figure 15. Roof-top HVAC unit

Ventilation requirements. The heating, cooling, and ventilation are on continuously because the building is constantly occupied and to prevent odor. According to North Carolina Administrative Code Title 10A, the minimum ventilation requirement in jails is 10cfm per inmate (NCAC, 2014). The IES VE model was set to 10cfm per person to reflect this. The eQuest model presets were adequate and left as they were.

Set points. The state has mandated that the acceptable range of temperatures in detention facilities is between 68° F in the winter and 85° F in the summer. However, county maintenance asked the jail to set the thermostats at 72° F and leave them. The systems have a dead band of +/-1° F

Although state and local governments have defined what temperature the jail should be, it was observed that the thermostats in single cells were set to 76° F and the thermostats in the tower are set to 69° F. The thermostats in the EMS building are not under thermostat guards (see Figure 16) and are controlled by the occupants of the building, leading to a wide range of temperature settings.

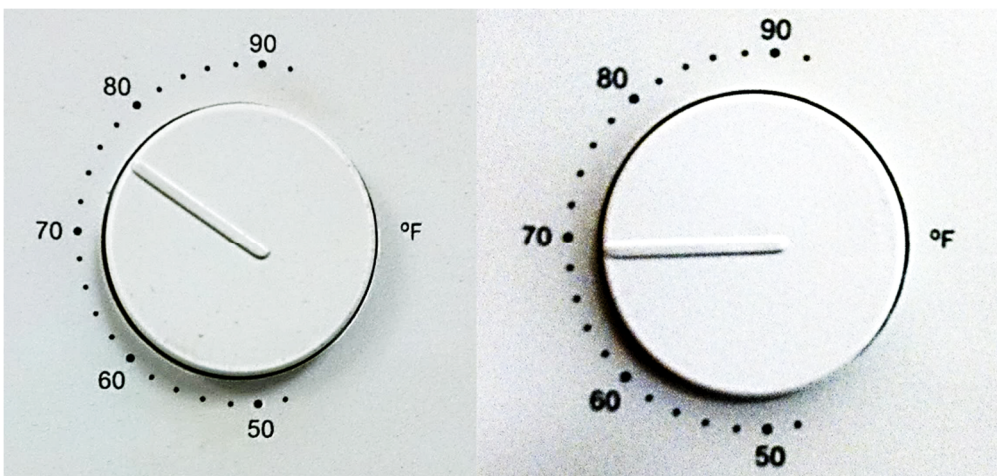


Figure 16. Photographs of thermostats in the EMS building taken September 10, 2015.

In the energy models, the thermostats were represented as having a heating set point at 69° F and a cooling set point of 73° F, the normal range of temperatures for most of the building. The HVAC efficiencies were cooling at 8.9 EER and heating at 80% efficient.

Nearly all the heating is provided by propane, but there are electric heating coils in the fan boxes that help regulate temperature. It was estimated that 15kW of electric heating is utilized based on the frequency of use measured for one electric resistance heating unit.

Domestic Hot Water Equipment. The North Carolina Administrative Code states that inmates must have the opportunity to shower at least three times a week and have unrestricted access to toilets (NCAC, 2014). This results in around the clock water use by inmates. Inmates in prisons typically use a large amount of water, about 120 gal/inmate/day (USDOE Office of Energy Efficiency & Renewable Energy, n.d.). The water bill for the jail indicates that WCDF inmates use less water than average prisoners. This is likely due to jail inmates being unused to showering in front of others and choosing to keep their showers short.

Watauga County Detention Facility also has constant water usage by the employees who have night shifts. These include workers in dispatch, 911, and jail staff.

Water is heated at the jail using electric water heaters and was modeled as such in eQuest and IES VE. The usage in the eQuest model is set to 14 gal/person/day while the usage in the IES model is 45 gal/hr. The temperature the water is heated to is 135° F. A water usage profile of 30% to 90% was selected to represent the usage of showers during the day and the use of toilets and sinks both day and night.

Data Analysis Procedures

The simulation results of the energy models were compared to the actual energy use on an annual and monthly basis to determine accuracy. The weather data used in the simulation was from the same year as the utility bills in order to make an accurate comparison. The modeling

tools were also compared with each other to determine what contributed to making one model more accurate than the other. The user experiences for the energy modeling programs were also summarized and compared to determine the relative advantages of using each simulation tool. The models were then used to simulate various energy efficiency upgrades (i.e., parametric studies). The results of the upgrade simulations were compared to the original models and each other to find the energy savings available to WCDF.

CHAPTER 4: RESEARCH FINDINGS

Research question 1 asked: How much energy does Watauga County Detention Facility, a jail of medium size and age, use?

By reviewing Watauga County Detention facility's energy bills it was determined that the facility uses about 3335 MMBtu per year; 653 MMBtu for propane heating and the rest in electricity. The approximate annual cost of energy for this facility is \$65,000 a year, representing a substantial expenditure for the county and its residents.

Research question 2 asked: How can these energy flows be modeled in eQuest and Integrated Environmental Solutions Virtual Environment (IES VE) energy modeling tools?

There are several steps required to model a detention facility accurately. To see how these steps were accomplished for Watauga County Detention Facility, see Chapter 3 of this document, which describes both the general and specific steps followed to model this facility.

Research question 3 asked: Which energy modeling tool more accurately quantifies the energy flows in Watauga County Detention Facility and why is it more accurate?

The energy models were simulated using a weather file compiled for Boone, North Carolina using 2012 weather data. The eQuest model calculated an annual energy use of 3232.1 MMBtu, three percent lower than the billed energy use in 2012. As seen in Figures 17 and 18, eQuest under-predicted summer electricity use and over-predicted winter propane use.

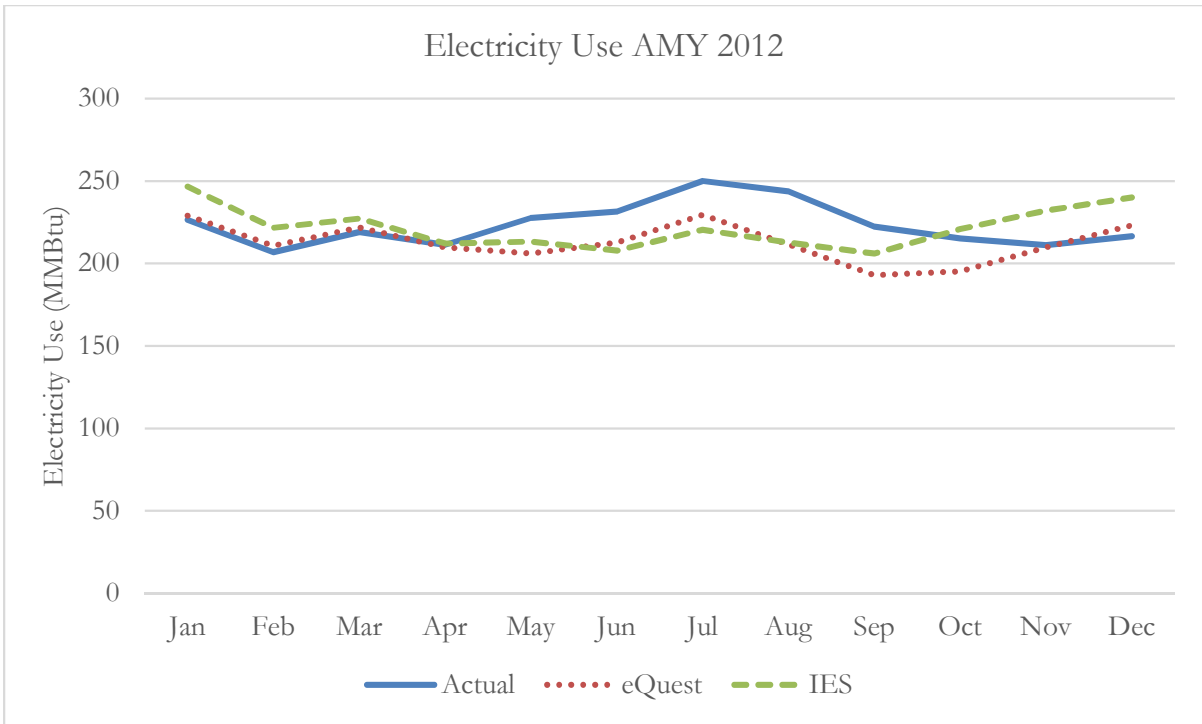


Figure 17. Electricity use for 2012, as predicted by eQuest and IES VE, compared to actual use.

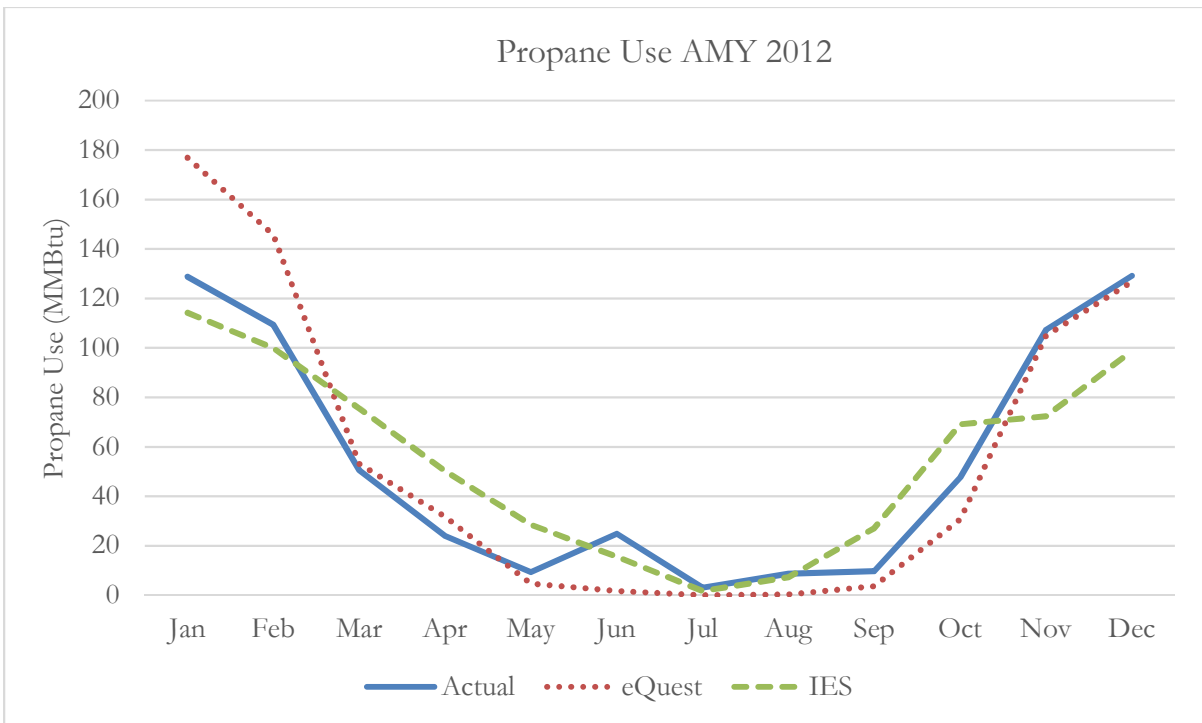


Figure 18. Propane use for 2012, as predicted by eQuest and IES VE, compared to actual use.

By contrast, IES VE over-predicted propane use in warmer months and under-predicted it in cold months. The IES VE model had the opposite problem with electricity; it was above actual electricity use in winter and below in summer. IES VE calculated an annual energy use of 3,321 MMBtu per year; 0.4% lower than the actual use for 2012.

The under-use of electricity predicted by both eQuest and IES VE in warmer months indicates that the actual cooling load of the building may be slightly higher than model inputs capture. IES VE over-predicting electricity use in winter and under-predicting propane use at the same time may indicate that the program is attempting to model use of the small electric heaters before consuming propane. In reality, these small electric heaters are only meant to reheat the air after the adjacent doors have been opened, not to heat the whole building. eQuest showed over-use of propane in the winter, likely due to the program's algorithms. eQuest calculates the energy needed to meet the thermostat set points, while IES VE sizes equipment and simulates the functioning of that equipment. Therefore, if it is a cold winter, eQuest may calculate heating beyond the capacity of the actual equipment. On the other hand, IES VE will have hours where the building temperature is below the heating set point due to the limited heating capacity of the equipment. The use of propane in the summer for the IES VE model and the actual building indicate that there might actually be simultaneous heating and cooling. This is likely occurring because of the thermostat set-points mis-match shown in Figure 16.

While both models produced results within 5% of the billed use, IES VE was slightly more accurate than eQuest.

Research question 4 asked: What are the comparative advantages of each energy modeling program?

As mentioned previously, IES VE is a bit more accurate than eQuest. The increase in accuracy is likely due to having more detailed inputs for construction materials, schedules, and HVAC systems. However, this improved accuracy does come at the cost of making the program more difficult to use. Table 9 summarizes the author’s experience as a first time user of both programs.

Table 9. *Comparison of Ease of Use for eQuest and IES VE*

Ease of Use		
	eQuest	IES VE
Navigation	Easy - linear	Moderate –multiple modules required
Building Footprint	Moderate – custom shapes must be defined counter-clockwise	Easy – draw building like in CAD programs
Construction Materials	Moderate – must estimate if actual values are unavailable	Easy – user can create custom constructions from a variety of materials
Load Schedules	Easy – profile ranges are editable but profile shapes are not	Moderate – input is hour by hour
Load Intensity	Easy – type in maximum usage	Easy – type in maximum usage
HVAC Selection	Easy – specify heating and cooling sources	Moderate –Quite a number of options to choose from
HVAC Controls	Easy – just input set points	Difficult – set points, schedules, set-back temperatures, and controller types required
Auto-Sizing	Easy – select from menu	Moderate – must run room loads and system loads separately
Simulating	Easy – Click of a button	Easy – click of a button
Reports	Easy – one standard report automatically generated	Difficult – multiple standard reports can be generated and individual variables can be queried. No automatic report generation.

Research question 5 asked: Do the models have similar estimated savings for various energy efficiency upgrades?

Energy reductions can be direct, by upgrading systems that use energy, such as lighting. Or energy savings can be indirect, like adding insulation to a roof to reduce energy use by the HVAC system. There are also interactive effects; for example, more efficient lighting generates less heat, so winter heating will increase slightly. The relative percentages of energy reduction are based on several factors, including building geometry and usage. For example, upgrading a roof will produce a larger percentage energy savings on a one-story building than a multi-story building. These geometric and usage differences are why each facility would benefit from having an energy model created; a given upgrade may be more effective in some facilities than others.

A 30% energy savings for lighting was estimated based on the difference in energy use of T-8 fluorescent tubes and Light Emitting Diode (LED) bulbs. Thirty percent water use reduction was based on the difference in water usage from current fixtures, circa 2004, and WaterSense fixtures, which the United States Environmental Protection Agency (USEPA) estimates saves 30% on average over standard fixtures (USEPA 2017). The USEPA started the WaterSense program in 2006, just after the expansion of Watauga County Detention Facility. Other upgrades considered were adding another R-10 of insulation to the roof and replacing the single-paned windows in B wing with double-paned windows.

To simulate energy upgrades, a TMY 3 file for Boone, North Carolina was used. Table 10 shows the simulated annual energy savings in percent of total baseline energy use for the upgrades. Due to the use of different energy calculation algorithms, the two programs produced differing results. This happens because IES VE considers more variables than eQuest, including heating and cooling capacity limits and entering daylight heating the spaces. If the programs both predict similar savings, the upgrade is more likely to have the predicted returns.

Table 10. *Total Energy Savings, in Percent by Improvement Type*

Energy Savings in Percent of Total Building Energy Use (%)		
	IES	eQuest
Improving windows in single cells area (Single to double pane)	0.00	1.15
Upgrading from T-8 to LED lighting (30% reduction lighting)	3.48	6.04
Changing to reduced flow rate water fixtures (30% reduction water heating)	7.27	7.43
Adding an additional R-10 to roof	0.99	2.90

As shown in Table 10, eQuest predicted more energy savings than IES VE for all options evaluated. However, if one ranks the upgrade options by percent savings from highest to lowest, both models produced results showing reductions in the same order (water fixtures, lighting fixtures, roof insulation, and, lastly, windows). Overall, these energy models agreed with one another about the relative energy savings available between the four options.

As shown in Table 11, window replacement had no return or minimal return in both programs. It is not recommended that WCDF invest in new windows, a strategy that may not pay back. Extra insulation being added to the roof had much higher savings in eQuest than IES VE, due to eQuest calculating heating and cooling beyond the real capacity of the HVAC system. Therefore, some of the energy reduction in eQuest is energy the real system is not able to produce and distribute to the building anyway. From a practical standpoint, re-insulating the roof is less convenient for the facility since it requires a group of people to accomplish, as well as the removal of the Roof Top Units (RTUs). In reality, the RTUs are unlikely to be removed except for replacement on an as-needed basis.

Replacing the T-8 fluorescent lighting with LED had good predicted savings in both programs, though not matching in scale. The magnitude of savings differed because eQuest and IES VE have different levels of customization in their lighting schedules, leading to slightly different energy use. The viability of this upgrade is largely dependent on the availability and cost of skilled labor required to accomplish the lighting ballast adjustment for LEDs. It would also be most beneficial to replace the lights in parts of the building that must remain on at all times. An added benefit of switching to LED lights is that they require replacement less often, reducing both maintenance hours and the risk of people having ladder-related injuries. Upgrading to WaterSense fixtures was calculated to provide similar and substantial annual savings in both programs. This is likely to be a good investment since aerators and showerheads are relatively inexpensive and the labor involved is minimal.

Table 11. *Net Savings by Energy Upgrade*

Net Annual Energy Savings (\$)		
	IES	eQuest
Improving windows in single cells area (Single to double pane)	0	736
Upgrading from T-8 to LED lighting (30% reduction lighting)	2935	4778
Changing to reduced flow rate water fixtures (30% reduction water heating)	4644	4963
Adding an additional R-10 to roof	525	1665

The net cost savings shown are based on electricity savings at \$0.07 per kWh (\$20.15/MMBtu) and propane savings at \$1.40/gal or (\$15.22/MMBtu). Net savings for each upgrade are shown in Table 11. More detailed calculations, including savings by energy source, are included in the Appendix.

CHAPTER 5: CONCLUSIONS AND DISCUSSION

Best Tool

Both eQuest and IES VE have their merits and drawbacks; which tool is best depends on what the user would like to accomplish.

For first-time users with minimal energy modeling background, eQuest is the fastest and most straight-forward tool to use. eQuest is also a free tool, which limits the up-front cost of energy analysis. Its linear nature, limited inputs, and simple systems are well suited for an initial internal evaluation of energy upgrades. eQuest is particularly suited to retrofits of older, simple buildings like the Watauga County Detention Facility.

The detail and accuracy of IES VE makes it desirable for evaluating deep retrofits and for designing new buildings. In situations where the building and its controls are complicated, IES VE has more flexibility. It is also good for buildings with odd usage schedules because the user can create timetables from the ground up. IES VE is most appropriate for evaluating projects where the capital investment would be large and where an energy engineer would be contracted to perform a formal evaluation.

Future Study

There are many avenues of future study to improve the knowledge base of energy simulation for secure detention facilities. Gathering more information about how water, lights, and equipment are used in detention facilities would help improve our knowledge of load profiles for this building type. It would also be helpful to know more about the way detention facilities of differing sizes function in order to determine appropriate profiles for each size of

facility. Other methods, such as HVAC zoning, should also be investigated to determine their impact on model accuracy. Additionally, investigating more energy modeling programs to determine the level of functionality and appropriateness for detention facility applications would help guide future users to optimal software choices. In addition, actual measurement and verification of jail energy use and corresponding models is needed to further develop best practices for modeling detention facilities.

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APPENDIX: ADDITIONAL TABLES

Table A1. *eQuest AMY 2012 Baseline Simulation Results*

eQuest AMY 2012 Baseline (MMBtu)									
Month	Space Cool	Space Heat	Hot Water	Vent. Fans	Pumps & Aux	Equip	Task Light	Area Light	Propane Heat
Jan	0.00	35.62	64.73	19.82	0.61	28.66	2.05	77.46	176.89
Feb	0.00	30.20	62.95	17.91	0.51	26.24	1.88	70.97	145.68
Mar	1.67	15.59	73.19	19.82	0.31	29.41	2.12	79.64	53.06
Apr	3.04	10.88	69.03	19.18	0.24	28.42	2.05	76.94	31.69
May	12.45	2.25	62.58	19.82	0.07	28.83	2.05	78.00	4.68
Jun	25.73	1.02	59.30	19.18	0.07	28.42	2.05	76.94	1.72
Jul	45.04	0.00	54.94	19.82	0.00	29.04	2.08	78.55	0.00
Aug	27.47	0.31	53.37	19.82	0.07	29.21	2.12	79.09	0.28
Sep	13.68	1.94	51.35	19.18	0.14	28.22	2.01	76.40	3.65
Oct	1.88	10.99	53.33	19.82	0.34	28.83	2.05	78.00	30.66
Nov	0.00	27.77	56.40	19.18	0.55	28.05	2.01	75.85	105.01
Dec	0.00	29.72	63.47	19.82	0.55	29.04	2.08	78.55	126.77
Total	130.96	166.31	724.64	233.39	3.45	342.37	24.53	926.40	680.09

Table A2. *IES AMY 2012 Baseline Simulation Results*

IES AMY 2012 Baseline (MMBtu)								
Month	Space Cool	Space Heat	Hot Water	Vent. Fans	Equip	Task Light	Area Light	Propane Heat
Jan	7.99	28.54	64.10	43.93	28.18	0.51	73.34	114.21
Feb	8.29	24.88	57.89	38.23	25.46	0.53	66.24	99.97
Mar	16.11	16.73	64.10	27.71	28.18	1.03	73.34	75.50
Apr	14.35	12.85	62.03	23.71	27.27	0.92	70.97	50.27
May	19.80	5.37	64.10	21.11	28.18	1.26	73.34	28.55
Jun	22.23	3.03	62.03	20.95	27.27	1.42	70.97	15.53
Jul	30.86	0.32	64.10	21.68	28.18	1.97	73.34	1.74
Aug	23.03	1.35	64.10	21.24	28.18	1.47	73.40	7.26
Sep	17.84	6.03	62.03	20.74	27.27	1.14	70.97	27.05
Oct	15.66	14.09	64.10	24.48	28.18	1.00	73.34	69.08
Nov	6.55	25.60	62.03	39.21	27.27	0.42	70.97	72.39
Dec	10.11	25.12	64.10	38.47	28.18	0.65	73.34	98.72
Total	192.81	163.89	754.67	341.46	331.82	12.31	863.51	660.26

Table A3. *AMY 2012 Baseline Simulation Electricity Results with Error*

Electricity AMY 2012					
Month	Actual	eQuest	IES	eQuest % Error	IES % Error
Jan	226.50	228.95	246.58	1.1%	8.9%
Feb	206.86	210.67	221.52	1.8%	7.1%
Mar	219.02	221.75	227.20	1.3%	3.7%
Apr	211.25	209.78	212.09	-0.7%	0.4%
May	227.54	206.06	213.16	-9.4%	-6.3%
Jun	231.57	212.71	207.90	-8.1%	-10.2%
Jul	250.03	229.47	220.44	-8.2%	-11.8%
Aug	243.73	211.45	212.70	-13.2%	-12.7%
Sep	222.43	192.92	206.02	-13.3%	-7.4%
Oct	215.22	195.24	220.85	-9.3%	2.6%
Nov	211.16	209.81	232.04	-0.6%	9.9%
Dec	216.63	223.22	239.96	3.0%	10.8%
Total	2681.93	2552.04	2660.46	-4.8%	-0.8%

Table A4. *AMY 2012 Baseline Simulation Propane Results with Error*

Propane AMY 2012					
Month	Actual	eQuest	IES	eQuest % Error	IES % Error
Jan	128.78	176.89	114.21	37.4%	-11.3%
Feb	109.32	145.68	99.97	33.3%	-8.5%
Mar	50.47	53.06	75.50	5.1%	49.6%
Apr	23.98	31.69	50.27	32.2%	109.6%
May	9.31	4.68	28.55	-49.8%	206.5%
Jun	24.93	1.72	15.53	-93.1%	-37.7%
Jul	3.07	0.00	1.74	-100.0%	-43.5%
Aug	8.69	0.28	7.26	-96.8%	-16.4%
Sep	9.77	3.65	27.05	-62.6%	176.9%
Oct	47.73	30.66	69.08	-35.8%	44.7%
Nov	107.34	105.01	72.39	-2.2%	-32.6%
Dec	129.16	126.77	98.72	-1.9%	-23.6%
Total	652.57	680.09	660.26	4.2%	1.2%

Table A5. *eQuest TMY 3 Baseline Simulation Results*

eQuest TMY 3 Baseline (MMBtu)									
Month	Space Cool	Space Heat	Hot Water	Vent. Fans	Pumps & Aux	Equip	Task Light	Area Light	Propane Heat
Jan	0.00	32.45	64.69	19.96	0.55	28.66	2.05	77.46	166.45
Feb	0.00	27.64	62.92	18.02	0.48	26.24	1.88	70.97	132.66
Mar	1.64	20.06	73.22	19.96	0.34	29.41	2.12	79.64	59.68
Apr	4.98	8.70	68.99	19.31	0.20	28.42	2.05	76.94	27.76
May	21.60	1.02	62.54	19.96	0.03	28.83	2.05	78.00	1.43
Jun	54.05	0.00	59.23	19.31	0.00	28.42	2.05	76.94	0.11
Jul	57.53	0.00	54.94	19.96	0.00	29.04	2.08	78.55	0.00
Aug	64.59	0.00	53.30	19.96	0.00	29.21	2.12	79.09	0.00
Sep	34.16	0.03	51.28	19.31	0.00	28.22	2.01	76.40	0.07
Oct	14.67	2.56	53.23	19.96	0.10	28.83	2.05	78.00	13.01
Nov	4.64	13.27	56.30	19.31	0.31	28.05	2.01	75.85	48.04
Dec	0.14	29.86	63.47	19.96	0.55	29.04	2.08	78.55	157.22
Total	257.99	135.60	724.12	234.99	2.56	342.37	24.53	926.40	606.43

Table A6. IES TMY 3 Baseline Simulation Results

IES TMY 3 Baseline (MMBtu)								
Month	Space Cool	Space Heat	Hot Water	Vent. Fans	Equip	Task Light	Area Light	Propane Heat
Jan	7.99	25.52	64.10	38.98	28.18	0.51	73.34	80.74
Feb	8.90	22.76	57.89	34.87	25.46	0.57	66.24	80.58
Mar	11.42	19.47	64.10	31.49	28.18	0.73	73.34	69.92
Apr	15.67	10.87	62.03	22.46	27.27	1.00	70.97	51.23
May	20.14	3.09	64.10	21.11	28.18	1.29	73.34	15.94
Jun	31.80	0.01	62.03	22.04	27.27	2.03	70.97	0.03
Jul	33.59	0.07	64.10	22.20	28.18	2.14	73.34	0.43
Aug	33.53	0.09	64.10	22.35	28.18	2.14	73.34	0.47
Sep	25.46	0.82	62.10	20.90	27.27	1.63	70.97	4.54
Oct	17.79	6.00	64.10	21.42	28.18	1.14	73.34	25.68
Nov	11.48	14.19	62.03	25.78	27.27	0.73	70.97	47.60
Dec	10.46	25.32	64.10	38.93	28.18	0.67	73.34	92.04
Total	228.23	128.19	754.67	322.52	331.82	14.57	863.51	469.19

Table A7. TMY 3 Baseline Simulation Electricity Results with Percent Difference

TMY 3 Electricity (MMBtu)			
Month	eQuest	IES	% Difference
Jan	225.82	238.61	5.7%
Feb	208.14	216.69	4.1%
Mar	226.40	228.73	1.0%
Apr	209.61	210.26	0.3%
May	214.04	211.25	-1.3%
Jun	240.01	216.14	-9.9%
Jul	242.09	223.62	-7.6%
Aug	248.27	223.72	-9.9%
Sep	211.42	209.08	-1.1%
Oct	199.41	211.95	6.3%
Nov	199.75	212.46	6.4%
Dec	223.63	240.99	7.8%
Total	2648.57	2643.51	-0.2%

Table A8. TMY 3 Baseline Simulation Propane Results with Percent Difference

TMY 3 Propane			
Month	eQuest	IES	% Difference
Jan	166.45	80.74	-51.5%
Feb	132.66	80.58	-39.3%
Mar	59.68	69.92	17.1%
Apr	27.76	51.23	84.6%
May	1.43	15.94	1014.6%
Jun	0.11	0.03	-74.5%
Jul	0.00	0.43	--
Aug	0.00	0.47	--
Sep	0.07	4.54	6387.1%
Oct	13.01	25.68	97.4%
Nov	48.04	47.60	-0.9%
Dec	157.22	92.04	-41.5%
Total	606.43	469.19	-22.6%

Table A9. Total Simulated Annual Energy Use by Upgrade in MMBtu

Total Energy (MMBtu)		
	IES	eQuest
Baseline TMY 3	3112.70	3255.00
Improving windows in single cells area (Single to double pane)	3112.70	3219.14
Upgrading from T-8 to LED lighting (30% reduction lighting)	3004.46	3058.25
Changing to reduced flow rate water fixtures (30% reduction water heating)	2886.28	3013.01
Adding an additional R-10 to roof	3081.75	3160.59

Table A10. *Total Annual Electricity Use by Upgrade in MMBtu*

Total Electricity (MMBtu)		
	IES	eQuest
Baseline TMY 3	2643.51	2633.38
Improving windows in single cells area (Single to double pane)	2643.51	2612.54
Upgrading from T-8 to LED lighting (30% reduction lighting)	2400.00	2311.42
Changing to reduced flow rate water fixtures (30% reduction water heating)	2417.10	2406.58
Adding an additional R-10 to roof	2633.38	2605.51

Table A11. *Total Annual Electricity Savings by Upgrade in Dollars*

Electricity Savings (\$)		
	IES	eQuest
Improving windows in single cells area (Single to double pane)	-0.05	739.00
Upgrading from T-8 to LED lighting (30% reduction lighting)	4994.34	6914.97
Changing to reduced flow rate water fixtures (30% reduction water heating)	4643.62	4963.24
Adding an additional R-10 to roof	207.72	883.19

Note: At \$0.07/kWh or \$20.51/MMBtu

Table A12. *Total Annual Propane Use by Energy Upgrade in MMBtu*

Total Propane (MMBtu)		
	IES	eQuest
Baseline TMY 3	469.19	606.43
Improving windows in single cells area (Single to double pane)	469.19	606.60
Upgrading from T-8 to LED lighting (30% reduction lighting)	604.46	746.83
Changing to reduced flow rate water fixtures (30% reduction water heating)	469.18	606.43
Adding an additional R-10 to roof	448.37	555.09

Table A13. *Total Annual Propane Savings by Upgrade in Dollars*

Propane Savings (\$)		
	IES	eQuest
Improving windows in single cells area (Single to double pane)	-0.06	-2.59
Upgrading from T-8 to LED lighting (30% reduction lighting)	-2058.87	-2136.89
Changing to reduced flow rate water fixtures (30% reduction water heating)	0.09	0.00
Adding an additional R-10 to roof	316.82	781.55

Note: At \$1.40/Gal and 92,000 Btu/Gal or \$15.22/MMBtu

Vita

Alexandra Lowrie was born in Winston Salem, North Carolina, to Bruce and Sara Lowrie. She graduated from Mount Tabor High School in Winston Salem, North Carolina, in June 2011. The following autumn, she entered North Carolina State University to study Mechanical Engineering; and in December 2014, she was awarded the Bachelor of Science degree in Mechanical Engineering with a Minor in Economics. In the spring of 2015, she accepted a research assistantship in Renewable Energy Engineering at Appalachian State University and began study toward a Master of Science degree. The M.S. was awarded in December 2017.

Ms. Lowrie is a member of Tau Beta Pi and enjoys hiking and camping. She resides in Charlotte, NC.