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Assessing the Energy Savings of Tankless Water Heater Retrofits in Public Housing

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Building Energy Efficient Homes for America (BEEHA)

January 2013

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Assessing the Energy Savings of Tankless Water Heater Retrofits in Public Housing

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Definitions

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration, and Air-conditioning Engineers
ASTM	American Society for Testing and Materials
BEopt	Building Energy Optimization Software
BTU	British Thermal Unit
BTU/day	Btu per day
BTU/hr	Btu per hour
DHWS	Domestic hot water systems
DOE	Department of Energy
FEMP	Federal Energy Management Program
GRU	Gainesville Regional Utilities
kBTU/hr	Thousand Btu per hour
LCC	Life cycle cost
MBTU/hr	Thousand Btu per hour
MM BTU/hr	Million Btu per hour
NEACA	National Energy Appliance Conservation Act
NREL	National Renewable Energy Laboratory
NIST	National Institute of Standards and Technology
NS	Net savings
PVLCC	Present value life cycle cost
SIR	Saving to investment ratio
Sq.ft.	Square foot
WHAM	Water heater analysis model
TWH	Tankless water heater
TTWH	Tank type water heater
^{o}F	Degree Fahrenheit

Overview and Summary of Findings

Residential water heating represents about 20% of total residential energy consumption (EIA 2009, Wenzel et al. 1997) and therefore, technology that can reduce residential water heating energy use should be thoroughly evaluated. A potential approach to reducing water heating energy use is upgrading from a tank type to a tankless water heater. Tankless water heaters have higher rated efficiencies than tank type systems, but also have a higher installed cost. In addition, tankless water heaters provide a supply of hot water not limited by the tank capacity, which may increase water usage. This report describes the methodology, analysis, and findings from a case study of a 110-unit retrofit of gas tankless water heaters in a hot/humid climate in Alachua County, Florida.

In December 2010, the Alachua County Housing Authority initiated a retrofit program in 110 public housing units. As part of a federal program that sought to reduce energy use in public housing, the gas-fired tank type water heaters in the housing units were replaced with gas-fired tankless water heaters. The units are single-family detached or semi-detached, and have individual metering for utilities, i.e., electricity, gas, and water. The units are located in three groups in various cities in Florida: ten are in one housing development in Gainesville; ten are in Waldo:, and ninety are in Alachua. The units were built in stages, which consist of multiple identical units. A unique advantage of using public housing in a study such as this is that the data is from a set of similar sized housing units that were upgraded as a group from tank type water heaters to identical tankless water heaters.

In this study, three strategies were used to estimate energy and water consumption pre- and post-retrofit:

- Utility bill analysis
    - Statistical analysis of energy and water consumption as recorded in the utility bills for natural gas, propane, and potable water.
- Calculation
    - Energy and water consumption estimated using Water Heater Analysis Model (WHAM) equations, regulations, and building codes.
- Simulation
    - Energy and water consumption estimated using BEopt simulation.

A goal of this study is to examine the potential benefits of system upgrades such as tankless water heaters both empirically and with models. Models that are good predictors of energy reduction and cost savings are important for making retrofit decisions that will lower energy use and energy costs, which benefit tenants and owners, and also lower the environmental impact of operating buildings.

The utility-based statistical analyses use data from the same units pre- and post-retrofit, which provides estimates of the average change in gas and water consumption in these units. Using paired analysis of the same units before and after the change in water heaters will reduce, but not eliminate, potential sources of variability between the units. The statistical analysis of utility data, the calculated, and the simulated estimates are used to assess the predictions of energy consumption and the economic feasibility of the tankless water heating system retrofit. The results from the three models were also compared to determine if any obvious differences could be found.

The statistical analyses of the utility data showed a significant decrease in average gas use of 33% (see Table 1) when comparing the therms of gas used in the pre- and post-retrofit study periods. The calculation method predicted energy savings of 44% and simulation predicted 39%. To account for the impact of having different water consumption in the pre- and post-retrofit utility data, an analysis of data normalized by dividing the therms of gas used by the gallons of water used during the study periods was also performed. The estimated energy savings ranged from 36% for the normalized utility data to 44% predicted by the calculation method. The calculation method consistently had the largest estimated savings. Both the calculation and simulation gas savings percentages were similar to the utility-based estimates in the Gainesville units. The gas savings percentage predicted for the Alachua units by calculation and simulation are greater than the average gas savings percentage estimated from the utility-based analysis. This result is confounded by the use of gas for cooking in the Alachua units during the study periods. When compared to the calculated and utility-based estimates, simulation underestimates the magnitude (not the percentage) of energy used pre- and post-retrofit and therefore may underestimate hot water usage. This has implications for cost effectiveness, as discussed below.

The statistical analysis of the utility water use data pre- and post-retrofit over the three-month study period showed that there was no statistically significant difference in water use in the homes. This corresponded with the calculated and simulated estimates, as the variables used in the calculation and simulation of water use did not change pre- and post-retrofit.

The cost effectiveness analyses used calculated-, simulated-, and utility-based energy savings estimates for determining present value life cycle cost (PVLCC), present value net savings (PVNS, see Table 2), and the savings to investment ratio (SIR). Tankless water heating was found to be cost effective when calculation- and utility-based gas use estimates were used. The PVLCC was lower and PVNS was positive when using the utility- and calculation-based gas savings estimates. The simulated estimates of energy use for tank type and tankless did not indicate that the tankless retrofit was cost effective. Simulation estimated lower energy use,therefore, lower hot water use in both the pre- and post-retrofit conditions. The simulation-based energy savings estimates were less than the maintenance cost of the tankless system, which was the primary reason that the PVLCC was higher and PVNS was negative for the tankless water heater compared to the tank type water heater. A sensitivity analysis showed that for the calculation and utility cases, the investment will remain favorable as long as the energy inflation rate remains above 3%, which is consistent with current forecasts.

Table 1. Estimates of Pre-Retrofit and Post-Retrofit Gas and Normalized Gas Consumption, Savings, and Percentages in the Gainesville Units

	Location	Calculated			Simulated			Utility				
		Mean gas use pre/post retrofit	Mean savings	%	Mean gas use pre/post retrofit	Mean savings	%	Mean gas use pre/post retrofit	Mean savings	%	95% CI	
											Low	High
Non-normalized (therms)	Gainesville	38/21	16.7	44%	27/17	10.5	39%	53/36	17.6	33%	22%	44%
Normalized (therms/kgal)	Gainesville	3.1/1.8	1.4	44%	NA			4.0/2.5	1.4	36%	8%	65%

Table 2. Gas Cost Savings and PVNS in the Pre- and Post-Retrofit Study Period for the Calculated, Simulated, and Utility-based Energy Savings Estimates for the Gainesville Units

	Calculated	Simulated	Utility
Annual gas cost savings ($)	$60.50	$37.53	$63.25
Present Value Net Savings ($)	$215	($557)	$307

1 Introduction

The properties and performance characteristics of both tank type and tankless water heaters are generally well established and available, and installation costs can be estimated based on past practices, so it is possible to conduct energy use, water use, and economic analyses. However, performance predictions do not always accurately represent how equipment will perform in real world conditions; therefore, this study includes estimates based on a longitudinal empirical utility data analysis that provides a point of comparison to the calculated and simulated pre- and post-retrofit performance estimates of a retrofit of tank-type water heating with tankless water heating in public housing units. This research compares utility data to modeled pre- and post-retrofit energy and water consumption from a retrofit program that replaced tank type water heaters with tankless water heaters in 110 public housing units.

The calculated pre- and post-retrofit performance estimates are based on current mathematical models of tank type and tankless water heaters (Lutz et al. 1999), and the simulated estimates are produced using BEopt version 1.1 energy modeling software (NREL 2011). The calculated and simulated performance estimates are then compared to installed performance as represented by statistical analysis of utility meter data. Differences between the utility, calculated, and simulated results are identified and used to examine the differences in the performance predictions for water heaters. If the modeled and empirical energy savings do not agree, the simulation and calculation parameters will be investigated further. Assessing the energy reduction potential of system upgrades such as tankless water heaters empirically, and then comparing them to model estimates is important. Models that are good predictors of energy reduction and cost savings are important for making decisions that will lower energy use and energy costs, which benefit tenants and owners and also lower the environmental impact of operating buildings. Studying the correspondence of predicted and empirical energy savings could improve the estimates of the energy benefits of system upgrades.

1.1 Research Questions

For homes in hot and humid climates, conventional center flue atmospheric tank type water heaters are by far the most common means of water heating. This technology has changed very little since its introduction and has several inherent inefficiencies. First, keeping a large supply of water heated at all times leads to thermal energy loss through the tank wall. This shortcoming is exacerbated in homes in cooling climates when the water heater is located in conditioned space, because this places an additional load on the cooling system. A second inherent inefficiency is that conventional water heaters are oversized to accommodate the times of the day with the heaviest demand. This shortcoming requires that energy be used to heat and maintain approximately 40 gallons of water at the hot water set point temperature 24 hours a day. Tankless water heaters overcome these inefficiencies by supplying hot water on demand without storage.

The following questions are addressed in this research:

- What are the energy consumption impacts of upgrading to a tankless system?
- What are the water use impacts of upgrading to a tankless system?

- What are the cost impacts of upgrading to a tankless system?
- Do pre- and post-retrofit modeled estimates of energy and water consumption align with energy and water utility data?
- What information is necessary to effectively model the water heater energy consumption in the pre- and post-retrofit home?
- What additional parameters or algorithm changes are necessary to align pre- and post-retrofit consumption estimates with actual field performance?

2 Methodology

Of the 110 units in the Alachua County Housing Authority retrofit program, ten units are in one housing development in the city of Gainesville, ten are in Waldo, and ninety are in the city of Alachua, Florida. Each subdivision contains houses of the same construction, including similar appliances and fixtures provided and maintained by the Alachua County Housing Authority, with the exception of a washer and dryer. The water heaters were replaced from January through March of 2011. No other appliances or fixtures were upgraded over the study period.

Only the units that were consistently occupied by the same tenants from January 2010 through December 2011 and where data were consistently available were used in the analysis. Seven units in Gainesville and thirty units in Alachua met these criteria. The Gainesville development consists of four buildings with three duplexes and one quadraplex, and all units have two bedrooms. In the Alachua development, there are four configurations ranging from two to five bedrooms. The Gainesville units use natural gas for water heating and space heating. The Alachua units use propane for water heating and cooking only. Water was not used for irrigation in any location.

The study periods are May 2010 to July 2010 for the pre-retrofit period, and May 2011 to July 2011 for the post-retrofit period. This time period was chosen to avoid as much non-water heating gas use as possible. The project study period from May through July 2010 for pre-retrofit and May through July 2011 for post-retrofit eliminates gas consumption for space heating in the Gainesville units. However, the utility data for the Alachua units include gas consumption for cooking. The utility data were obtained from Gainesville Regional Utilities (GRU), Alachua Water Authority, and Davis Gas Company.

The statistical analysis of the utility data using the same units pre- and post-retrofit provides estimates of the average change in gas and water consumption in these units. Using paired analyses of the same units before and after the change in water heaters will reduce, but not eliminate, the potential sources of variability between the units. The statistical analysis, calculated, and simulated estimates are used to compare and assess the three models' predictions of consumption. The utility data, calculated, and simulated results were also compared to determine if any obvious differences could be found. Utility data, calculated, and simulated energy savings estimates are also used to calculate the economic impact of the tankless water heating system retrofit.

The methods used to estimate water heating energy use and cost effectiveness are: 1) estimate energy consumption (Section 2.1) and water use (Section 2.2) based on utility data; 2) use equations to calculate energy consumption (reviewed in Section 2.3), total water use (Section 2.4) and hot water use (described in Section 2.5); 3) use energy simulation software to predict energy use (reviewed in Section 2.6). In addition, the utility data was normalized (Section 2.7) and statistical analyses were used to compare pre- and post-retrofit data (Section 2.8). Finally, economic cost-effectiveness analyses were conducted, including PVLCC, PVNS, and the savings-to-investment ratio (Section 2.9).

2.1 Utility-Based Energy Consumption

Energy use in the pre-retrofit and the post-retrofit periods are estimated using the meter readings as recorded in the utility bills for natural gas and propane. The difference of the meter readings at the beginning and end of the study periods are converted to therms of gas usage using utility meter multipliers and unit conversions. The difference in tank type and tankless water heating energy consumption is the difference in pre-retrofit and post-retrofit gas consumption. Statistical analysis is used to estimate the average change in energy consumption (see Section 2.9). The calculations are detailed in Appendix A.

2.2 Utility-Based Water Consumption

As with energy use, water use in the pre-retrofit and the post-retrofit periods are also estimated using the meter readings as recorded in the water utility bills. Metered water use in the pre-retrofit and the post-retrofit periods are converted to gallons of water using a meter to gallon conversion factor. The difference in water consumption in units with tank type and tankless water heating is the difference in pre-retrofit and post-retrofit water consumption. Statistical analysis is used to estimate the average change in water consumption (see Section 2.9). The calculations are detailed in Appendix A.

2.3 Calculated Energy Consumption

Water Heater Analysis Model (WHAM) equations are used to estimate the energy consumption of tank type water heaters (Lutz et al. 1999). Adjusted WHAM equations (DOE 2010) are used to estimate energy consumption for tankless water heaters. The parameters are adopted or derived from the Energy Data Sourcebook for the U.S. Residential Sector (Wenzel et al. 1997), the HVAC Applications Handbook (ASHRAE 1999), the Building America House Simulation Protocols (Hendron et al. 2010), the National Appliance Energy Conservation Act of 1987 (NAECA 1987), and the Rulemaking Framework for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters (DOE 2006). The difference in energy consumption pre- and post-retrofit is the difference in calculated energy consumption for the tank type water heater and the tankless water heater. The calculations and parameters are reviewed in detail in Appendix B.

2.4 Calculated Total Water Consumption

The water consumption calculations use fixture assumptions based on the Energy Policy Act of 1992 (EPAct 1992) and federal rulemaking for energy conservation in consumer products (DOE 2001, DOE 2009). The average water consumption for a residential unit is calculated from the number of occupants, the number of uses per fixture type per occupant, the flow rate per fixture type (in gallons per minute or cycle), and the duration of use for each fixture type. The calculations and assumptions are detailed in Appendix C.

Water use is also calculated using equations per fixture based on the Building America House Simulation Protocols (Hendron et al. 2010). The water consumption per day per fixture type is calculated using the number of bedrooms as the variable. The equations were developed from a regression analysis of water consumption in an empirical study of residential water use. The calculations are shown in more detail in Appendix C.

2.5 Simulated Energy Consumption

BEopt energy simulation was used to estimate water heating energy use in both pre- and post-retrofit cases. Assumptions are based on the Building America House Simulation Protocols (Hendron et al. 2010) and the default parameters for water use were used. The input parameters for the Gainesville simulations are discussed in Appendix D and the parameters for the Alachua units are shown in Appendix E.

2.6 Simulated Hot Water Consumption

BEopt simulation results include hot water consumption. The simulation results are expressed as a water flow rate, which is converted to gallons using the procedure shown in Appendix F.

2.7 Normalization

The utility-based water data is total water usage and the exact ratio of hot to cold water usage in any given unit is not known. The expectation is that the ratio of hot to cold water used will remain similar in a given unit in the units in the study, i.e., where occupancy has not changed. In order to compare utility data-, calculation-, and simulation-based estimates for energy and water consumption pre- and post-retrofit, the results are normalized in the following way.

For pre-retrofit in unit i:

$$N_{i\ pre-retrofit} = \frac{Gas\,usage_i\ [therms]}{Water\,usage_i\ [gals]} \tag{2.7.1}$$

where:
$N_{i\ pre\text{-}retrofit}$ = normalization for unit i, pre-retrofit period
Gas $usage_i$ = gas usage for unit i (therms)
Water $usage_i$ = water usage for unit i (gallons)

For post-retrofit in unit i:

$$N_{i\ post-retrofit} = \frac{Gas\,usage_i\ [therms]}{Water\,usage_i\ [gals]} \tag{2.7.2}$$

where:
$N_{i\ post\text{-}retrofit}$ = normalization for unit i, post-retrofit period (therms/gallon)
Gas $usage_i$ = gas usage for unit i (therms)
Water $usage_i$ = water usage for unit i (gallons)

$$\Delta N_i = N_{i\ pre-retrofit} - N_{i\ post-retrofit} \tag{2.7.3}$$

where:
ΔN_i = difference in normalized energy use for unit i (therms/gallon)

$$\Delta N_i\ [\%] = \frac{\Delta N_i}{N_{i\ pre-retrofit}} \qquad (2.7.4)$$

where:
ΔN_i = percentage difference in normalized energy use for unit i (%)

Statistical paired sample analysis of the normalized energy use is used to determine whether the pre- and post-retrofit difference is statistically significant.

2.8 Statistical Analysis

A paired t-test with two tails was used to analyze the pre- and post-retrofit normalized and non-normalized gas consumption. The paired t-test compares the difference in observations of the subjects before and after a change, which provides an opportunity to evaluate the effectiveness of the change. The paired t-test is used in this case because it is effective in removing extraneous sources of variation, such as variation in the units and in occupant behavior. Generally, this makes it more likely that differences between the population means will be detected when such differences exist. This test assumes that the data is normally distributed, and therefore, the data is also tested for normality.

In the paired t-test, the mean difference (d) between the energy use pre- and post- retrofit is calculated. Then, the standard deviation (S_d), standard error ($SE_{\bar{d}}$), and the t-statistic are calculated. For the 95% confidence level used in the study, if the p value is less than 0.05, the alternative hypothesis, H_a, is accepted. If $p > 0.05$, the null hypothesis, H_0, is accepted. If there is confidence in the alternative hypothesis, the next step is to determine the confidence interval. This will provide the expected range or span of the results (such as the gas savings pre- and post-retrofit) at the 95% confidence level.

A one-tailed t-test, which is calculated in a similar way, was used to determine if the normalized and non-normalized gas savings percentage pre- and post-retrofit calculated for the units was statistically significant. In other words, can we expect the normalized energy savings percentage to be greater than zero with a high degree of confidence? The statistical analyses, including tests for the normality of data, are discussed in Appendix G.

2.9 Evaluation of Cost Effectiveness

Present value life cycle cost (PVLCC), PVNS, and the SIR are used to investigate the cost effectiveness of the water heater retrofits (ASTM 1994, Fuller & Petersen 1995). Future values are discounted and future energy costs that have a differential escalation rate are escalated from present costs using an energy specific escalation rate. PVLCC of the tank-type and tankless systems are calculated, and the alternative with the lowest PVLCC is preferred. Present values are also used in the PVNS approach. The decision rules for PVNS are that an alternative with a PVNS > 0 is acceptable, and the alternative with the greatest PVNS is preferred. In the PVNS calculation, the initial investment is the difference between the alternatives. For the SIR, the decision rules are that an alternative with an SIR ≥ 1 is acceptable, and the alternative with the greatest SIR is preferred.

The study period used for all economic analyses is 30 years. The discount rate, general inflation rate, and interest rate are set to 3%, and the energy inflation rate is set to 4% based on the expected escalation for Florida (Rushing et al. 2010). Sensitivity analyses of the life cycle cost and the net savings of the water heater upgrade were conducted to determine the impact of variations in the discount, energy inflation, and general inflation rates on the investment. For a detailed review of the economic evaluation of the cost effectiveness measures, see Appendix H.

3 Results

3.1 Utility Data-Based Energy and Water Analyses

The monthly gas (therms) and water (kgals) consumption pre-retrofit (2010) and post-retrofit (2011) for one Gainesville unit are shown in Figures 1 and 2. Table 3 shows the data for the May-July 2010 and May-July 2011 study periods for the Gainesville and Alachua units, including the pre- and post-retrofit difference in gas use per gallon of water consumed ($Gas_{pre-retrofit} - Gas_{post-retrofit}$, Column 8); the percentage reduction in gas use (($Gas_{pre-retrofit} - Gas_{post-retrofit}$) / $Gas_{pre-retrofit}$, Column 9); the pre- and post-retrofit difference in normalized energy use per gallon of water consumed ($N_{pre-retrofit} - N_{post-retrofit}$, Column 10); and the percentage reduction in normalized gas use (($N_{pre-retrofit} - N_{post-retrofit}$) / $N_{pre-retrofit}$, Column 11). The utility data for water in Gainesville is recorded to the nearest 1,000 gallons. The calculations for Table 3 are detailed in Appendix A.

The data in Table 3 show that there is variability in gas and water use between similar units and between the two study periods for the same unit. We hypothesize that the variability is primarily due to differences in demographics and occupant behavior. The impact of the variance between the units was reduced by comparing each unit's gas and water use pre- and post-retrofit and analyzing the average change in gas and water use pre- and post-retrofit to determine if there was a statistically significant difference. To reduce the variability of the utility data, the gas and water use was normalized by dividing the gas used in therms by the total water used in gallons. This does not imply that hot to total water use ratios do not vary from household to household or in a given household between the two study periods. The therms/gallon calculated from the utility data is not intended to represent water heater efficiency. Although the total water utility data includes both hot and cold water consumption, the gas used (in therms) is correlated with total water used (in gallons) as shown in Appendix G.

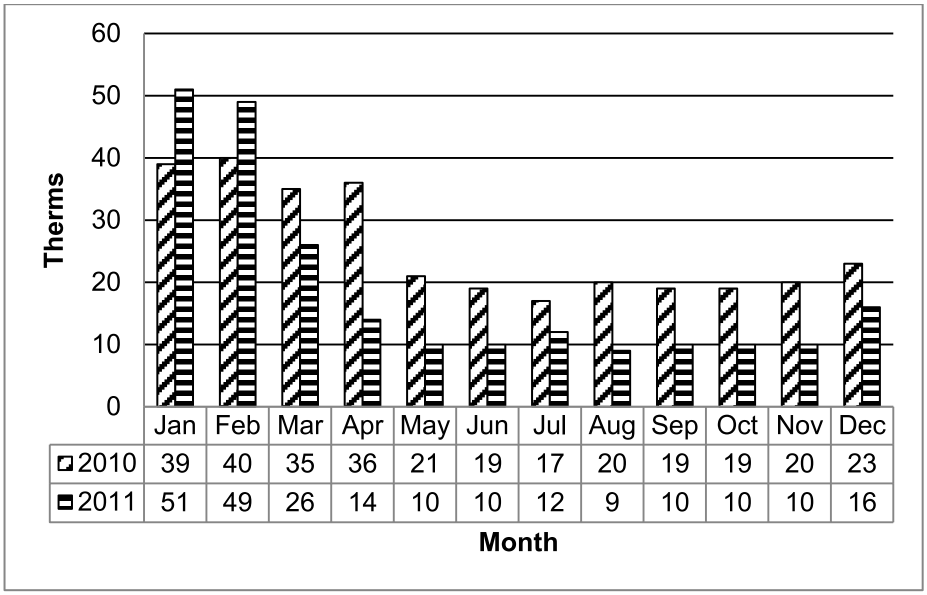


Figure 1. Monthly gas usage pre-retrofit (2010) and post-retrofit (2011) for one Gainesville unit

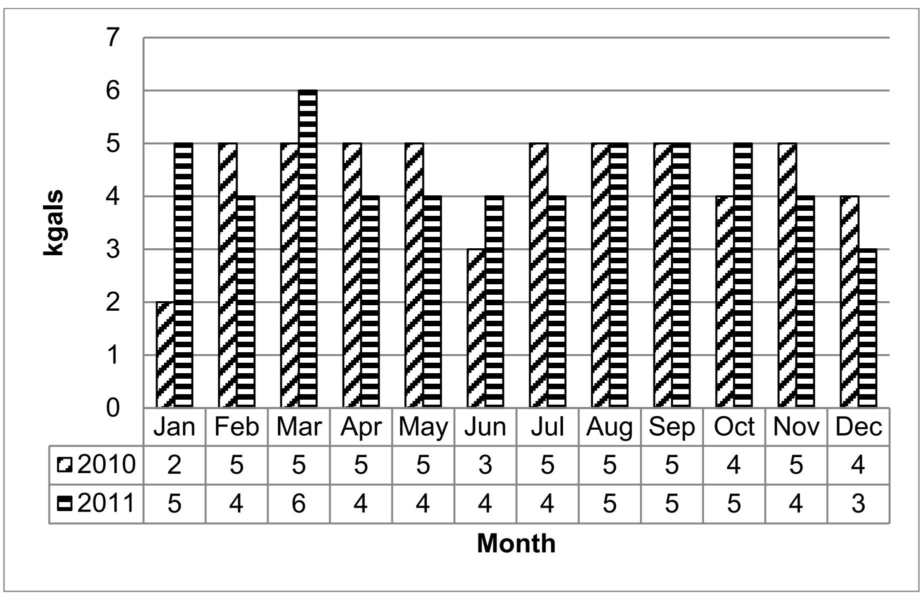


Figure 2. Monthly water consumption pre-retrofit (2010) and post-retrofit (2011) for one Gainesville unit

Table 3. Summary of the Pre- and Post-Retrofit Study Period Data for the Gainesville and Alachua Units

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Case Number	Gas (therms)	Water (gal)	Normalized gas use (therms/gal)	Gas (therms)	Water (gal)	Normalized gas use (therms/gal)	Difference in gas use (therms)	Reduction in gas use (%)	Difference in normalized gas use (therms/gal)	Reduction in normalized gas use (%)
	May - July 2010			May - July 2011			Difference May-July 2010 to May-July 2011			
Gainesville units										
1	49	12,000	0.0041	39	11,000	0.0035	10.0	20%	0.0005	13%
2	30	8,000	0.0038	19	9,000	0.0021	11.0	37%	0.0016	44%
3	69	20,000	0.0035	50	21,000	0.0024	19.0	28%	0.0011	31%
4	80	24,000	0.0033	53	26,000	0.0020	27.0	34%	0.0013	39%
5	57	13,000	0.0044	32	12,000	0.0027	25.0	44%	0.0017	39%
6	43	18,000	0.0024	35	11,000	0.0032	8.0	19%	-0.0008	-33%
7	44	7,000	0.0063	21	12,000	0.0018	23.0	52%	0.0045	72%
MEAN Gainesville	*53*	*14,571*	*0.0040*	*36*	*14,571*	*0.0025*	*17.6*	*33%*	*0.0014*	*29%*
Alachua units										
8	46	13,660	0.0034	30	10,520	0.0029	16.0	35%	0.0005	15%
9	74	36,370	0.0020	42	25,420	0.0017	32.0	43%	0.0004	19%
10	25	21,990	0.0011	23	16,700	0.0014	2.0	8%	-0.0002	-21%
11	53	23,170	0.0023	12	3,540	0.0034	41.0	77%	-0.0011	-48%
12	23	7,240	0.0032	16	7,050	0.0023	7.0	30%	0.0009	29%
13	68	24,590	0.0028	44	19,560	0.0022	24.0	35%	0.0005	19%
14	58	36,160	0.0016	65	58,890	0.0011	-7.0	-12%	0.0005	31%
15	31	7,630	0.0040	18	9,870	0.0018	13.0	42%	0.0022	55%
16	55	16,580	0.0033	38	15,270	0.0025	17.0	31%	0.0008	25%
17	63	31,300	0.0020	40	25,030	0.0016	23.0	37%	0.0004	21%
18	36	11,010	0.0033	16	5,700	0.0028	20.0	56%	0.0005	14%
19	21	5,160	0.0041	37	14,460	0.0026	-16.0	-76%	0.0015	37%
20	42	22,360	0.0019	52	27,550	0.0019	-10.0	-24%	0.0000	0%
21	64	11,750	0.0055	33	11,530	0.0029	31.0	48%	0.0026	47%
22	53	13,700	0.0039	29	14,830	0.0020	24.0	45%	0.0019	49%
23	31	11,040	0.0028	22	16,600	0.0013	9.0	29%	0.0015	53%
24	65	29,280	0.0022	45	22,650	0.0020	20.0	31%	0.0002	11%
25	25	6,030	0.0041	18	6,910	0.0026	7.0	28%	0.0015	37%
26	26	5,310	0.0050	24	7,310	0.0033	2.0	8%	0.0016	33%
27	76	32,330	0.0023	58	28,690	0.0020	18.0	24%	0.0003	14%
28	24	22,400	0.0011	21	14,390	0.0015	3.0	13%	-0.0004	-36%
29	50	21,430	0.0023	28	15,900	0.0018	22.0	44%	0.0006	25%
30	30	7,280	0.0041	27	22,730	0.0012	3.0	10%	0.0029	71%
31	55	21,810	0.0025	40	15,480	0.0026	15.0	27%	-0.0001	-2%
32	33	18,740	0.0018	46	12,250	0.0038	-13.0	-39%	-0.0020	-113%
33	48	14,500	0.0033	37	14,550	0.0025	11.0	23%	0.0008	23%
34	51	58,620	0.0009	77	58,570	0.0013	-26.0	-51%	-0.0004	-51%
35	47	15,630	0.0030	34	19,690	0.0017	13.0	28%	0.0013	43%
36	32	9,740	0.0033	29	11,090	0.0026	3.0	9%	0.0007	20%
37	43	23,220	0.0019	44	23,580	0.0019	-1.0	-2%	0.0000	-1%
MEAN Alachua	*45*	*19,334*	*0.0028*	*35*	*18,544*	*0.0022*	*10.1*	*19%*	*0.0007*	*14%*
MEAN All units	*46.5*	*18,433*	*0.0030*	*35*	*17,792*	*0.0022*	*11.5*	*21%*	*0.0008*	*17%*

3.2 Calculated Energy Consumption

The following section reviews the approach to estimating energy consumption for tank type and tankless water heating using heat transfer-based calculations.

3.2.1 Calculated Energy Consumption for Tank Type Water Heating

The calculation of the energy consumption for the tank type water heater uses equation B2 with the parameters based on the data and assumptions shown in Appendix B. The results for the tank type water heater for the two bedroom Gainesville units are shown in Table 4. Column 2 shows the daily energy consumption in Btu/day for each month of the year and column 3 shows the monthly energy use in therms. Table 5 summarizes the calculated monthly gas consumption in therms for all of the test cases. The highlighted rows indicate the study period.

Table 4. Calculated Daily (in Btu/day) and Monthly (in therms) Energy Consumption for the Tank Type Water Heater in Two Bedroom Units

[1]	[2]	[3]
Month	**(Btu/day)**	**(therms)**
January	50,358	15.61
February	50,175	14.05
March	48,683	15.09
April	46,220	13.87
May	43,452	13.47
June	41,136	12.34
July	39,889	12.37
August	40,069	12.42
September	41,598	12.48
October	44,085	13.67
November	46,860	14.06
December	49,147	15.24
TOTAL		*164.67*

Table 5. Monthly Calculated Energy Use for Tank Type Water Heaters for 12 Months for Two, Three, Four, and Five Bedroom Units

[1]	[2]	[3]	[4]	[5]
Month	**Calculated Gas Consumption (therms)**			
	2 Bed	**3 Bed**	**4 Bed**	**5 Bed**
January	15.61	17.70	19.82	21.88
February	14.05	15.92	17.83	19.68
March	15.09	17.07	19.09	21.04
April	13.87	15.64	17.44	19.18
May	13.47	15.13	16.82	18.45
June	12.34	13.81	15.30	16.75
July	12.37	13.80	15.27	16.69
August	12.42	13.87	15.34	16.77
September	12.48	13.97	15.49	16.97
October	13.67	15.36	17.09	18.77
November	14.06	15.87	17.71	19.49
December	15.24	17.25	19.29	21.28
TOTAL	*164.67*	*185.39*	*206.49*	*226.95*

3.2.2 Calculated Energy Consumption for Tankless Water Heating

The calculation of the energy consumption for the tankless water heater uses equation B3 with the parameters based on the data and assumptions shown in Appendix B. The results for the tankless water heater for the two bedroom Gainesville units are shown in Table 6. Column 2 shows the daily energy consumption in Btu/day for each month of the year and column 3 shows the monthly energy use in therms. Table 7 summarizes the calculated monthly gas consumption in therms for all of the test cases. The highlighted rows indicate the study period.

Table 6. Calculated Daily (in Btu/day) and Monthly (in therms) Eenergy Consumption for the Ttankless Water Heater in Two-bedroom Units

[1]	[2]	[3]
Month	**(Btu/day)**	**(therms)**
January	31,621	9.80
February	31,440	8.80
March	30,047	9.31
April	27,740	8.32
May	25,150	7.80
June	22,976	6.89
July	21,809	6.76
August	21,971	6.81
September	23,413	7.02
October	25,744	7.98
November	28,335	8.50
December	30,482	9.45
TOTAL		*97.44*

Table 7. Calculated Monthly Energy Consumption for Tankless Water heaters for 12 Months for Two, Three, Four, and Five Bedroom Units

[1]	[2]	[3]	[4]	[5]
Month	**Calculated Gas Consumption (therms)**			
	2 Beds	**3 Beds**	**4 Beds**	**5 Beds**
January	9.80	11.76	13.74	15.67
February	8.80	10.56	12.34	14.08
March	9.31	11.17	13.06	14.89
April	8.32	9.98	11.67	13.31
May	7.80	9.35	10.93	12.47
June	6.89	8.27	9.66	11.02
July	6.76	8.11	9.48	10.81
August	6.81	8.17	9.55	10.89
September	7.02	8.42	9.85	11.23
October	7.98	9.57	11.19	12.76
November	8.50	10.19	11.92	13.59
December	9.45	11.33	13.25	15.11
TOTAL	*97.44*	*116.88*	*136.64*	*155.83*

3.3 Calculated Total Water Consumption

The variables for calculating total water use for a single family house with three occupants based on equation C1 in Appendix C are shown in Table 8. The results estimate the average total water usage of the units pre- and post-retrofit since the variables do not change over the study periods.

Table 8. Calculated Daily Total (hot and cold) Water Consumption in a Unit with Three Occupants

[1]	[2]	[3]	[4]	[5]
Fixture type	**Uses per occupant per day**	**Water volume per use [gals]**	**Number of occupants**	**Water volume per day [gals]**
Lavatory faucet	5	0.55	3	8.25
Kitchen faucet	4	2.20	3	26.40
Shower	1	12.50	3	37.50
Water closet	5	1.60	3	24.00
Dish washer	0.25	10.00	3	7.50
Clothes washer	0.25	39.20	3	29.40
			TOTAL	*133.00*

The equations in the Building America House Simulation Protocols (Hendron et al 2010) were also used to calculate total water consumption as illustrated in Table C.3 in Appendix C. The results for the unit types in the study are summarized in Table 9. The results from these calculations were not used for estimating total water use because not all fixtures, e.g., water closets, are included and the estimates for the clothes washer are for hot water only. The water consumption estimate per unit type is the same pre- and post-retrofit as the parameters do not change.

Table 9. Calculated Daily Water Consumption for Two, Three, Four, and Five Bedroom Units

[1]	[2]	[3]	[4]	[5]
End Use	**Total Daily Household Water Use (gallons/day)**			
	2 Bed	**3 Bed**	**4 Bed**	**5 Bed**
Clothes Washer (hot water only)	3.9	4.7	5.5	6.25
Dishwasher	3.8	4.5	5.3	6.01
Shower	23.3	28	32.8	37.35
Bath	5.8	7	8.2	9.35
Sinks	20.8	25	29.1	33.3
TOTAL	*57.6*	*69.2*	*80.9*	*92.26*

3.4 Simulated Energy Consumption for Tank Type and Tankless Water Heating

BEopt simulations of both the pre- and post-retrofit conditions use assumptions similar to the calculated approach. Reference drawings for the Gainesville and Alachua units are in Appendix D and Appendix E, respectively. The simulated water heater energy consumption estimate for two to five bedroom units for pre-retrofit tank type water heating are shown in Table 10 and the results for post-retrofit tankless water heating are shown in Table 11.

Table 10. Monthly Simulated Energy Use for Tank Type Water heaters for 12 Months for Two, Three, Four, and Five Bedroom Units

[1]	[2]	[3]	[4]	[5]	[6]
Month	**Simulated Gas Consumption (therms)**				
	Natural Gas	**Propane**			
	2 Bed	**2 Bed**	**3 Bed**	**4 Bed**	**5 Bed**
January	12.28	11.82	13.48	15.15	16.82
February	11.03	10.62	12.11	13.60	15.10
March	11.65	11.22	12.76	14.31	15.85
April	10.59	10.20	11.56	12.92	14.28
May	9.43	9.07	10.19	11.30	12.43
June	8.99	8.66	9.72	10.77	11.82
July	8.94	8.61	9.64	10.66	11.69
August	7.73	7.45	8.25	9.04	9.84
September	9.15	8.81	9.90	10.98	12.06
October	10.34	9.96	11.24	12.53	13.81
November	10.81	10.41	11.81	13.21	14.62
December	10.80	10.40	11.78	13.17	14.56
TOTAL	*121.74*	*117.22*	*132.43*	*147.65*	*162.87*

Table 11. Monthly Simulated Energy Use for Tankless Water Heaters for 12 Months for Two, Three, Four, and Five Bedroom Units

[1]	[2]	[3]	[4]	[5]	[6]
Month	Simulated Gas Consumption (therms)				
	Natural Gas	Propane			
	2 Bed	2 Bed	3 Bed	4 Bed	5 Bed
January	8.75	8.42	10.10	11.78	13.47
February	7.84	7.55	9.06	10.57	12.08
March	8.12	7.81	9.37	10.94	12.50
April	7.17	6.91	8.28	9.66	11.04
May	5.88	5.66	6.80	7.92	9.06
June	5.55	5.35	6.41	7.49	8.55
July	5.39	5.19	6.23	7.26	8.30
August	4.19	4.03	4.84	5.65	6.45
September	5.71	5.50	6.60	7.69	8.80
October	6.79	6.54	7.84	9.15	10.45
November	7.38	7.11	8.53	9.95	11.37
December	7.27	7.00	8.40	9.81	11.20
TOTAL	*80.03*	*77.06*	*92.46*	*107.87*	*123.28*

3.5 Simulated Hot Water Consumption

The method for converting BEopt simulation results to gallons of hot water consumption is shown in Appendix F. The simulated hot water consumption for two, three, four, and five bedroom units is shown in Table 12. The number of bedrooms is the main driver for estimating hot water consumption. The pre-retrofit and post-retrofit hot water consumption is the same since there are no changes in the relevant parameters.

Table 12. Monthly Simulated Hot Water Consumption for 12 Months for Two, Three, Four, and Five Bedroom Units

[1]	[2]	[3]	[4]	[5]
Month	Simulated Hot Water Consumption (gallons)			
	2 Bed	3 Bed	4 Bed	5 Bed
January	1,459	1,751	2,042	2,334
February	1,316	1,579	1,842	2,105
March	1,425	1,709	1,994	2,279
April	1,363	1,635	1,908	2,181
May	1,229	1,474	1,719	1,965
June	1,275	1,529	1,784	2,038
July	1,304	1,563	1,824	2,084
August	1,006	1,205	1,406	1,607
September	1,287	1,543	1,800	2,057
October	1,390	1,667	1,945	2,223
November	1,374	1,648	1,923	2,198
December	1,261	1,513	1,766	2,018
TOTAL	*15,689*	*18,816*	*21,953*	*25,089*

3.6 Statistical Analysis of the Utility-Based Energy Consumption Estimates

Statistical analysis of the pre-retrofit and post-retrofit utility-based normalized and non-normalized energy consumption was conducted (see Section 2.9 and Appendix G) to determine if there was a significant difference between the normalized and non-normalized empirical energy consumption pre- and post-retrofit. Two analyses were conducted: a paired t-test of pre- and post-retrofit energy consumption and a paired one-tailed t-test of the energy savings percentage to determine if there were statistically significant savings across all of the units. The tests were conducted on both normalized (in therms of gas per gallon of water used) and non-normalized (therms of gas used) data.

3.6.1 Paired t-tests of the Normalized Gas Consumption

The pre- and post-retrofit gas and water consumption estimates for the units from the utility data were used in this paired analysis. The difference in the normalized gas consumption pre- and post-retrofit for each unit was used to calculate the mean reduction in consumption and the 95% confidence interval.

The hypotheses are:

H_0 = the normalized gas use after the retrofit is the same as before the retrofit
H_a = the normalized gas use after the retrofit is different than before the retrofit

The hypotheses were tested on the Gainesville Alachua data (see Table 3). The paired t-test was performed using the Statistical Analysis System (SAS) (SAS Institute 2010) along with manual calculation as shown in Appendix G.

For the Gainesville units (N = 7, p = 0.0291, see Table 13), the alternative hypothesis is accepted at the 95% confidence level. This is a strong indication that with a high degree of confidence, the pre- and post-retrofit utility-based normalized gas consumption is different. The mean difference in normalized energy consumption is -0.00143 therms/gallon, which indicates that on average, the tankless hot water heaters are using less natural gas for water heating in the Gainesville units after the retrofit. Pre-retrofit, the mean normalized natural gas consumption was 0.0040 therms/gallon and post-retrofit, the mean normalized natural gas consumption was reduced to 0.0025 therms/gallon. t*, the 2.5% point for the t-distribution with 6 degrees of freedom (DF), is 2.447. Therefore, the range of the mean with 95% confidence is:

$$-0.00143 \pm (2.447 \times 0.00061) = -0.00143 \pm (0.00149)$$

which results in an upper limit of the normalized energy savings of 0.00292 therms/gallon and a lower limit of -0.00007 therms/gallon.

The analysis of the utility-based data for the Alachua units (N = 30, p = 0.0017, see Table 14), also show that the retrofit significantly reduced normalized gas consumption at a 95% confidence level. The mean normalized gas consumption reduction is -0.00066 therms/gallon. The mean normalized propane consumption in the Alachua units was 0.0028 therms/gallon pre-retrofit and 0.0022 post-retrofit. t*, the 2.5% point for the t-distribution with 29 degrees of freedom, is 2.045. Therefore, the range of the mean with 95% confidence is:

$$-0.00066 \pm (2.045 \times 0.00019) = -0.00066 \pm (0.000391)$$

which results in an upper limit of the normalized energy savings of -0.00106 therms/gallon and a lower limit of -0.00027 therms/gallon.

Table 13. Paired t-test Results of Normalized Energy Consumption over the Study Period for the Gainesville Units

[1]	[2]	[3]	[4]	[5]	[6]	[7]
N	DF	p	Mean	Standard Deviation	Standard Error	95% Confidence Interval
7	6	0.0291	-0.00143	0.00162	0.000611	-0.00292 to 0.00007

Table 14. Paired t-test Results of Normalized Energy Consumption over the Study Period for the Alachua Units

[1]	[2]	[3]	[4]	[5]	[6]	[7]
N	DF	P	Mean	Standard Deviation	Standard Error	95% Confidence Interval
30	29	0.0028	-0.00066	0.00105	0.00019	-0.00106 to -0.00027

3.6.2 Paired t-tests of the Non-Normalized Energy Consumption

The pre- and post-retrofit gas consumption values for the units from the utility data were used in this paired analysis. The difference in the non-normalized energy consumption pre- and post-retrofit for each unit was used to calculate the mean reduction in consumption and the 95% confidence interval.

The hypotheses are:

H_0 = the non-normalized energy use after the retrofit is the same as before the retrofit
H_a = the non-normalized energy use after the retrofit is different than before the retrofit

The hypotheses were tested on the Gainesville and Alachua data (see Table 3). The paired t-test was performed using SAS (SAS Institute 2010) along with manual calculation as shown in Appendix G.

For the Gainesville units (N = 7, p = 0.0010, see Table 15), the alternative hypothesis is accepted at the 95% confidence level. This is a strong indication that with a high degree of confidence, the pre- and post-retrofit utility-based energy consumption is different. The mean difference in energy consumption is -17.6 therms, which indicates that on average, the tankless hot water heaters are using less natural gas for water heating in the Gainesville units after the retrofit. Pre-retrofit, the mean natural gas consumption was 53.1 therms and post-retrofit, the mean natural gas consumption was reduced to 35.6 therms. t*, the 2.5% point for the t-distribution with 6 degrees of freedom (DF), is 2.447. Therefore, the range of the mean with 95% confidence is:

$-17.6 \pm (2.447 \times 3.0) = -17.6 \pm (7.2)$

which results in an upper limit of the energy savings of -10.3 therms and a lower limit of -24.8 therms.

The analysis of the utility-based data for the Alachua units (N = 30, p = 0.0010, see Table 16), also show that the retrofit reduced energy consumption at a statistically significant 95% confidence level. The mean energy consumption reduction is -10.1 therms. The mean propane consumption in the Alachua units was 44.9 therms pre-retrofit and 34.8 post-retrofit. t*, the 2.5%

point for the t-distribution with 29 degrees of freedom, is 2.045. Therefore, the range of the mean with 95% confidence is:

-10.1 ± (2.045 x 2.8) = -10.1 ± (5.6)

which results in an upper limit of the energy savings of -4.5 therms and a lower limit of -15.7 therms.

Table 15. Paired t-test Results of Non-Normalized Energy Consumption Over the Study Period for the Gainesville Units

[1]	[2]	[3]	[4]	[5]	[6]	[7]
N	DF	P	Mean	Standard Deviation	Standard Error	95% Confidence Interval
7	6	0.0010	-17.6	7.8	3.0	-10.3 to -24.8

Table 16. Paired t-test Results of Non-Normalized Energy Consumption Over the Study Period for the Alachua Units

[1]	[2]	[3]	[4]	[5]	[6]	[7]
N	DF	P	Mean	Standard Deviation	Standard Error	95% Confidence Interval
30	29	0.0010	-10.1	15.1	2.8	-4.5 to -15.7

3.6.3 One-Tailed Paired t-test of the Normalized Gas Savings Percentage

A one-tailed paired t-test was performed for the utility-based normalized gas consumption to determine if the normalized gas savings for all the units was indeed greater than zero. In other words, this would show whether the energy savings predicted by the mean normalized gas savings percentage was statistically significant. To aid in comparing the post-retrofit savings between the calculated, simulated, and utility-based estimates, the normalized gas savings percentage pre- and post-retrofit was used. The percentage was calculated by taking the normalized therms of gas consumption per gallon of water used pre-retrofit ($N_{i\ pre\text{-}retrofit}$) and subtracting the therms of gas consumption per gallon of water used post-retrofit ($N_{i\ post\text{-}retrofit}$). This difference was then divided by $N_{i\ pre\text{-}retrofit}$ to calculate the percentage savings as a result of the retrofit.

The hypotheses are:

H_0 = the normalized gas savings percentage is less than or equal to zero
H_a = the normalized gas savings percentage is greater than zero

The results of the one-tailed paired t-test (N = 37, p = 0.00425, see Table 17) show that the 26.6% mean normalized gas savings percentage for all units is statistically significant at the 95% confidence level. t*, the 2.5% point for the t-distribution with 36 degrees of freedom, is 2.031. Therefore, the range of the expected energy savings with 95% confidence is:

0.266 ± (2.031 x 0.052) = 0.266 ± (0.107)

which results in an upper limit of the normalized energy savings percentage of 0.373 or 37.3% and a lower limit of 0.160 or 16.0% with 95% confidence. Based on the utility data, there is a high degree of confidence that the retrofit will result in average energy savings of 26.6% and savings of between 16.0 and 37.3%.

Table 17. One-Tailed t-test Results of Normalized Energy Savings Percentage Over the Study Period for all Units in the Study

[1]	[2]	[3]	[4]	[5]	[6]	[7]
N	DF	P	Mean	Standard Deviation	Standard Error	95% Confidence Interval
37	36	0.00425	0.266	0.319	0.052	0.160 to 0.373

3.6.4 One-Tailed Paired t-test of the Non-Normalized Gas Savings Percentage

A one-tailed paired t-test was performed for the utility-based gas consumption to determine if the gas savings for all the units was indeed greater than zero. In other words, whether the energy savings predicted by the mean gas savings percentage was statistically significant. To aid in comparing the post-retrofit savings between the calculated, simulated, and utility-based estimates, the gas savings percentage pre- and post-retrofit was used. The percentage was calculated by taking the therms of gas consumption used pre-retrofit ($Gas_{i\ pre\text{-}retrofit}$) and subtracting the therms of gas consumption used post-retrofit ($Gas_{i\ post\text{-}retrofit}$). This difference was then divided by $Gas_{i\ pre\text{-}retrofit}$ to calculate the percentage savings as a result of the retrofit.

The hypotheses are:

H_0 = the gas savings percentage is less than or equal to zero
H_a = the gas savings percentage is greater than zero

The results of the one-tailed paired t-test (N = 37, p = 0.00006, see Table 18) show that the 24.8% mean normalized gas savings percentage for all units is statistically significant at the 95% confidence level. t*, the 2.5% point for the t-distribution with 6 degrees of freedom, is 2.031. Therefore, the range of the expected energy savings with 95% confidence is:

$$0.248 \pm (2.031 \times 0.045) = 0.248 \pm (0.092)$$

which results in an upper limit of the normalized energy savings percentage of 0.340 or 34% and a lower limit of 0.155or 15.5% with 95% confidence. Based on the utility data, there is a high degree of confidence that the retrofit will result in average energy savings of 24.8% and savings of between 15.5 and 34%.

Table 18. One-Tailed t-test Results of Non-Normalized Energy Savings Percentage Over the Study Period for all Units in the Study

[1]	[2]	[3]	[4]	[5]	[6]	[7]
N	DF	P	Mean	Standard Deviation	Standard Error	95% Confidence Interval
37	36	0.00006	0.248	0.276	0.045	0.155 to 0.340

3.7 Statistical Analysis of Water Use

Water use varies greatly among the units, and some units increase water consumption and some decrease consumption after the retrofit (see Table 3). However, on average, water consumption pre- and post-retrofit changed very little. Pre-retrofit, the average water consumption per unit over the study period was 18,433 gallons and post-retrofit, the average was 17,792 gallons, a difference of about 3%. Although the utility-based mean water consumption in the two bedroom housing units in Gainesville (157 gallons per day) was greater than the mean use estimated with the calculation method (133 gallons per day, shown in Table 8) the difference was not statistically significant. The total water usage during the study period for each unit is included in Appendix J.

The utility water data failed the Shapiro-Wilks test for normality, which indicates that the data may not be normally distributed. A paired Wilcoxon Signed Rank Test of total water consumption as derived from the utility data was conducted to determine if water use pre-retrofit was different than post-retrofit. This is important because a retrofit with tankless water heaters could result in a change in water use. The hypotheses are:

H_0 = the water use after retrofit is the same as before the retrofit
H_a = the water use after retrofit is different than before the retrofit

The Wilcoxon Signed Rank Test showed no significant difference in either the Gainesville or the Alachua pre- and post-retrofit water usage. Therefore, the null hypothesis that there is not a statistically significant difference between the pre- and post-retrofit water consumption is accepted. The results of the test for Gainesville units are shown in Table 19. The Wilcoxon test for small sample sizes returned a value of W=4, which is below the critical value of 24. Similar to the Gainesville cases, the 30 Alachua units also showed no statistically significant difference between pre- and post-retrofit water use as can be seen in the results in Table 20. So we accept the null hypothesis that there is no difference in water use before and after retrofit. The Wilcoxon test produced a result of W=98. The sample size was large enough to estimate a Z value of 1.0. The critical Z value for a 0.05 test of significance is 1.96, so the null hypothesis is accepted that there is no significant difference between the pre- and post-retrofit data.

Table 19. Wilcoxon Signed Rank Test Results of Water Use Over the Study Period for the Gainesville Units

[1]	[2]	[3]	[4]
N	DF	W	W*
7	6	4	24

Table 20. Wilcoxon Signed Rank Test Results of Water Use Over the Study Period for the Alachua Units

[1]	[2]	[3]	[4]	[5]
N	DF	W	Z	Z* 0.05 sig.
30	29	98	1.0	1.96

3.8 Summary of Utility-, Calculation-, and Simulation-Based Estimates for the Pre-Retrofit and Post-Retrofit Study Periods

The non-normalized gas savings percentage for the calculated, simulated, and utility-based gas consumption estimates are summarized in Table 21 and shown by unit in Table 22. For the Gainesville units, the mean gas savings percentages for the calculated, simulated, and utility-based estimates range from 33% to 44%. However, the variability in utility-based estimates ranges from 19% to 52% gas consumption savings. The utility estimate has the lowest energy savings percentage and the calculated estimate has the highest savings. For the Alachua units, the mean gas savings percentages for the calculated, simulated, and utility-based estimates range from 22% to 39%. As with the Gainesville cases, the utility estimate has the lowest energy savings percentage and the calculated estimate has the highest savings. However, the Alachua units have a lower mean utility-based gas savings percentage and greater variability compared to the Gainesville units. Unlike in the Gainesville units, the utility-based gas savings percentages are not similar to the calculation- and simulation-based estimates. In the Alachua units, gas consumption ranges from 77% savings to a 76% consumption increase. Two differences between the Alachua and Gainesville units are the use of gas for cooking in the Alachua units whereas the Gainesville units have electric stoves, and the fuel in the Alachua units, which is propane rather than the natural gas in the Gainesville units.

Table 21. Calculated-, Simulated-, and Utility-based Estimates of Pre-Retrofit and Post-Retrofit Gas and Normalized Gas Consumption, Gas Savings, Gas Savings Percentages, and Water Consumption

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
	Location	Calculated			Simulated			Utility				
		Mean pre/post retrofit	Mean savings	%	Mean pre/post retrofit	Mean savings	%	Mean pre/post retrofit	Mean savings	%	95% CI Low	95% CI High
Non-normalized gas (therms)	Gainesville	38/21	16.7	44%	27/17	10.5	39%	53/36	17.6	33%	22	44
	Alachua	44/27	17.1	39%	30/20	10.1	33%	45/35	10.1	22%	11	34
	All units	43/26	17.0	40%	30/20	10.2	34%	47/35	11.5	25%	16	34
Normalized gas (therms/kgal)	Gainesville	3.1/1.8	1.4	44%	NA			4.0/2.5	1.4	36%	8	65
	Alachua	2.6/1.6	1.0	40%				2.8/1.9	0.7	24%	11	36
	All units	2.7/1.6	1.1	40%				3.0/2.2	0.8	27%	16	37
Water (kgals)	Gainesville	12.2/12.2	NA		NA			14.6/14.6	0.0	0%	NA	
	Alachua	17.5/17.5						19.3/18.5	0.8	4%		
	All units	16.2/16.2						18.4/17.8	0.6	3%		

The summary of the normalized gas consumption estimates for the calculated- and utility-based methods are shown in Table 21. Overall, the normalized percentage savings are similar to the non-normalized percentage savings estimated by the same method. For the Gainesville units, the mean savings of 1.4 therms/kgal is the same for the calculated and utility methods. However, the mean normalized gas use pre- and post-retrofit for the utility-based estimate is greater than the calculated estimate. This could mean that the water heaters are less efficient than predicted by the calculations or that the hot to cold water use ratio is different than predicted by the calculations. The data and analysis in this study is not sufficient to answer this question and further research is required. The normalized gas percentage savings in the Alachua units show that the utility estimate is somewhat lower than the calculated estimate. This may be because gas is used for cooking in the Alachua units.

Lastly, total water use estimates are similar for the calculated and utility methods. With a 4% difference in water use in the Alachua units being the largest change, these two methods agree that water use does not significantly change over the pre- and post-retrofit study periods. It is important to note that the difference in water consumption estimates is not because the number of occupants is underestimated. The actual average number of occupants is less than the number estimated by the calculation method, i.e., based on the number of bedrooms. The utility analysis indicates that the actual consumption per person is higher than assumed by the calculation method.

Table 22. Calculated, Simulated, and Utility-Based Gas Saving Percentages for All Units

[1]	[2]	[3]	[4]	[5]
Case	Number of Bedrooms	Saving Percentage = ($Gas_{i\ pre\text{-}retrofit}$ - $Gas_{i\ post\text{-}retrofit}$) / $Gas_{i\ pre\text{-}retrofit}$ (%)		
		Calculated	Simulated	Utility
1	2	44%	39%	20%
2	2	44%	39%	37%
3	2	44%	39%	28%
4	2	44%	39%	34%
5	2	44%	39%	44%
6	2	44%	39%	19%
7	2	44%	39%	52%
MEAN Gainesville		*44%*	*39%*	*33%*
8	3	40%	34%	35%
9	3	40%	34%	43%
10	3	40%	34%	8%
11	2	44%	38%	77%
12	3	40%	34%	30%
13	4	37%	31%	35%
14	5	34%	28%	-12%
15	2	44%	38%	42%
16	4	37%	31%	31%
17	4	37%	31%	37%
18	2	44%	38%	56%
19	4	37%	31%	-76%
20	4	37%	31%	-24%
21	4	37%	31%	48%
22	4	37%	31%	45%
23	2	44%	38%	29%
24	4	37%	31%	31%
25	3	40%	34%	28%
26	3	40%	34%	8%
27	5	34%	28%	24%
28	2	44%	38%	13%
29	2	44%	38%	44%
30	2	44%	38%	10%
31	4	37%	31%	27%
32	3	40%	34%	-39%
33	3	40%	34%	23%
34	4	37%	31%	-51%
35	4	37%	31%	28%
36	2	44%	38%	9%
37	5	34%	28%	-2%
MEAN Alachua		*39%*	*33%*	*22%*
MEAN All units		*40%*	*34%*	*25%*

3.9 Evaluation of the Cost Effectiveness of the Measures

Estimated energy consumption for tank type and tankless water heating will vary depending on whether the estimates use calculated, simulated, or utility-based data. To demonstrate the sensitivity of the cost analysis to the energy consumption estimate, the PVLCC, PVNS, and the SIR were determined for the calculated, simulated, and utility-based average energy consumption estimates for the two bedroom Gainesville units. Table 23 and Table 24 contain the costs for both the tank type and the tankless water heaters. The installation costs are based on project conditions, which included a vent through the roof. Table 25 shows the energy costs for the calculated, simulated, and utility data using GRU's $0.90 per therm gas price for residential usage. The monthly utility-based cost is the mean gas consumption for water heating during the study period, which is assumed to be representative of the water heating gas consumption for the remainder of the year and is therefore used to calculate the annual water heating gas consumption and cost.

In the calculation case, the annual energy cost for the tank type water heater (pre-retrofit) is $148.20 (refer to Table 25, column 2) and the annual energy cost for tankless water heating (post-retrofit) is $87.70 (refer to Table 25, column 3). For the simulation estimate, the annual energy cost for the tank type water heater is $109.57 (refer to Table 25, column 4) and the annual energy cost for tankless water heating is $72.04 (refer to Table 25, column 5). The utility-based estimate yields an annual energy cost for the tank type water heater of $191.31 (refer to Table 25, column 6) and an annual energy cost for tankless water heating of $128.06 (refer to Table 25, column 7).

The estimated life for a tank type water heater is 13 years and the estimated life for a tankless water heater is 20 years (USDOE 2008). The maintenance cost of $45/year for the tankless water heaters is for annual descaling and is based on local costs.

Table 23. Installation Cost Estimates for Tank Type Water Heaters[1]

[1]	[2]	[3]	[4]	[5]	[6]	[7]
Quantity	**Item Description**	**Material ($)**	**Subtotal ($)**	**Labor (hours)**	**Subtotal ($)**	**Total ($)**
1	Remove gas water heater			1.33	48	48
1	40 gallon gas water heater	280	280	4.00	143	423
1	Permit fees	90	90			90
	TOTAL COST		*370*		*191*	*561*

Table 24. Installation Cost Estimates for Tankless Water Heaters

[1]	[2]	[3]	[4]	[5]	[6]	[7]
Quantity	**Item Description**	**Material ($)**	**Subtotal ($)**	**Labor (hours)**	**Subtotal ($)**	**Total ($)**
1	Remove gas water heater		0	1.33	48	48
1	Tankless water heater - gas	499	499	4.00	143	642
1	Service valves	37	37		0	37
6	Direct vent - 3" (per foot)	15	90	0.22	48	138
1	Direct vent roof flashing	37	37	0.44	16	53
1	Direct vent rain cap	77	77	0.35	12	89
1	Duplex outlet	8	8	1.10	39	47
1	Permit fees	90	90			90
	TOTAL COST		*838*		*306*	*1,144*

[1] Labor hours are based on residential rates from the R.S. Means Cost Data Book. The costs of the tankless water heater and service valve are based on actual project costs. All other costs are based on local market pricing. The permit fee is based on the cost in Alachua County Florida. Material quantities are based on project conditions.

Table 25. Calculated, Simulated, and Utility-Based Monthly Energy Cost Estimates for Tank Type and Tankless Water Heaters.

[1]	[2]	[3]	[4]	[5]	[6]	[7]
Month	Calculated		Simulated		Utility	
	TTWH ($)	TWH ($)	TTWH ($)	TWH ($)	TTWH ($)	TWH ($)
January	14.05	8.82	11.05	7.88	15.94	10.67
February	12.65	7.92	9.93	7.06	15.94	10.67
March	13.58	8.38	10.49	7.31	15.94	10.67
April	12.48	7.49	9.53	6.45	15.94	10.67
May	12.12	7.02	8.49	5.29	15.94	10.67
June	11.11	6.20	8.09	5.00	15.94	10.67
July	11.13	6.08	8.05	4.85	15.94	10.67
August	11.18	6.13	6.96	3.77	15.94	10.67
September	11.23	6.32	8.24	5.14	15.94	10.67
October	12.30	7.18	9.31	6.11	15.94	10.67
November	12.65	7.65	9.73	6.64	15.94	10.67
December	13.72	8.51	9.72	6.54	15.94	10.67
TOTAL	*148.20*	*87.70*	*109.57*	*72.04*	*191.31*	*128.06*

3.9.1 Electricity Usage in Gas Tankless Water Heaters

A gas tankless water heater (TWH) uses electricity for the combustion vent fan and controls. Typical fan use is 50 to 80 Watts during water heating, with controls using about 5 Watts continuously. The fan operates when water is flowing for venting the gas combustion air, and continues to operate for a short time after the water flow stops to purge the combustion air. Typically, the speed of the fan varies with water flow rate.

Estimating the electricity use based on gas use and fan power is difficult because it depends on the hot water draw profiles. Few studies have been conducted to measure electricity consumption for gas TWHs. In a study performed for the Okaloosa Gas District of Florida (Exelon 2002), the TWH tested used 0.6 kWh of electricity and 11.3 therms of gas over a thirty day period, or 0.05 kWh/therm. In a study by Bohac et. al (2010), the energy use of several different models of TWHs was monitored, including two Rheem models of the type used in this study. Table 26 shows the natural gas and electricity usage for these two units. Column 3 shows the electricity used for the controls, ignition, and combustion fan which does not include freeze protection. The average electricity to gas usage ratio is 0.68 kWh/therm.

Table 26. Natural Gas Usage, Electricity Usage, and the Electricity to Gas Usage Ratio for a Non-Condensing Rheem Tankless Water Heater

[1]	[2]	[3]	[4]
	Natural Gas (therms)	Electricity (kWh)	Electricity/Gas (kWh/therm)
Unit 1	65.2	45.3	0.69
Unit 2	47.6	31.4	0.66
Average			*0.68*

The electricity to gas usage ratio reported in these two studies ranges from 0.05 kWh/therm to 0.69 kWh/therm. The cost calculation in Table 27 uses the average kWh/therm ratio from the Bohac et al (2010) study. Multiplying the annual calculated, simulated, and utility gas usage estimates in therms by the kWh/therm ratio and the $/kWh electricity charge results in an estimated annual electricity cost range from $5.44 to $9.68 per year or about 7.6% of gas cost in this study (see Table 27). The electricity rate is based on the project conditions for 2011 in Gainesville, where the tenant had an average rate of $0.101/kWh.

Table 27. Estimated Annual Gas and Electricity Usage and Costs for Calculated, Simulated, and Utility Gas Usage

[1]	[2] Calculated	[3] Simulated	[4] Utility
Gas (therms)	97.4	80.0	142.3
Electricity (kWh)	66.3	54.4	96.8
Gas ($)	$87.70	$72.04	$128.06
Electricity ($)	$6.63	$5.44	$9.68

3.9.2 Present Value Life Cycle Cost

The summary PVLCC for the tank type and tankless water heaters in the two bedroom Gainesville units for the calculated, simulated, and utility gas consumption estimates are shown in Table 28. The detailed PVLCC are shown in Table H.1 through Table H.3. In the calculated gas consumption estimate case, the PVLCC for the tank type water heater is $5,914.82 and the PVLCC for the tankless water heater is $5,701.95, which makes the tankless system the preferred alternative. In the simulation case, the PVLCC for the tank type water heater is $4,616.61 and the PVLCC for the tankless water heater is $5,175.41. In this case, the simulated energy savings do not offset the annual maintenance cost and the tank type water heater is the preferred alternative. In the utility case, the PVLCC for the tank type water heater is $7,365.01 and for tankless system is $7,059.01. Therefore, the tankless system is preferred.

3.9.3 Present Value Net Savings

The summary results of the PVNS calculations for the alternative tankless water heater versus the baseline tank type water heater in the two bedroom Gainesville units are shown in Table 28 and the detailed PVNS calculation are in Table H.4 through Table H.6. The PVNS for the calculated energy consumption estimate is $214.64. Since the PVNS is greater than zero, the tankless system is preferred. The PVNS for the simulated energy consumption estimate is -$557.03. Using the simulated energy consumption estimate, the tank type water heater is the preferred alternative. The PVNS for the calculated energy consumption estimate is $307.77, and therefore the tankless system is the preferred alternative.

3.9.4 Savings to Investment Ratio

The SIR of the tankless system is 1.42 and 1.61 for the calculated and utility-based energy consumption estimates, respectively. Since the simulation-based analysis did not show savings, the SIR is not applicable. As with the PVLCC and PVNS analyses, this would lead to a preference for the tankless alternative when the calculated and utility-based energy consumption estimates are used and the selection of the tank-type water heater when the simulation-based energy consumption estimate is used. The summary of SIR is shown in Table 28 and the sensitivity analyses of the SIR are in Appendix K.

Table 28. Summary PVLCC, PVNS, and the Savings to Investment Ratio for the Tank Type and Tankless Water Heaters in the Gainesville Units for the Calculated, Simulated and Utility Gas Consumption Estimates

[1]	[2]	[3]	[4]	[5]	[6]	[7]
Economic analysis type	Calculated		Simulated		Utility	
	TTWH	TWH	TTWH	TWH	TTWH	TWH
PVLCC ($)	5914.82	5701.95	4616.61	5175.41	7365.01	7059.01
PVNS ($)	214.64		(557.03)		307.77	
SIR	1.42		N/A		1.61	
	TWH preferred		TTWH preferred		TWH preferred	

3.9.5 Impact of Tankless Water Heater Electricity Use on Cost Effectiveness

As discussed in Section 3.10.1, few studies have examined fan energy on TWHs. Based on the most reliable estimate, a value of $6.63 was calculated as shown in Table 27. Adding this estimate to the calculated PVLCC, PVNS, and SIR equations increases the PVLCC of the THW to about equal to the TTWH, decreases the PVNS to $21.53, and decreases the SIR to 1.04. Including the electricity cost reduces the benefit of the THW in the calculated estimates such that the benefit is negligible.

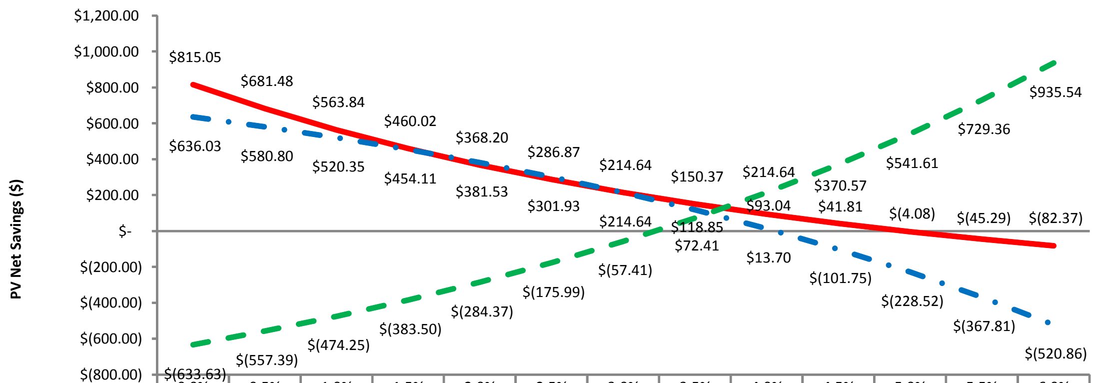
Table 29. Impact of Fan and Controls Electricity Use on PVLCC, PVNS, and the Savings to Investment Ratio for the Tank Type and Tankless Water Heaters in the Gainesville Units for the Calculated Gas Consumption Estimates

[1]	[2]	[3]
Economic analysis type	Calculated	
	TTWH	TWH
PVLCC ($)	5914.82	5895.06
PVNS ($)	21.53	
SIR	1.04	
	TWH preferred	

3.10 Sensitivity Analyses for Present Value Net Savings Using Three Energy Consumption Estimates

The PVNS results were calculated with a range of discount, general inflation, and energy inflation rates in a sensitivity analysis. The baseline discount and general inflation rates are set to 3% and the energy inflation rate is set to 4% as recommended by (Rushing et al. 2011) for long term assessment. The parameters were then individually varied between 1% and 6% to determine the sensitivity of the PVNS to variations in the discount, general inflation, and energy inflation rates.

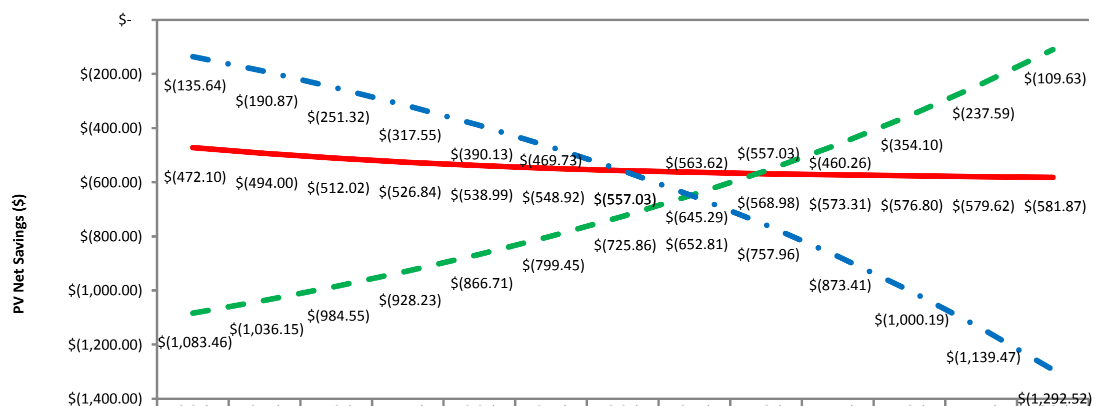
When the calculated energy consumption estimates are used, PVNS are positive for the baseline analysis (see Figure 3). The PVNS will start to become negative at discount rates greater than 6%, a general inflation rate greater than 5%, or an energy inflation rate below 3%. If the simulated energy consumption estimates are used, the PVNS are negative for the baseline analysis (see Figure 4). The PVNS will become positive only if energy inflation is greater than 6%. Finally, for the utility-based energy consumption estimate, the PVNS are positive for the baseline analysis (see Figure 5). The PVNS will become negative if the energy inflation rate drops to 2% or less or if the general inflation rate is 5% or more.



	0.0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%
Discount	$815.05	$681.48	$563.84	$460.02	$368.20	$286.87	$214.64	$150.37	$93.04	$41.81	$(4.08)	$(45.29)	$(82.37)
Energy	$(633.63	$(557.39	$(474.25	$(383.50	$(284.37	$(175.99	$(57.41)	$72.41	$214.64	$370.57	$541.61	$729.36	$935.54
General	$636.03	$580.80	$520.35	$454.11	$381.53	$301.93	$214.64	$118.85	$13.70	$(101.75	$(228.52	$(367.81	$(520.86

Rate %

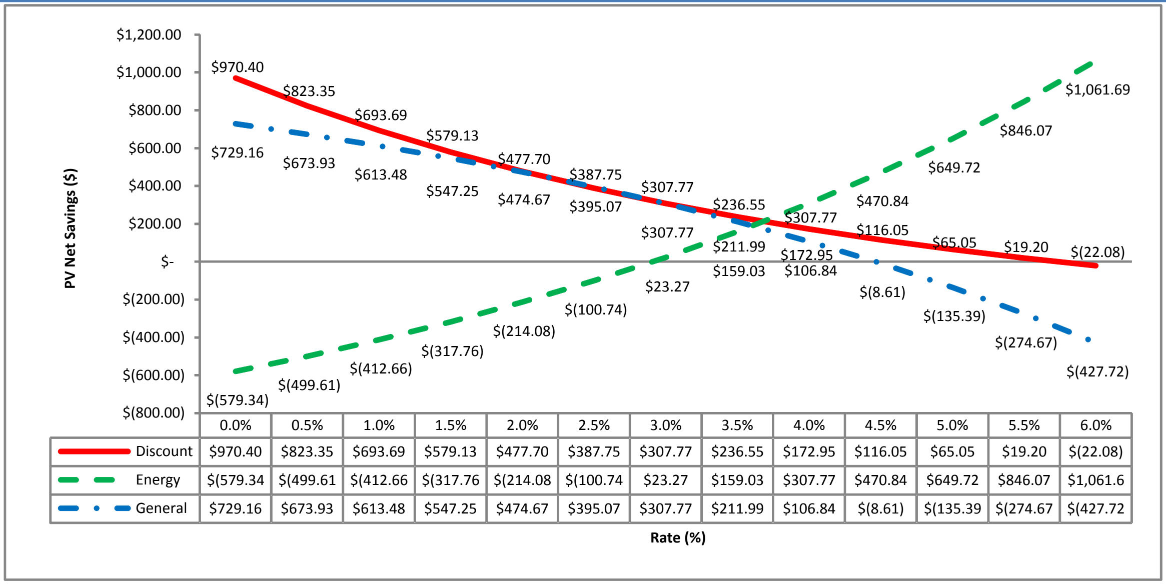
Figure 3. Sensitivity analysis of the PVNS for the calculated energy consumption estimate versus the discount, general inflation, and energy inflation rates



	0.0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%
Discount	$(472.10	$(494.00	$(512.02	$(526.84	$(538.99	$(548.92	$(557.03	$(563.62	$(568.98	$(573.31	$(576.80	$(579.62	$(581.87
Energy	$(1,083.	$(1,036.	$(984.55	$(928.23	$(866.71	$(799.45	$(725.86	$(645.29	$(557.03	$(460.26	$(354.10	$(237.59	$(109.63
General	$(135.64	$(190.87	$(251.32	$(317.55	$(390.13	$(469.73	$(557.03	$(652.81	$(757.96	$(873.41	$(1,000.	$(1,139.	$(1,292.

Rate (%)

Figure 4. Sensitivity analysis of the PVNS for the simulated energy consumption estimate versus the discount, general inflation, and energy inflation rates



	0.0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%
Discount	$970.40	$823.35	$693.69	$579.13	$477.70	$387.75	$307.77	$236.55	$172.95	$116.05	$65.05	$19.20	$(22.08)
Energy	$(579.34	$(499.61	$(412.66	$(317.76	$(214.08	$(100.74	$23.27	$159.03	$307.77	$470.84	$649.72	$846.07	$1,061.6
General	$729.16	$673.93	$613.48	$547.25	$474.67	$395.07	$307.77	$211.99	$106.84	$(8.61)	$(135.39	$(274.67	$(427.72

Figure 5. Sensitivity analysis of the PVNS for the utility bill-based energy consumption estimate versus the discount, general inflation, and energy inflation rates

4 Conclusions

The statistical analysis of the utility-based estimates showed a statistically significant reduction in energy use and no statistically significant difference in water use from the tankless retrofit in the units in the study over the study periods. The calculated and simulated results predict similar energy savings percentages, with the utility-based estimates somewhat lower. However, simulation appears to underestimate water usage and therefore underestimates the magnitude of the energy saved by the retrofit, which does impact the cost effectiveness of the retrofit.

The cost effectiveness of the retrofit was estimated using calculation-, simulation-, and utility-based gas savings estimates as the basis for the PVLCC, PVNS, and SIR analyses. The calculation method was the most optimistic in terms of the percent energy savings, but did not have the greatest cost savings. The simulation results were similar in terms of the percent savings, but tended to underestimate the gas use for both the pre- and post-retrofit conditions. The simulation-based energy savings estimates were less than the maintenance cost of the tankless system, which resulted in simulation-based PVLCC, PVNS, and SIR analyses that indicated that the retrofit was not cost effective. However, the economic analysis was favorable when using the utility- and calculation-based energy savings estimates. A sensitivity analysis showed that the investment will remain favorable as long as the energy inflation rate remains above 3%, which is consistent with current forecasts.

The models used to evaluate energy savings and cost effectiveness of alternatives are important for decision making. The three methods for evaluating the retrofit used in this study estimated different energy savings percentages, primarily caused by differences in water consumption. The calculated water consumption estimates for the units were lower than the utility-based estimates, although the difference was not statistically significant. It is not possible to directly compare simulation-based water consumption estimates to calculated and utility-based, since simulation provides a hot water use estimate and calculated and utility data do not. However, the study did show a correlation between water and gas use and the difference between utility and calculation gas consumption estimates are not statistically different while the utility and calculated gas consumption estimates are significantly different from the simulated estimates. This may indicate that water consumption is underestimated in these cases. Therefore, we recommend that when evaluating water heating alternatives, it is important to estimate water consumption, particularly when local consumption patterns may be different from national norms.

There is no question that the utility data used in these analyses are imperfect at determining hot water use and the related water heater gas use in a given unit. However, the utility data can illustrate the variability in water and gas use between units and the variability in one unit over time. The calculation and simulation models, although technically very good at representing water heater performance, may not capture individual or average usage characteristics in a particular group. The units in this study had utility-based total water use that was greater than water use estimated by calculation. The difference in water consumption was not caused by underestimating the number of occupants, but more likely was caused by a greater than expected water use per person. In this case, the difference could change the result of the cost effectiveness assessment. Even though this study was limited in that gas and total water use was estimated from utility meter data and not from on-site monitoring of gas and hot water use, the conclusions can be useful in developing a better understanding of the relative importance of model parameters. Additional research is needed to better understand these effects. Potentially, a mixed modeling approach could be used for energy use estimates and cost effectiveness assessments.

Table 30. Gas Savings and Gas Savings Percentage in the Pre- and Post-Retrofit Study Period for the Calculated, Simulated, and Utility-based Energy Savings Estimates

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
	Location	Calculated		Simulated		Utility			
							95% CI		
		Savings	%	Savings	%	Mean Savings	Low	High	%
Non-normalized (therms)	Gainesville	16.7	44%	10.5	39%	17.6	10.3	24.8	33%
	Alachua	17.1	39%	10.1	33%	10.1	4.5	15.7	22%
	All units	17.0	40%	10.2	34%	11.5	6.8	16.3	25%
Normalized (therms/kgal)	Gainesville	1.4	44%	NA		1.4	-\0	2.9	36%
	Alachua	1.0	39%			0.7	0.3	1.1	24%
	All units	1.1	40%			0.8	0.4	1.2	27%

4.1 Research Questions

The five research questions that guided the analysis of the tankless water heating retrofit are:

What are the energy consumption impacts of upgrading to a tankless system?

The energy consumption for water heating after the tankless water heating retrofit was less than before the retrofit. The calculated, simulated, and utility-based energy consumption reduction estimates range from 25% to 40% on average across the unit types in the study. When looking at the Gainesville units only, the energy consumption reduction estimates range from 33% to 44%. In terms of normalized gas consumption, although some units had an increase in their normalized gas consumption and their normalized gas savings percentage (see Table 3), the units had, on average, a mean reduction in normalized energy use of 27% at the 95% confidence level. An estimate of electricity consumption on a tankless system showed that although the value is small, the cost of electricity combined with the cost of gas reduces the economic benefit of the retrofit to the point where it could potentially change the decision.

What are the water use impacts of upgrading to a tankless system?

The pre- and post-retrofit water use predicted by the calculation, simulation, and the utility-based analyses were within 3% and therefore we conclude that water use will not change with a tankless water heating retrofit. The utility data analysis shows that, although some units had an increase in water use and some had a decrease, on average at the 95% confidence level, the water use did not change from pre- to post-retrofit in the units in the study.

What are the cost impacts of upgrading to a tankless system?

The cost implications of the retrofit from a tank type water heater to a tankless was evaluated with PVLCC, PVNS, and the SIR. The economic analysis shows that the retrofit is preferred when the calculation- and utility-based energy savings estimates are used and not preferred when the energy reduction estimate from the simulation results are used. This result is not related to the percentage in energy reduction estimated by the simulation because the percentage reduction is close to the calculated and utility-based estimates. Rather, this relates to the simulation's estimate of the magnitude of the energy used. The simulation's estimates of the hot water use are lower and therefore the absolute energy and energy cost savings are lower than in the calculated and utility-based estimates.

Do pre- and post-retrofit modeled estimates of energy and water consumption align with energy and water utility data?

The calculation and simulation estimates both tend to have lower estimates of both the pre- and post-retrofit energy consumption, with the simulation producing the lowest estimate. In terms of the accuracy of the gas savings percentage, the comparison of the modeled and utility-based estimates of energy savings have mixed results. For example, the energy savings predicted for the Gainesville units by calculation, simulation, and utility-based analysis are within 15% of one another. The simulation method produced an estimate that was closer to the utility-based estimate. The energy savings predicted for the Alachua units by calculation and simulation are greater than the average gas savings percentage estimated from the utility-based analysis. This result is confounded by the use of gas for cooking in the Alachua units during the study period.

The utility data shows that water use varies widely amongst the units in the study, but no statistical difference could be determined between pre- and post-retrofit water consumption. Although the calculation and simulation methods do not show the variability in water use, the calculation, simulation, and utility-based water use estimates all agree that there is no significant change in water use pre- and post-retrofit.

What parameters effectively model the water heater energy consumption in the pre- and post-retrofit home?

There are several parameters that have been identified as important to effectively model energy consumption. The age and type of the existing system must be known to accurately estimate its efficiency. The quantity and type of fixtures and hot water-using appliances must be known to accurately estimate hot water usage. Water use varies considerably between homes, which may be due to occupant behavior or differences in the number of occupants even if the number of bedrooms is the same. However, models (for example, the calculation method overestimates the number of occupants and underestimates water use) and model structure (for example, how to incorporate local variability in estimates) should also be improved. Occupant behavior and the effects of the number of occupants and the incorporation of variability needs to be studied further in order to improve the estimates of energy savings and cost effectiveness of tankless water heating.

What additional parameters or algorithm changes are necessary to align pre- and post-retrofit consumption estimates with actual field performance?

A more accurate representation and prediction of hot water consumption would enhance both the calculated and simulated estimates and yield better information on the economic value of the retrofit. Households with low hot water consumption may not benefit from a retrofit to tankless water heating.

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Appendix A: Calculations, Models and Assumptions

A.1 Utility Energy and Water Use Data

The first step of the analysis is to determine the metered consumption before and after retrofit. Energy use in the pre-retrofit and the post-retrofit periods are calculated in the following way:

$$\Delta M_{pre-retrofit} = M_j - M_{i-1} \qquad \text{(A1)}$$

where:

$\Delta M_{pre-retrofit}$ = difference for the meter usage in pre-retrofit
M_j = meter reading for energy in month j
M_{i-1} = meter reading for energy in month i-1

$$\Delta M_{post-retrofit} = M_j - M_{i-1} \qquad \text{(A2)}$$

where:

$\Delta M_{post-retrofit}$ = difference for the meter usage in post-retrofit
M_j = meter reading for energy in month j
M_{i-1} = meter reading for energy in month i-1

For natural gas, metered usage is converted to therms in the following way:

$$Gas\ usage\ \ [therms] = \Delta M \times 1.017 \times .1.029 \qquad \text{(A3)}$$

where:

ΔM = metered gas usage
1.017[2] = meter multiplier
1.029[3] = Btu factor

For propane, metered usage is converted to therms in the following way:

$$Pr opane\ \ usage\ \ [therms] = (\Delta M \times 0.958 \times 91{,}950)/100{,}000 \qquad \text{(A4)}$$

where:

ΔM = metered gas usage
0.958[4] = meter multiplier to gallons
91,950[5] = gallon to Btu multiplier (Btu)
100,000[6] = Btu to therms

[2] 1.017 is the Gainesville Regional Utilities (GRU) meter multiplier.
[3] 1.029 is the Gainesville Regional Utilities (GRU) Btu factor.
[4] 0.958 is the meter to gallon conversion used by the propane distributor (Davis Gas Co., Gainesville, FL).
[5] 91,950 is the gallon to Btu multiplier used by the propane distributor (Davis Gas Co., Gainesville, FL).
[6] 100,000 is the Btu to therms conversion factor.

Metered water use in the pre-retrofit and the post-retrofit periods are calculated using A5. For water, metered usage is converted to gallons in the following way:

$$Water\ usage\ \ [gallons] = \Delta M \times 1000 \qquad \text{(A5)}$$

where:
ΔM = metered water usage
1000 = meter multiplier to gallons

A.2 Example Calculation of Utility Data for a Gainesville Unit (Case 1)

The first step of the analysis is to determine the metered consumption before and after retrofit. The May through July analysis period represents water heating because space heating is not used during this time. The period before retrofit is May 2010 (month i) to July 2010 (month j). Likewise, the period after retrofit is May 2011 (month i) to July 2011 (month j). For natural gas, the metered usage is calculated using equation A1 and A2.

$$\begin{aligned} \Delta M_{pre-retrofit} &= M_j - M_{i-1} \\ &= 5873 - 5826 \\ &= 47 \end{aligned}$$

The actual meter reading for gas consumption in April 2010 is 5648 and the meter reading in July 2010 is 5826.

Using equation A3:

$$\begin{aligned} Gas\ usage\ \ [therms] &= \Delta M \times 1.017 \times .1.029 \\ &= 47 \times 1.017 \times 1.029 \\ &= 49.2 \end{aligned}$$

For water the metered usage is calculated using equation A1 and A2:

$$\begin{aligned} \Delta M_{pre-retrofit} &= M_j - M_{i-1} \\ &= 225 - 213 \\ &= 12 \end{aligned}$$

Using equation A5:

$$\begin{aligned} Water\ usage\ \ [gallons] &= \Delta M \times 1000 \\ &= 12 \times 1000 \\ &= 12{,}000 \end{aligned}$$

For normalizing energy use, pre-retrofit, equation 2.8.1 is used:

$$N_{i\ pre-retrofit} = \frac{Gas\,usage}{Water\,usage}$$

$$= \frac{49}{12{,}000}$$

$$= 0.004083\left[\frac{therms}{gal}\right]$$

The pre- and post-retrofit difference between normalized energy use is calculated using equation 2.8.3:

$$\Delta N_i = N_{i\ post-retrofit} - N_{i\ pre-retrofit}$$

$$= 0.00114 - 0.0041$$

$$= -0.00296\left[\frac{therms}{gal}\right]$$

Appendix B: Energy Use Calculation for Water Heating

B.1 Energy Use Calculation for Tank Type Water Heaters

Water Heater Analysis Model (WHAM) equations and the parameters shown are used to estimate the energy consumption of tank type water heaters (Lutz et al. 1999):

$$UA\left[\frac{Btu}{hr^{o}F}\right] = \frac{\frac{1}{EF} - \frac{1}{RE}}{\left(T_{tnk} - T_{amb}\right) \times \left(\frac{24}{41{,}004} - \frac{1}{RE \times P_{on}}\right)} \qquad \text{(B1)}$$

$$Q_{in} = \frac{vol \times \rho \times Cp \times (T_{tnk} - T_{in})}{RE} \times \left(1 - \frac{UA \times \left(T_{tnk} - T_{amb}\right)}{P_{on}}\right) + 24 \times UA \times \left(T_{tnk} - T_{amb}\right) \qquad \text{(B2)}$$

where:

Q_{in} = total water heater energy consumption [Btu/day]
vol = daily draw volume [gal/day]
ρ = density of water [lb/gal]
C_p = specific heat of water [Btu/lb-°F]
T_{tnk} = tank thermostat setpoint temperature [°F]
T_{in} = inlet water temperature [°F]
RE = recovery efficiency
UA = standby heat loss coefficient [Btu/hr-°F]
P_{on} = rated input power [Btu/hr]
T_{amb} = temperature of ambient air surrounding water heater [°F]
EF = efficiency factor

B.2 Energy Use Calculation for Tankless Water Heaters

Adjusted WHAM energy consumption equation (DOE 2010) for tankless water heaters is given by:

$$Q_{in} = \frac{vol \times \rho \times Cp \times (T_{tnk} - T_{in})}{RE \times \left(1 + PA\right)} \times \left(1 - \frac{Q_p}{P_{ON}}\right) + 24 \times Q_P \times \left(T_{tnk} - T_{amb}\right) \qquad \text{(B3)}$$

=

where:

Q_p = pilot input rate [Btu/hr]
PA = performance adjustment factor

The values for Q_{in}, RE, P_{on}, and EF are taken from 0 through 0. R and C_p varies with water temperature. The remaining input values will be based on conditions for the test houses. Energy savings will then be calculated as the difference between pre- and post-retrofit.

$$\Delta E_i = E_i^{a} - E_i^{b} \qquad \text{(B4)}$$

where:

ΔE_i = difference in energy usage from installing measure i;
E_i^a = energy usage after i is installed;
E_i^b = energy usage before i is installed.

Table B.1. Recovery Efficiency for Water Heaters[7].

Fuel Source	Recovery Efficiency (RE)
Electric	98%
Natural Gas or Propane	76%
Oil	76%

Table B.2. Benchmark Domestic Hot Water Storage and Burner Capacity[8].

Number of Bedrooms	1	2			3			4			5	6
Number of Bathrooms	All	≤1.5	2–2.5	≥3	≤1.5	2–2.5	≥3	≤1.5	2–2.5	≥3	All	All
Gas												
Storage (gal)	20	30	30	40	30	40	40	40	40	50	50	50
Burner (kBtu/h)	27	36	36	36	36	36	36	36	38	38	47	50
Electric												
Storage (gal)	20	30	40	50	40	50	50	50	50	66	66	80
Burner (kW)	3	3.5	4.5	6	4.5	5.5	6	5.5	5.5	6	6	6

Table B.3. Minimum Energy Factors Required after January 20, 2004[9].

Type	Volume (Gallons)	Storage Type Water Heaters New Minimum Energy Factor
Gas	30	0.61
	40	0.59
	50	0.58
Electric	30	0.93
	40	0.92
	50	0.90
	60	0.89
	70	0.88
	80	0.86

B.3 Example Energy Use Calculation for Water Heating for a Tank Type Water Heater in a Gainesville Unit

Tank type water heater energy use can be calculated according to equations B1 and B2.

The tank type gas water heaters replaced were 2004 vintage on average and 40 gallon capacity. The thermostats were set to 120°F. The inlet water temperature and ambient temperatures (Table B.4) were estimated using BEopt simulations for Gainesville, FL.

[7] Adopted from Energy Data Sourcebook for the US Residential Sector, Wenzel et al, 1997.
[8] Adopted from HVAC Applications Handbook, ASHRAE, 1999; Building America House Simulation Protocols, Hendron et al, 2010.
[9] Adopted from Rulemaking Framework for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters, DOE, 2006

Data and assumptions:
Tank capacity 40 gallons
EF = 0.59 (tank type water heaters were installed around 2004)
2 bedrooms
1.5 bathrooms and post 1990 installation

Table B.4. Average Monthly Water Inlet and Ambient Temperatures in Gainesville from BEopt

Gainesville Temperatures	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Water Inlet temperature (T_{in}) = T_{mains}	65.701	66.011	68.404	72.365	76.813	80.546	82.549	82.271	79.796	75.792	71.343	67.657
Ambient temperature (T_{amb})	52.520	58.640	63.140	68.360	76.100	77.360	79.700	80.600	76.460	70.340	60.080	53.600

Data:
ρ: Density = 8.345404 lb/gallon
C_p: Specific heat = 1 Btu/lb-^{o}F
T_{tnk}: Thermostat setpoint = 120 ^{o}F[10]
RE: Recovery Efficiency = 0.76 (Table B.1)
P_{on}: Rated power input = 36,000 Btu/hr (Table B.2)
EF: Energy Factor = 0.59 (Table B.3)
T_{in}: Water inlet for Gainesville, FL (Table B.4) = 65.701 ^{o}F
T_{amb}: Ambient temperature for Gainesville, FL in January = 52.52 ^{o}F (Table B.4)
vol: Hot water volume = 57.7 gallons/day (Table C.3)

The first step is to define standby heat loss coefficient UA (refer to equation 2.3.1) in Btu/lb- ^{o}F

$$UA = \frac{\frac{1}{EF} - \frac{1}{RE}}{(T_{tnk} - T_{amb}) \times \left(\frac{24}{41{,}004} - \frac{1}{RE \times P_{on}} \right)}$$

$$UA = \frac{\frac{1}{0.59} - \frac{1}{0.76}}{(120 - 52.52) \times \left(\frac{24}{41{,}094} - \frac{1}{0.76 \times 36{,}000} \right)}$$

$$UA = 10.26 \left[\frac{Btu}{hr^o F} \right]$$

The second step is to calculate daily energy usage (refer to equation B2):

$$Q_{in} = \frac{vol \times \rho \times Cp \times (T_{\tan k} - T_{in})}{RE} \times \left(1 - \frac{UA \times (T_{tnk} - T_{amb})}{P_{on}} \right) + 24 \times UA \times (T_{\tan k} - T_{amb})$$

[10] 120^{o}F is based on actual installed both tank type and tankless water heater in the field.

$$Q_{in} = \frac{57.7 \times 8.345404 \times 1 \times (120 - 65.701)}{0.76} \times \left(1 - \frac{10.26 \times (120 - 52.52)}{36{,}000}\right) + 24 \times 10.26 \times (120 - 52.52)$$

$$Q_{in} \approx 50{,}358 \left[\frac{Btu}{day}\right] \quad (January)$$

Applying the calculations over the months in a year results in the values in Table B4. The monthly cost can be calculated by dividing the results by 100,000 and multiplying the results using the $0.9/therm Gainesville Regional Utilities natural gas cost rate (Gainesville Regional Utilities (GRU) 2010).

B.4 Example Energy Use Calculation for Water Heating for a Tankless Water Heater in a Gainesville Unit (Case 1)

The variables remain as shown in Section B3 unless noted below.

Data and assumptions:
EF: Energy Factor = 0.82 for Energy Star minimum requirement (DOE 2010)
PA: Performance Adjustment Factor = 0.088 (DOE 2010)
Q_p: Pilot Input Rate = 0 (no standing pilot installed)

$$Q_{in} = \frac{vol \times \rho \times Cp \times (T_{tnk} - T_{in})}{RE \times (1 + PA)}$$

$$Q_{in} = \frac{57.7 \times 8.345404 \times 1 \times (120 - 65.701)}{0.76 \times (1 + 0.088)}$$

$$Q_{in} \approx 31{,}620 \left[\frac{Btu}{day}\right] \quad (January)$$

Appendix C: Water Use Calculations

C.1 Total Water Use Calculation using EPact

The water consumption calculations use fixture assumptions based on the Energy Policy Act of 1992. The average water consumption for a residential unit is calculated from the number of occupants, the number of uses per occupant, the flow rate (in gallons per minute or cycle), and the duration of use for each fixture type.

For each fixture:

$$Water\ usage\ per\ day\ \ [\,gallons\,] = WPU \times U \times NO \qquad (C1)$$

where:

WPU = Water volume per use in gallons (Table C.2)
U = Number of uses per occupant per day obtained (Table C.1)
NO = number of occupants

Table C.1. Standard Fixture Uses and Durations for Residential Building[11].

Standard Fixtures	Uses per occupant per day	Duration (second)
Lavatory Faucet	5	15
Kitchen faucet	4	60
Shower	1	300
Water closet	5	-
Dish washer	0.25	-
Clothes washer	0.25	-

Table C.2. Flow Rate by Fixture Type as Specified by the Florida Building Code[12].

Fixture Type	Flow Rate Standard fixture	Water volume per use [gals]
Lavatory faucet	2.2 gpm	0.55
Kitchen faucet	2.2 gpm	2.2
Shower	2.5 gpm	12.5
Water closet		1.6
Dish washer		10
Clothes washer		39.2

[11] EPact 1992

[12] Adopted from Energy Conservation Program for Consumer Products: Clothes washer energy conservation standards; final rule finding of no significant impact; energy conservation program for consumer products. Notice 10 CFR Part 430 Part IX, DOE, 2001; Energy Conservation Program: Energy conservation standards for certain consumer products (dishwashers, dehumidifiers, microwave ovens, and electric and gas kitchen ranges and ovens) and for certain commercial and industrial equipment (commercial clothes washers); final rule: 10CFR Part 430, Part II, DOE 2009

C.2 Total Water Use Calculation Using House Simulation Protocols

Water use is calculated based on the equations and assumptions shown in Table C.3.

Table C.3. Average Daily Household Water Usage Calculation for a Two Bedroom Unit[13]

End Use	Average Daily Household Hot Water Use	2 Bedroom (gals/day)
Clothes washer	$2.35 + 0.78 \times N_{br}$	3.9
Dishwasher	$2.26 + 0.75 \times N_{br}$	3.8
Shower	$14.0 + 4.67 \times N_{br}$	23.3
Bath	$3.5 + 1.17 \times N_{br}$	5.8
Sinks	$12.5 + 4.16 \times N_{br}$	20.8
	TOTAL	*57.6*

N_{br}: Number of bedrooms

[13] Building America House Simulation Protocols, Hendron et al. 2010

Appendix D: Gainesville Unit Characteristics for Simulation

The simulations are based on the same underlying parameters as shown for the calculations in Appendix B. The building dimensions and wall construction are provided for reference, and are not necessary to simulate hot water consumption. Hot water consumption is driven by occupancy (from the number of bedrooms), type of water heater, and quantity and type of hot water appliances and fixtures.

Type 1: Case 1, 2

Year built: 1984
Use: duplex
Bedrooms: 2
Baths: 1
Stories: 2
Exterior Wall: Face brick
AC: Central air
Heating: Forced air duct
Area Type Data
Base Area (BAS): 984 sq.ft.
Finished Open Porch (FOP): 20 sq.ft.
Finished Storage (FST): 32 sq.ft.
Finished Upper Story (FUS): 1036 sq.ft.
Unfinished Open Porch (UOP): 36 sq.ft.
Heated Area: 2020 sq.ft.
Total Area: 2108 sq.ft.

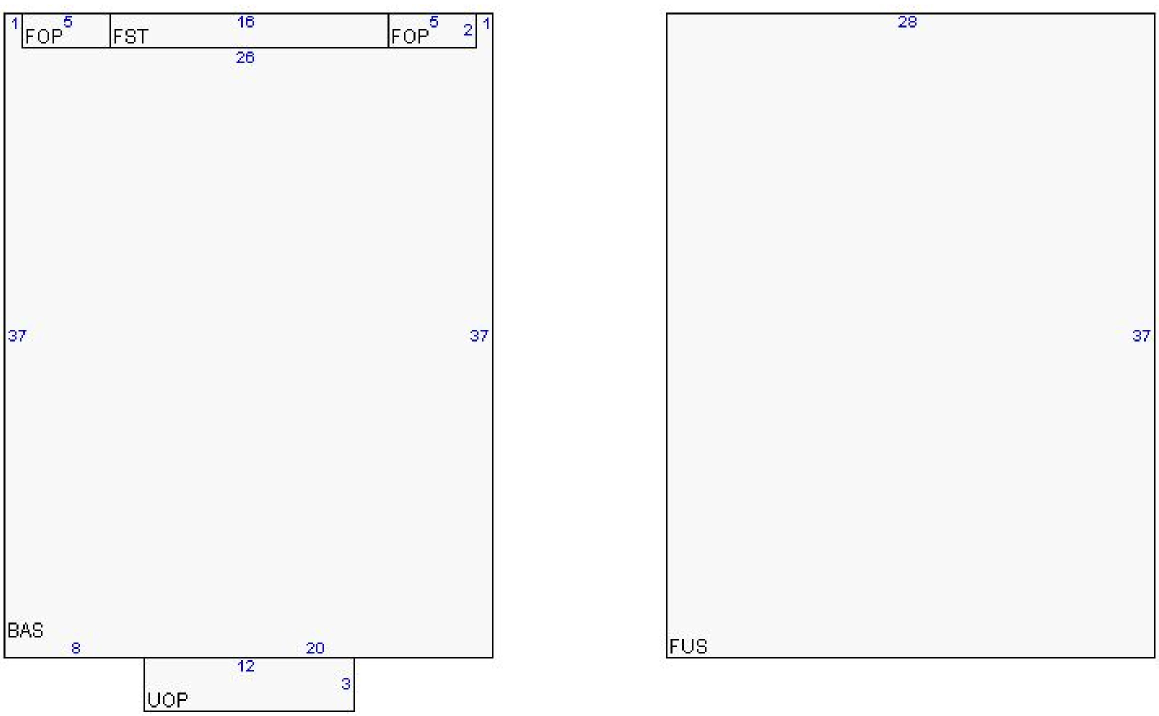


Figure D.1. Drawing for Type 1 Gainesville

Type 2: Case 3
Actual year built: 1984
Use: duplex
Bedrooms: 2
Baths: 1.5
Stories: 2
Exterior Wall: Face brick
AC: Central air
Heating: Forced air duct
Area Type Data
Base Area (BAS): 1212 sq.ft.
Finished Open Porch (FOP): 48 sq.ft.
Finished Storage (FST): 42 sq.ft.
Finished Upper Story (FUS): 1344 sq.ft.
Unfinished Open Porch (UOP): 42 sq.ft.
Heated Area: 2556 sq.ft.
Total Area: 2688 sq.ft.

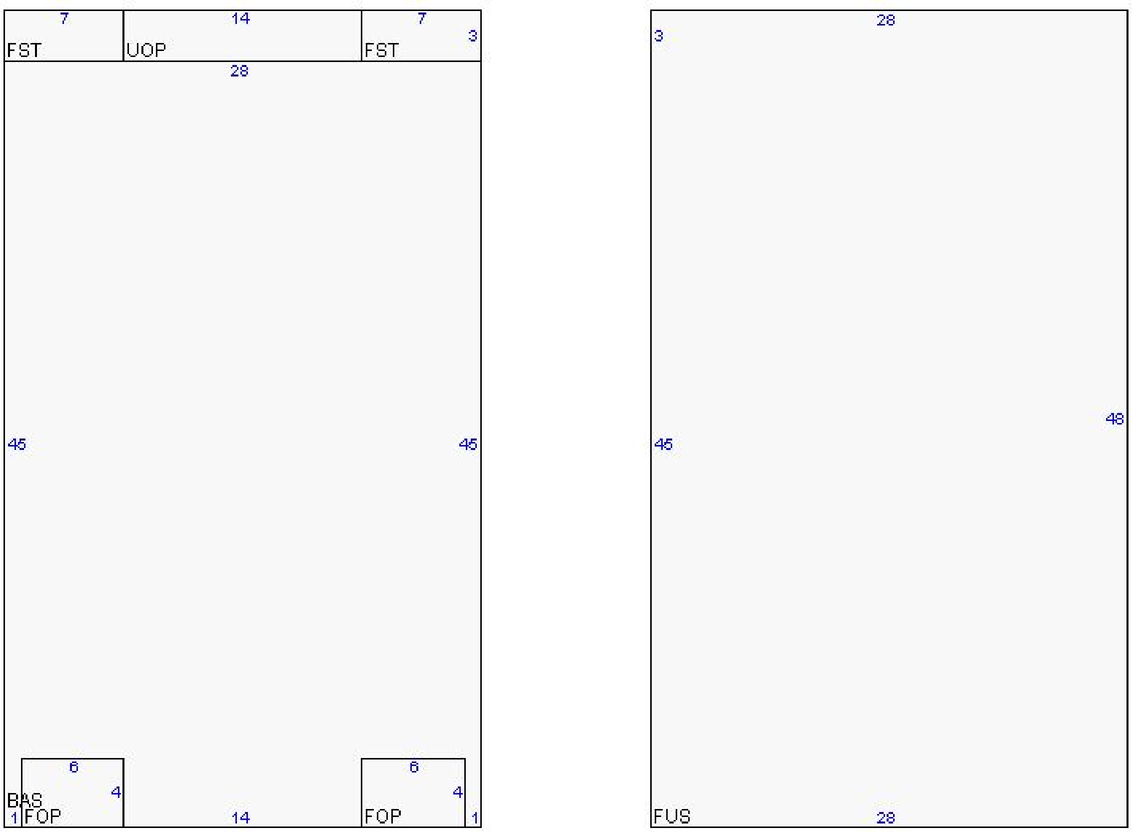


Figure D.2. Drawing for Type 2 Gainesville

Type 3: Case 4, 5, 6, 7

Actual year built: 1984
Use: Quadruplex
Bedrooms: 2
Baths: 1.5
Stories: 2
Exterior Wall: Face brick
AC: None
Heating: Forced air duct
Area Type Data
Base Area (BAS): 2308 sq.ft.
Finished Open Porch (FOP): 48 sq.ft.
Finished Storage (FST): 42 sq.ft.
Finished Upper Story (FUS): 1864 sq.ft.
Unfinished Open Porch (UOP): 128 sq.ft.
Heated Area: 4172 sq.ft.
Total Area: 4388 sq.ft.

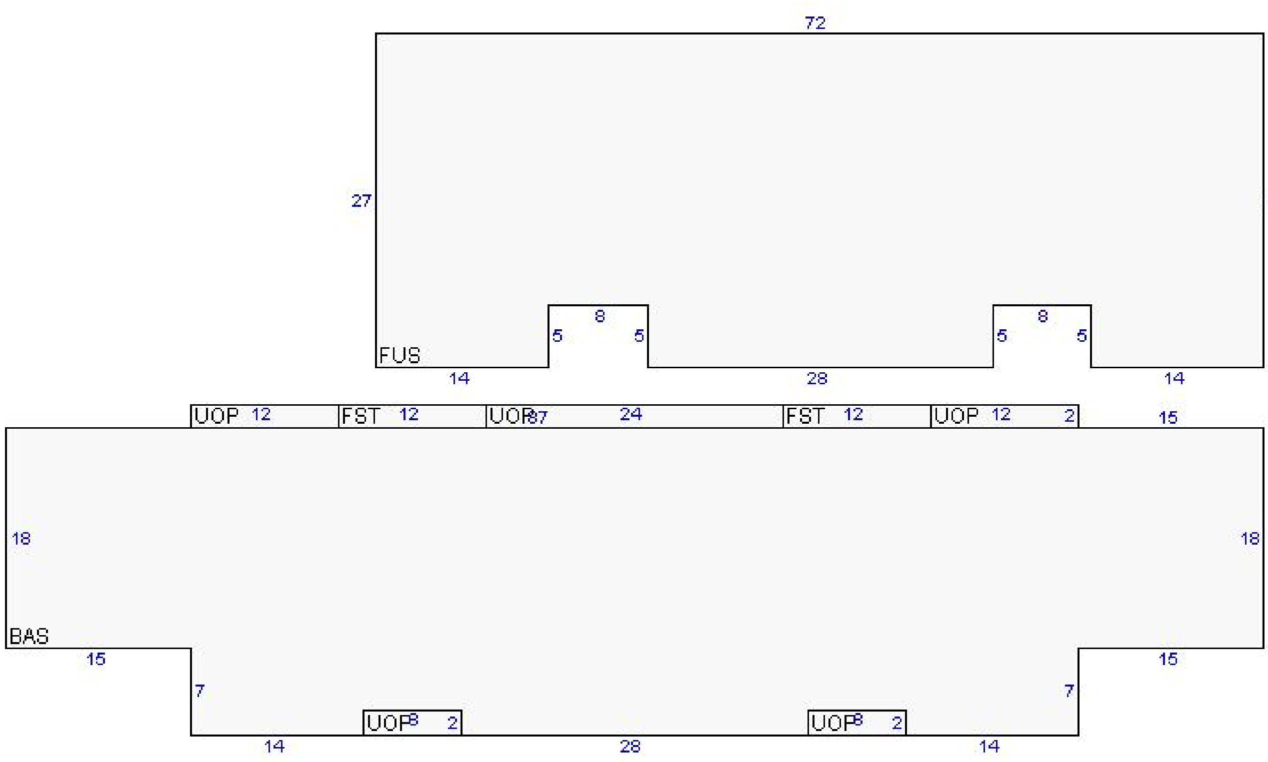


Figure D.3. Drawing for Type 3 Gainesville

Appendix E: Alachua Unit Characteristics for Simulation

Four cases were used to model the Alachua units. Type 1 represents housing units in Alachua with two bedrooms, Type 2 represents units in Alachua with three bedrooms, Type 3 has four bedrooms and Type 4 is for five bedroom units. The simulations use the same paramaters as for the calculations shown in Appendix B. The fuel in Alachua is propane.

Type 1: Alachua Case 11, 15, 18, 23, 28, 29, 30, 36

Actual year built: 1971
Use: Single
Bedrooms: 2
Baths: 1
Stories: 1
Exterior Wall: Concrete block
AC: Central air
Heating: Forced air duct
Area Type Data
Base Area (BAS): 825 sq.ft.
Unfinished Open Porch (UOP): 15 sq.ft.
Heated Area: 825 sq.ft.
Total Area: 840 sq.ft.

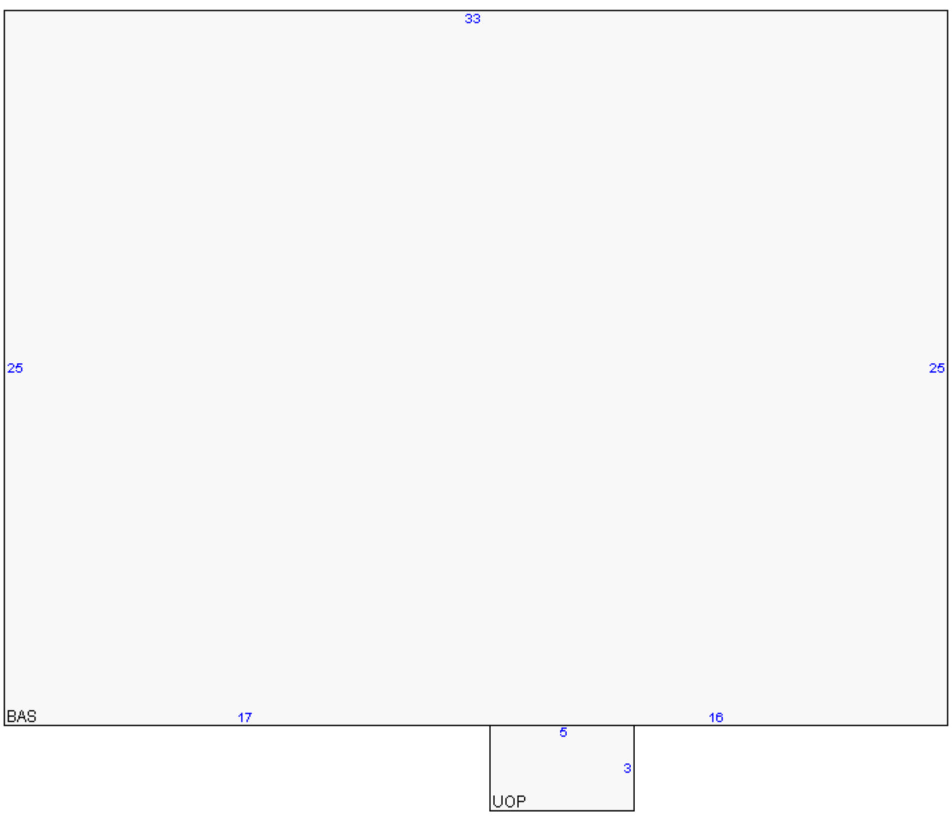


Figure E.1. Drawing for Type 1 Alachua two bedroom units

Type 2: Alachua Case 8, 9, 10, 12, 25, 26, 32, 33
Actual year built: 1971
Use: Single
Bedrooms: 3
Baths: 1
Stories: 1
Exterior Wall: Concrete block
AC: Central air
Heating: Forced air duct
Area Type Data
Base Area (BAS): 1075 sq.ft.
Unfinished Open Porch (UOP): 15 sq.ft.
Heated Area: 1075 sq.ft.
Total Area: 1090 sq.ft.

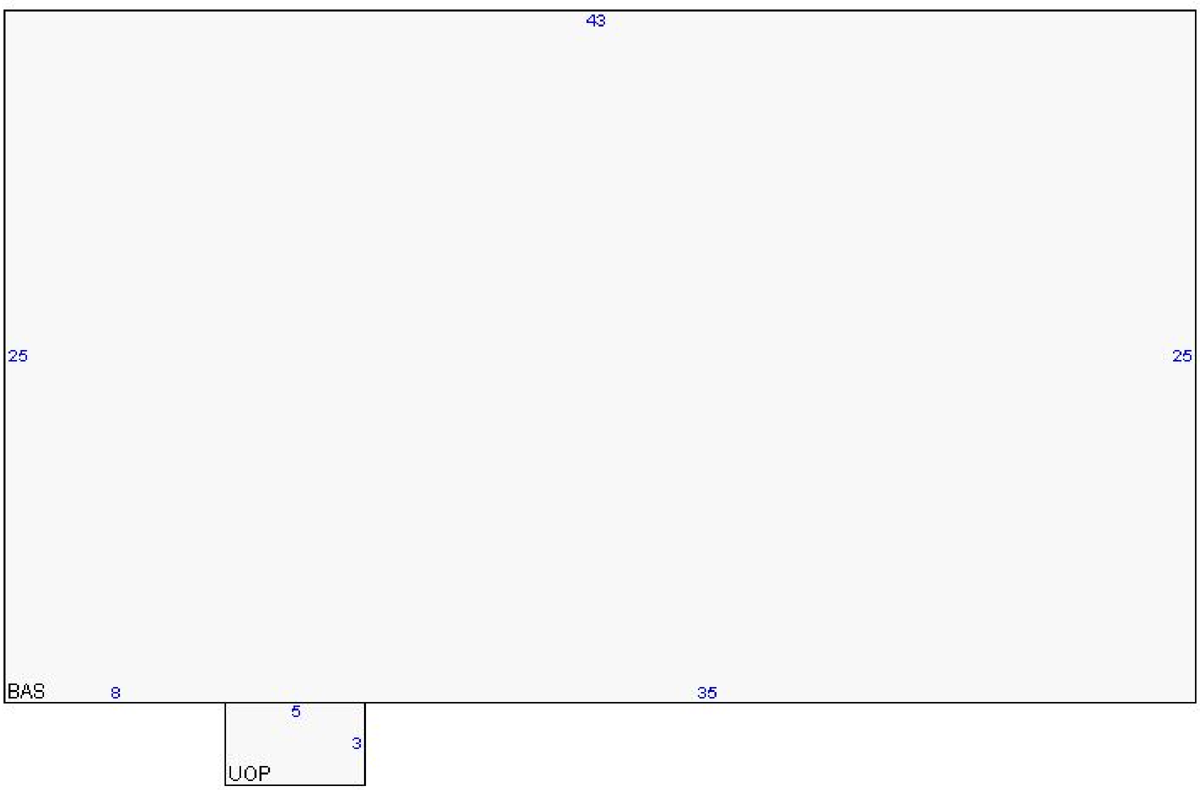


Figure E.2. Drawing for Type 2 Alachua three bedroom units

Type 3: Alachua Case 13, 16, 17, 19, 20, 21, 22, 24, 31, 34, 35

Actual year built: 1971
Use: Single
Bedrooms: 4
Baths: 1.5
Stories: 1
Exterior Wall: Concrete block
AC: Central air
Heating: Forced air duct
Area Type Data
Base Area (BAS): 1275 sq.ft.
Unfinished Open Porch (UOP): 15 sq.ft.
Heated Area: 1275 sq.ft.
Total Area: 1290 sq.ft.

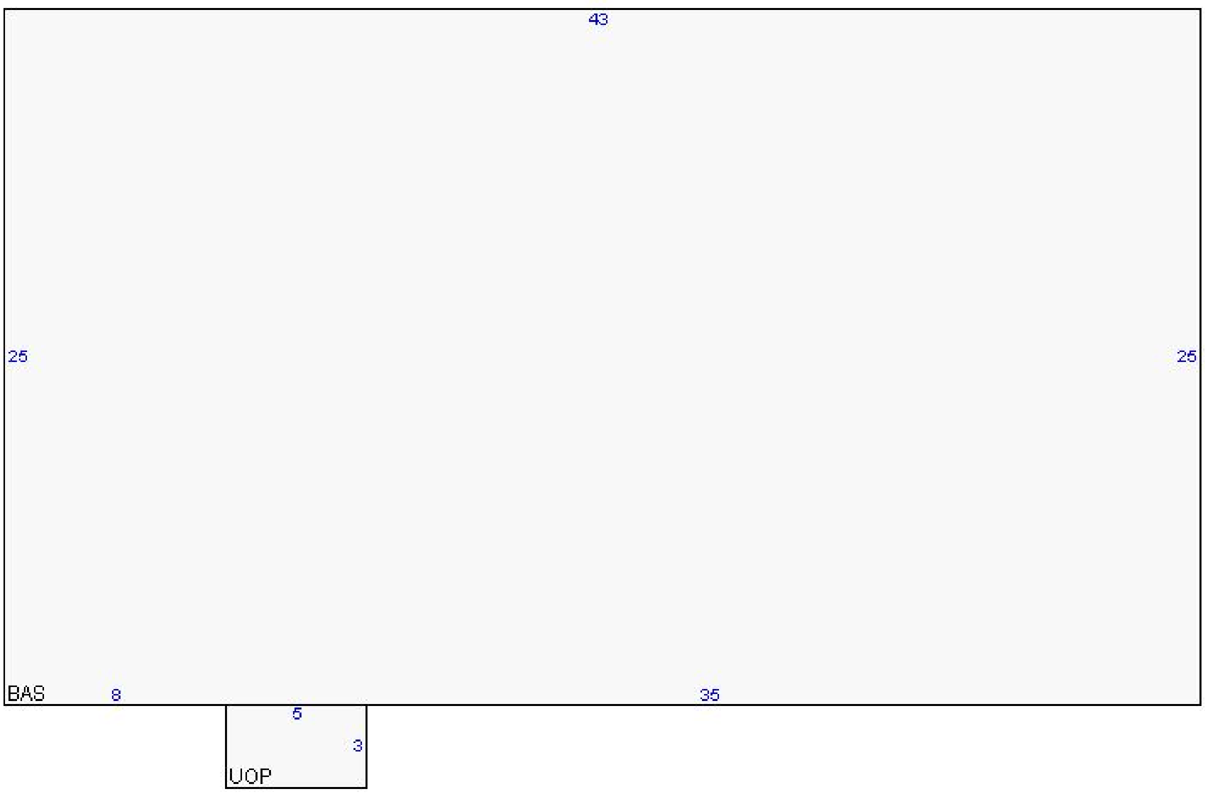


Figure E.3. Drawing for Type 3 Alachua four bedroom units

Type 4: Alachua Case 14, 27, 37

Actual year built: 1971
Use: Single
Bedrooms: 5
Baths: 1.5
Stories: 1
Exterior Wall: Concrete block
AC: Central air
Heating: Forced air duct
Area Type Data
Base Area (BAS): 1500 sq.ft.
Unfinished Open Porch (UOP): 15 sq.ft.
Heated Area: 1500 sq.ft.
Total Area: 1515 sq.ft.

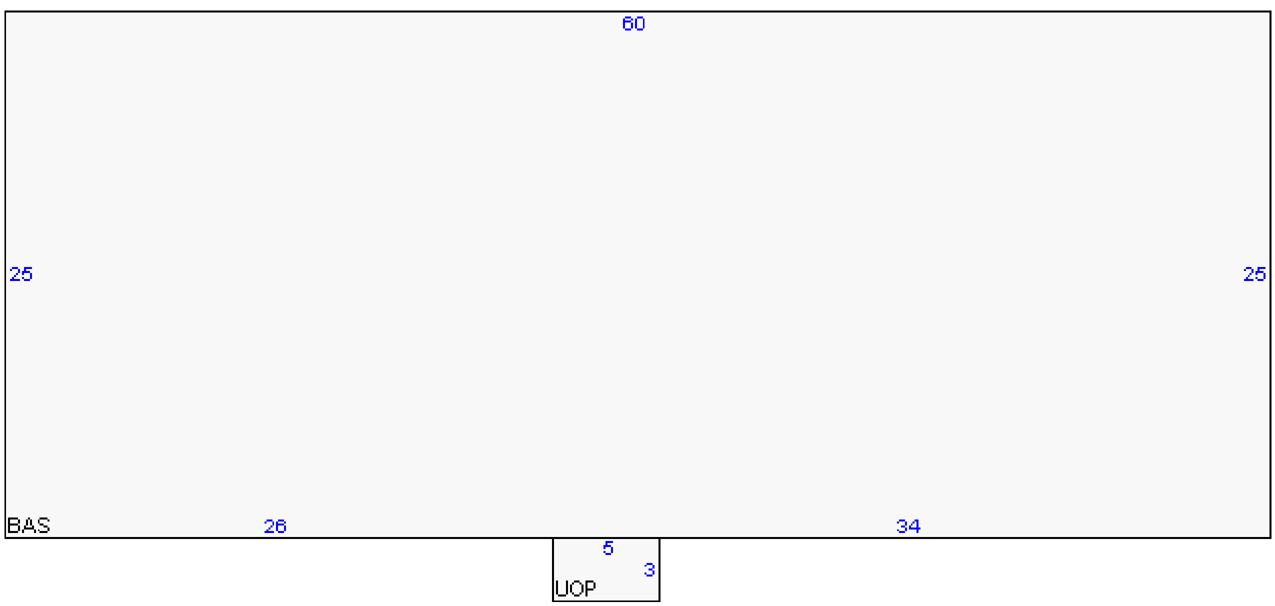


Figure E.4. Drawing for Type 4 Alachua five bedroom units

Appendix F: Hot Water Simulation

F.1 Example Calculation For Conversion of Simulation Results

The method to convert BEopt hot water consumption simulation results to hot water consumption has been provided. BEopt output for hot water usage is the hourly flow rate, *F*. This number was converted to gallons using the equation F1 below.

$$Volume\ January = F_{January}\left[\frac{ft^3}{mnt}\right]\times 7.48\left[\frac{gal}{ft^3}\right]\times 60\left[\frac{mnt}{hr}\right]\times 24\left[\frac{hr}{day}\right] \qquad \text{(F1)}$$

$$Volume\ January = 0.00437\left[\frac{ft^3}{mnt}\right]\times 7.48\left[\frac{gal}{ft^3}\right]\times 60\left[\frac{mnt}{hr}\right]\times 24\left[\frac{hr}{day}\right] = 47.07\left[\frac{gal}{day}\right]$$

where:

mnt	= minute
hr	= hour
gal	= gallon
F	= flow rate from BEopt [ft^3/mnt]
7.48	= ft^3 to gallon conversion

For each month, the gallons per day were multiplied by the number of days in the month in order to calculate the total volume during the month. The usage is 47.07 gallons per day. In January, the total volume of hot water will be 31 days of usage times 47.07 which is equal to 1459 gallons, as can be seen in Table 12, column 2. Table 12, columns 3 through 5 summarize the simulation results.

Appendix G: Statistical Calculations and Analysis

The statistical analysis of the normalized gas consumption uses the paired t-test. For the study period pre-retrofit and post-retrofit the mean difference of the energy use per gallon of water used in the units was estimated through utility-based analysis. In order to determine whether the difference in normalized energy consumption had changed with a high degree of confidence, a paired t-test was used. The paired t-test uses the following calculations:

Standard Error ($SE_{\bar{d}}$) can be calculated using the following formula:

$$SE_{\bar{d}} = \frac{S_d}{\sqrt{n}} \qquad \text{(G1)}$$

where:
n = number of cases

The t value can be calculated by dividing the mean by the standard error:

$$t = \frac{d}{SE_{\bar{d}}} \qquad \text{(G2)}$$

where:
t = t-value
$SE_{\bar{d}}$ = standard error
d = mean of difference between post- and pre-retrofit

If the p value is less than 0.05, H_a is accepted, and if $p > 0.05$, H_0 is accepted. If there is confidence in the hypothesis, the next step is to determine the confidence interval using the following equations:

$$d \pm t^* \times \frac{S_d}{\sqrt{n}} \qquad \text{(G3)}$$

or

$$d \pm (t^* \times SE_{\bar{d}}) \qquad \text{(G4)}$$

where:
$SE_{\bar{d}}$ = standard error
d = mean
t* = 2.5% point of the t-distribution with (n-1) degrees of freedom

The Shapiro-Wilks test was used to test for the normality of the data distribution. The non-normalized and normalized data for the Gainesville, Alachua, and combined data sets all tested to be normally distributed.

The correlation of total water consumption with gas consumption is a factor that has to be considered when using total water as a normalizing factor when hot water consumption is not available. To check the correlation of total water, two types of analysis were used: Pearson's correlation and a graphical analysis. Pearson's correlation returns a value between -1 and 1, where a value of 1 indicates complete correlation, a value of 0 indicates no correlation, and negative values indicate negative correlation. Total water was compared to gas consumption for the study period under the assumption that as hot water consumption increased, total water will proportionally increase. Table G.1 shows the Pearson values comparing gas consumption (therms) to total water consumption (gallons). The Gainesville pre- and post-retrofit data along with the Alachua post-retrofit data tested with high correlation with values between 0.82 to 0.86. Figures G.1, G.2, G.3, and G.4 graphically portray the alignment of the gas data with total water. The Alachua pre-retrofit data also shows good correlation value of 0.61. For the Gainesville data, gas was only used for water heating, and in Alachua gas was used for water heating and cooking. One unit in the Alachua pre-retrofit data has very high water consumption for one billing cycle (noted with a star on Figure G.3) which is partially responsible for the lower correlation value. The correlation analysis does show that total water consumption is aligned with gas consumption, and supports the normalized analysis used in this study.

Table G.1. Pearson Correlation Values for Utility Gas and Total Water Consumption

[1]	[2]	[3]
	Pre-retrofit	Post-retrofit
Gainesville	0.82	0.85
Alachua	0.61	0.86

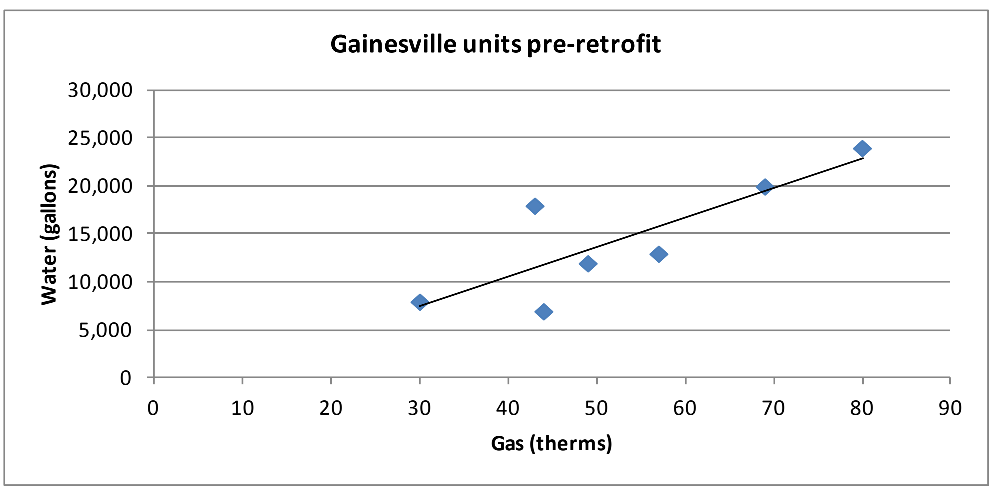


Figure G.1. Plot of water and gas use in the pre-retrofit study period in the Gainesville units

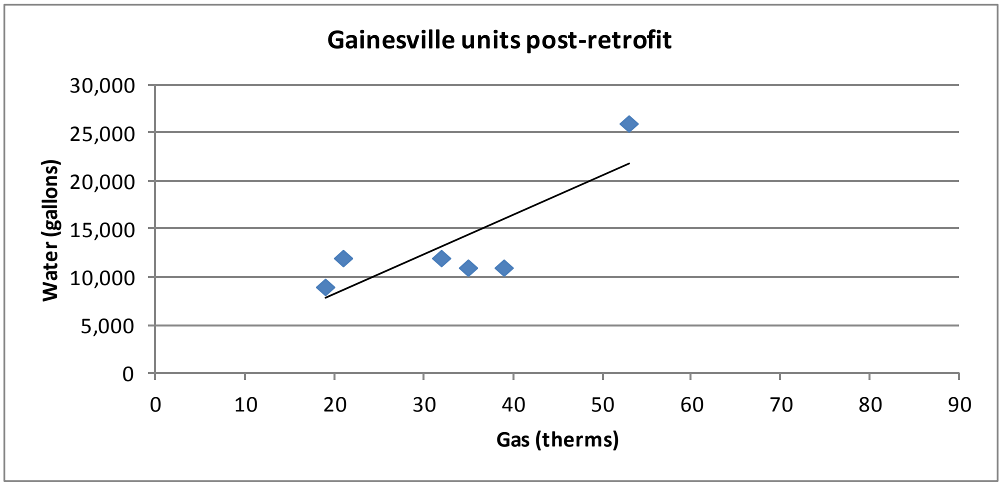


Figure G.2. Plot of water and gas use in the post-retrofit study period in the Gainesville units

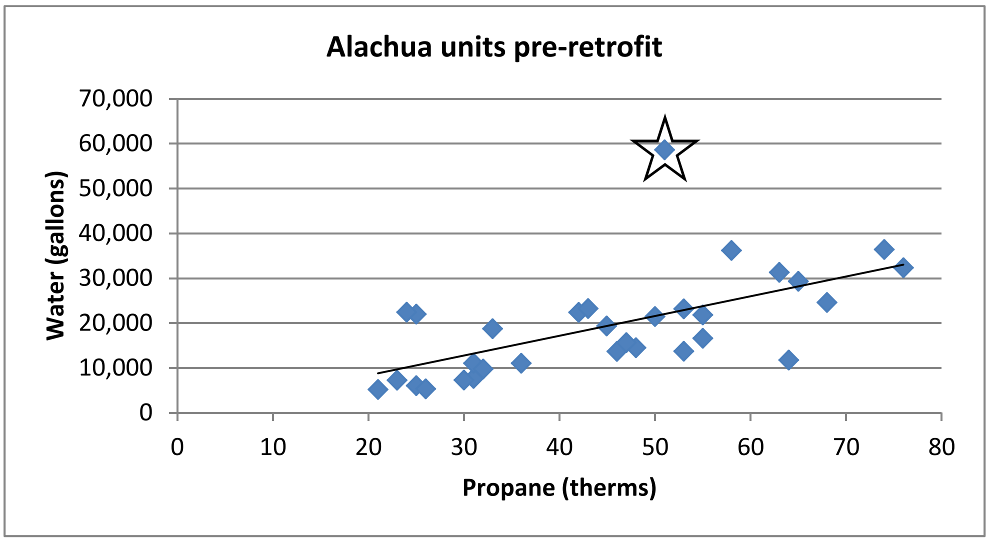


Figure G.3. Plot of water and gas use in the pre-retrofit study period in the Alachua units

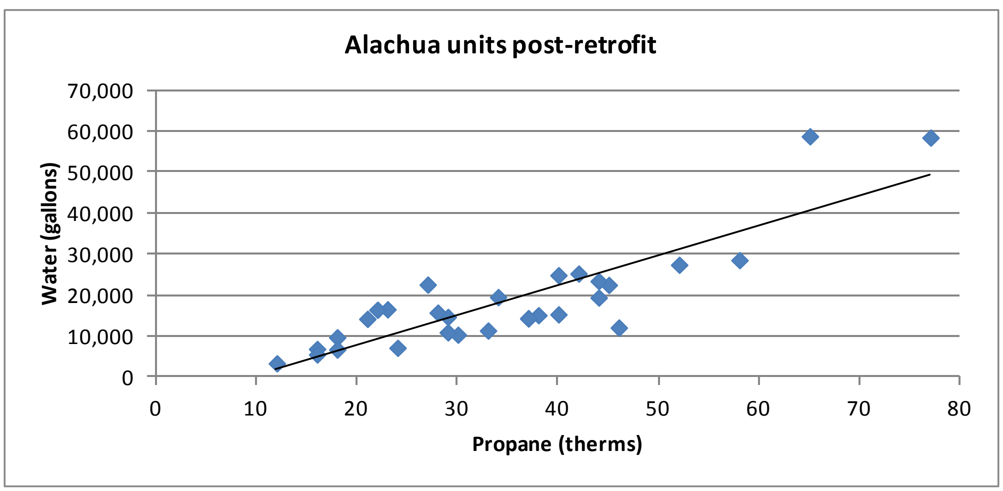


Figure G.4. Plot of water and gas use in the post-retrofit study period in the Alachua units

Appendix H: Evaluation of Cost Effectiveness

Present value life cycle cost (PVLCC), present value net savings (PVNS), and the savings to investment ratio (SIR) have been used to investigate the cost effectiveness of the water heater retrofits (ASTM 1994, Fuller & Petersen 1995). Future values are discounted based on equation H1.

$$PV = \frac{F}{(1+d)^t} \quad \text{(H1)}$$

where:

PV = present value, ($)
F = future value, ($)
d = discount rate
t = time period (year)

Future costs are escalated from current costs by:

$$FV = PV \times (1+d)^t \quad \text{(H2)}$$

where:

FV = future value ($)

Future energy costs that have a differential escalation rate are escalated from present costs using an energy specific escalation rate:

$$E_t = E_{current} \times (1 + d_{Energy\ Inflation\ Rate})^t \quad \text{(H3)}$$

where:

E_t = energy value in year t ($)
E_t = energy value in current year ($)
d = discount factor (%)

PVLCC with and without the retrofit are calculated using the following equation:

$$PVLCC = \sum_{t=1}^{n} \frac{\overline{C}_t}{(1+d)^t} - PV\ Salvage \quad \text{(H4)}$$

where:

PVLCC = present value of the LCC
$\overline{C}_t$ = cost value in year t ($)
n = study period (years)
PV Salvage = present value of salvage value of the equipment at the end of the study

The decision rule is that the alternative with the lowest LCC is preferred.

The discounted NS for the retrofit is calculated using the following equation:

$$PVNS = \sum_{t=1}^{n} \frac{(S_t - \overline{C_t})}{(1+i)^t} - PV\ Salvage \qquad \text{(H5)}$$

where:

PVNS = present value of the Net Savings
S_t = savings value in year t ($)
$\overline{C_t}$ = cost value in year t; including initial investment cost ($)
n = study period (years)
PV Salvage = present value of salvage value of the equipment at the end of the study

The decision rules are that an alternative with a NS > 0 is acceptable, and the alternative with the greatest NS is preferred.

The discounted SIR is calculated using the following equation:

$$SIR = \frac{NS}{Initial\ investment} \qquad \text{(H6)}$$

In the NS calculation, the initial investment is the difference between the alternatives. The decision rules are that an alternative with a SIR ≥ 1 is acceptable, and the alternative with the greatest SIR is preferred.

The study period used for all economic analyses is 30 years. The discount rate, general inflation rate, and interest rate are set to 3%, and the energy inflation rate is set to 4% based on the expected escalation for Florida (Rushing et al. 2011). A sensitivity analysis of the life cycle cost and the net savings of the water heater upgrade was conducted to determine the impact of variations in the discount, energy inflation, and general inflation rates on the investment.

Table H.1. PVLCC for Two Bedroom Units Using the Calculated Energy Consumption Estimate

Year	Life Cycle Cost									
	Investment Cost ($)		Annual Energy ($)		Maintenance ($)		TOTAL COST ($)		PV TOTAL COST ($)	
	TTWH	TWH	TTWH	TWH	TTWH	TWH	TTWH	TWH	TTWH	TWH
	($)	($)	($)	($)	($)	($)	($)	($)	($)	($)
0	561.00	1144.00							561.00	1144.00
1			148.18	87.69		45.00	148.18	132.69	143.86	128.83
2			154.11	91.20		46.35	154.11	137.55	145.26	129.65
3			160.27	94.85		47.74	160.27	142.59	146.67	130.49
4			166.68	98.64		49.17	166.68	147.81	148.10	131.33
5			173.35	102.58		50.65	173.35	153.23	149.53	132.18
6			180.28	106.69		52.17	180.28	158.86	150.98	133.04
7			187.49	110.96		53.73	187.49	164.69	152.45	133.91
8			194.99	115.39		55.34	194.99	170.74	153.93	134.78
9			202.79	120.01		57.00	202.79	177.01	155.43	135.67
10			210.91	124.81		58.71	210.91	183.53	156.93	136.56
11			219.34	129.80		60.48	219.34	190.28	158.46	137.46
12			228.12	134.99		62.29	228.12	197.29	160.00	138.37
13	411.19		237.24	140.39		64.16	237.24	204.55	161.55	139.29
14			246.73	146.01		66.08	657.92	212.09	434.96	140.22
15			256.60	151.85		68.07	256.60	219.92	164.70	141.16
16			266.86	157.92		70.11	266.86	228.03	166.30	142.10
17			277.54	164.24		72.21	277.54	236.45	167.92	143.06
18			288.64	170.81		74.38	288.64	245.19	169.55	144.02
19			300.19	177.64		76.61	300.19	254.25	171.19	145.00
20		901.25	312.19	184.75		78.91	312.19	263.66	172.85	145.98
21			324.68	192.14		81.28	324.68	1174.66	174.53	631.44
22			337.67	199.83		83.71	337.67	283.54	176.23	147.98
23			351.17	207.82		86.22	351.17	294.04	177.94	148.99
24			365.22	216.13		88.81	365.22	304.94	179.66	150.01
25			379.83	224.78		91.48	379.83	316.25	181.41	151.04
26	603.85		395.02	233.77		94.22	395.02	327.99	183.17	152.09
27			410.82	243.12		97.05	1014.67	340.16	456.79	153.14
28			427.26	252.84		99.96	427.26	352.80	186.74	154.20
29			444.35	262.96		102.96	444.35	365.91	188.56	155.27
30			462.12	273.47		106.05	462.12	379.52	190.39	156.36
Salvage	(418.05)	(450.62)						PV Salvage	(172.23)	(185.65)
								E+M+R	6087.05	5887.61
								LCC	5914.82	5701.95

Table H.2. PVLCC for Two Bedroom Units Using the Simulated Energy Consumption Estimate.

Year	Life Cycle Cost									
	Investment Cost ($)		Annual Energy ($)		Maintenance ($)		TOTAL COST ($)		PV TOTAL COST ($)	
	TTWH	TWH	TTWH	TWH	TTWH	TWH	TTWH	TWH	TTWH	TWH
	($)	($)	($)	($)	($)	($)	($)	($)	($)	($)
0	561.00	1144.00							561.00	1144.00
1			109.57	72.03		45.00	109.57	117.03	106.38	113.62
2			113.95	74.91		46.35	113.95	121.26	107.41	114.30
3			118.51	77.91		47.74	118.51	125.65	108.45	114.99
4			123.25	81.02		49.17	123.25	130.20	109.51	115.68
5			128.18	84.26		50.65	128.18	134.91	110.57	116.38
6			133.31	87.64		52.17	133.31	139.80	111.64	117.08
7			138.64	91.14		53.73	138.64	144.87	112.73	117.80
8			144.19	94.79		55.34	144.19	150.13	113.82	118.51
9			149.95	98.58		57.00	149.95	155.58	114.93	119.24
10			155.95	102.52		58.71	155.95	161.24	116.04	119.97
11			162.19	106.62		60.48	162.19	167.10	117.17	120.72
12			168.68	110.89		62.29	168.68	173.18	118.31	121.46
13	411.19		175.43	115.32		64.16	175.43	179.48	119.46	122.22
14			182.44	119.94		66.08	593.63	186.02	392.46	122.98
15			189.74	124.73		68.07	189.74	192.80	121.79	123.75
16			197.33	129.72		70.11	197.33	199.83	122.97	124.53
17			205.22	134.91		72.21	205.22	207.12	124.16	125.31
18			213.43	140.31		74.38	213.43	214.69	125.37	126.11
19			221.97	145.92		76.61	221.97	222.53	126.59	126.91
20		901.25	230.85	151.76		78.91	230.85	230.66	127.81	127.71
21			240.08	157.83		81.28	240.08	1140.35	129.06	612.99
22			249.68	164.14		83.71	249.68	247.85	130.31	129.35
23			259.67	170.71		86.22	259.67	256.93	131.57	130.18
24			270.06	177.53		88.81	270.06	266.34	132.85	131.02
25			280.86	184.63		91.48	280.86	276.11	134.14	131.87
26	603.85		292.10	192.02		94.22	292.10	286.24	135.44	132.73
27			303.78	199.70		97.05	907.63	296.75	408.60	133.59
28			315.93	207.69		99.96	315.93	307.65	138.09	134.47
29			328.57	216.00		102.96	328.57	318.95	139.43	135.35
30			341.71	224.64		106.05	341.71	330.68	140.78	136.24
Salvage	(418.05)	(450.62)						PV Salvage	(172.23)	(185.65)
								E+M+R	4788.84	5361.06
								LCC	4616.61	5175.41

Table H.3. PVLCC for Two Bedroom Units Using the Utility-based Energy Consumption Estimate

Year	Life Cycle Cost									
	Investment Cost ($)		Annual Energy ($)		Maintenance ($)		TOTAL COST ($)		PV TOTAL COST ($)	
	TTWH	TWH	TTWH	TWH	TTWH	TWH	TTWH	TWH	TTWH	TWH
	($)	($)	($)	($)	($)	($)	($)	($)	($)	($)
0	561.00	1144.00							561.00	1144.00
1			191.31	128.05		45.00	191.31	173.05	185.74	168.01
2			198.96	133.17		46.35	198.96	179.52	187.54	169.22
3			206.92	138.50		47.74	206.92	186.24	189.36	170.44
4			215.20	144.04		49.17	215.20	193.21	191.20	171.67
5			223.81	149.80		50.65	223.81	200.45	193.06	172.91
6			232.76	155.79		52.17	232.76	207.96	194.93	174.16
7			242.07	162.02		53.73	242.07	215.76	196.82	175.43
8			251.75	168.51		55.34	251.75	223.85	198.73	176.71
9			261.82	175.25		57.00	261.82	232.25	200.66	178.00
10			272.29	182.26		58.71	272.29	240.97	202.61	179.30
11			283.19	189.55		60.48	283.19	250.02	204.58	180.62
12			294.51	197.13		62.29	294.51	259.42	206.57	181.95
13	411.19		306.29	205.01		64.16	306.29	269.17	208.57	183.29
14			318.55	213.21		66.08	729.73	279.30	482.44	184.65
15			331.29	221.74		68.07	331.29	289.81	212.64	186.02
16			344.54	230.61		70.11	344.54	300.72	214.71	187.40
17			358.32	239.84		72.21	358.32	312.05	216.79	188.79
18			372.65	249.43		74.38	372.65	323.81	218.89	190.20
19			387.56	259.41		76.61	387.56	336.02	221.02	191.62
20		901.25	403.06	269.78		78.91	403.06	348.69	223.17	193.06
21			419.18	280.57		81.28	419.18	1263.10	225.33	678.98
22			435.95	291.80		83.71	435.95	375.51	227.52	195.98
23			453.39	303.47		86.22	453.39	389.69	229.73	197.45
24			471.52	315.61		88.81	471.52	404.42	231.96	198.95
25			490.39	328.23		91.48	490.39	419.71	234.21	200.45
26	603.85		510.00	341.36		94.22	510.00	435.58	236.48	201.98
27			530.40	355.01		97.05	1134.25	452.06	510.63	203.51
28			551.62	369.22		99.96	551.62	469.17	241.10	205.06
29			573.68	383.98		102.96	573.68	486.94	243.44	206.63
30			596.63	399.34		106.05	596.63	505.39	245.80	208.21
Salvage	(418.05)	(450.62)						PV Salvage	(172.23)	(185.65)
								E+M+R	7537.24	7244.66
								LCC	7365.01	7059.01

Table H.4. PVNS and SIR for Two Bedroom Units Using Calculated Energy Consumption

Year	Operational Costs ($)					Investment Costs ($)		
	Energy		Maintenance		PV Savings			PV Investment
	TTWH	TWH	TTWH	TWH		TTWH	TWH	
0						561.00	1144.00	583.00
1	148.18	87.69		45.00	15.04			
2	154.11	91.20		46.35	15.61			
3	160.27	94.85		47.74	16.18			
4	166.68	98.64		49.17	16.77			
5	173.35	102.58		50.65	17.35			
6	180.28	106.69		52.17	17.95			
7	187.49	110.96		53.73	18.54			
8	194.99	115.39		55.34	19.15			
9	202.79	120.01		57.00	19.76			
10	210.91	124.81		58.71	20.37			
11	219.34	129.80		60.48	21.00			
12	228.12	134.99		62.29	21.62			
13	237.24	140.39		64.16	22.26	411.19		(280.00)
14	246.73	146.01		66.08	22.90			
15	256.60	151.85		68.07	23.55			
16	266.86	157.92		70.11	24.20			
17	277.54	164.24		72.21	24.86			
18	288.64	170.81		74.38	25.52			
19	300.19	177.64		76.61	26.19			
20	312.19	184.75		78.91	26.87		901.25	499.00
21	324.68	192.14		81.28	27.56			
22	337.67	199.83		83.71	28.25			
23	351.17	207.82		86.22	28.95			
24	365.22	216.13		88.81	29.65			
25	379.83	224.78		91.48	30.37			
26	395.02	233.77		94.22	31.08	603.85		(280.00)
27	410.82	243.12		97.05	31.81			
28	427.26	252.84		99.96	32.54			
29	444.35	262.96		102.96	33.28			
30	462.12	273.47		106.05	34.03			
PV Salvage						(418.05)	(450.62)	(13.42)
					723.22			508.58
							SIR	1.42
							NS	214.64

Table H.5. PVNS and SIR for Two Bedroom Units Using Simulated Energy Consumption

Year	Operational Costs ($)					Investment Costs ($)		
	Energy		Maintenance		PV Savings			PV Investment
	TTWH	TWH	TTWH	TWH		TTWH	TWH	
0						561.00	1144.00	583.00
1	109.57	72.03		45.00	(7.24)			
2	113.95	74.91		46.35	(6.89)			
3	118.51	77.91		47.74	(6.53)			
4	123.25	81.02		49.17	(6.17)			
5	128.18	84.26		50.65	(5.81)			
6	133.31	87.64		52.17	(5.44)			
7	138.64	91.14		53.73	(5.07)			
8	144.19	94.79		55.34	(4.69)			
9	149.95	98.58		57.00	(4.31)			
10	155.95	102.52		58.71	(3.93)			
11	162.19	106.62		60.48	(3.55)			
12	168.68	110.89		62.29	(3.16)			
13	175.43	115.32		64.16	(2.76)	411.19		(280.00)
14	182.44	119.94		66.08	(2.36)			
15	189.74	124.73		68.07	(1.96)			
16	197.33	129.72		70.11	(1.56)			
17	205.22	134.91		72.21	(1.15)			
18	213.43	140.31		74.38	(0.74)			
19	221.97	145.92		76.61	(0.32)			
20	230.85	151.76		78.91	0.10		901.25	499.00
21	240.08	157.83		81.28	0.53			
22	249.68	164.14		83.71	0.96			
23	259.67	170.71		86.22	1.39			
24	270.06	177.53		88.81	1.83			
25	280.86	184.63		91.48	2.27			
26	292.10	192.02		94.22	2.72	603.85		(280.00)
27	303.78	199.70		97.05	3.17			
28	315.93	207.69		99.96	3.62			
29	328.57	216.00		102.96	4.08			
30	341.71	224.64		106.05	4.54			
PV Salvage						(418.05)	(450.62)	(13.42)
					(48.45)			508.58
							SIR	N/A
							NS	(557.03)

Table H.6. PVNS and SIR for Two Bedroom Units Using Utility Bill-based Energy Consumption

Year	Operational Costs ($)					Investment Costs ($)		
	Energy		Maintenance		PV Savings			PV Investment
	TTWH	TWH	TTWH	TWH		TTWH	TWH	
0						561.00	1144.00	583.00
1	191.31	128.05		45.00	17.73			
2	198.96	133.17		46.35	18.32			
3	206.92	138.50		47.74	18.93			
4	215.20	144.04		49.17	19.53			
5	223.81	149.80		50.65	20.15			
6	232.76	155.79		52.17	20.77			
7	242.07	162.02		53.73	21.39			
8	251.75	168.51		55.34	22.03			
9	261.82	175.25		57.00	22.66			
10	272.29	182.26		58.71	23.31			
11	283.19	189.55		60.48	23.96			
12	294.51	197.13		62.29	24.62			
13	306.29	205.01		64.16	25.28	411.19		(280.00)
14	318.55	213.21		66.08	25.95			
15	331.29	221.74		68.07	26.62			
16	344.54	230.61		70.11	27.31			
17	358.32	239.84		72.21	28.00			
18	372.65	249.43		74.38	28.69			
19	387.56	259.41		76.61	29.39			
20	403.06	269.78		78.91	30.10		901.25	499.00
21	419.18	280.57		81.28	30.82			
22	435.95	291.80		83.71	31.54			
23	453.39	303.47		86.22	32.27			
24	471.52	315.61		88.81	33.01			
25	490.39	328.23		91.48	33.76			
26	510.00	341.36		94.22	34.51	603.85		(280.00)
27	530.40	355.01		97.05	35.27			
28	551.62	369.22		99.96	36.03			
29	573.68	383.98		102.96	36.81			
30	596.63	399.34		106.05	37.59			
PV Salvage						(418.05)	(450.62)	(13.42)
					816.35			508.58
							SIR	1.61
							NS	307.77

Appendix I: Summary Calculated, Simulated, and Utility Bill-Based Gas, Water, and Normalized Results

Table I.1. Results Comparison in May, June and July 2010 Gainesville Units

Case	Number of Bedrooms	2010 Summer-Gas and Water								
		Calculated			Simulated			Utility		
		Gas	Total Water	Normalized	Gas	Hot Water	Normalized	Gas	Total Water	Normalized
		(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)
1	2	38	12241	0.0031	27	3809	0.007088	49	12000	0.0040
2	2	38	12241	0.0031	27	3809	0.007088	30	8000	0.0038
3	2	38	12241	0.0031	27	3809	0.007088	69	20000	0.0035
4	2	38	12241	0.0031	27	3809	0.007088	80	24000	0.0033
5	2	38	12241	0.0031	27	3809	0.007088	57	13000	0.0043
6	2	38	12241	0.0031	27	3809	0.007088	43	18000	0.0024
7	2	38	12241	0.0031	27	3809	0.007088	44	7000	0.0063
		Average	*12241*	*0.0031*			*0.007088*		*14571*	*0.0039*

Table I.2. Results Comparison in May, June and July 2010 Alachua Units

Case	No of Bedroom	2010 Summer-Gas and Water								
		Calculated			Simulated			Utility		
		Propane	Total Water	Normalized	Propane	Hot Water	Normalized	Propane	Total Water	Normalized
		(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)
8	3	43	16321	0.0026	31	4566	0.006789	46	13660	0.0034
9	3	43	16321	0.0026	31	4566	0.006789	74	36370	0.002
10	3	43	16321	0.0026	31	4566	0.006789	25	21990	0.0011
11	2	38	12241	0.0031	30	3809	0.007876	53	23170	0.0023
12	3	43	16321	0.0026	31	4566	0.006789	23	7240	0.0032
13	4	47	20401	0.0023	33	5326	0.006196	68	24590	0.0028
14	5	52	24481	0.0021	36	6087	0.005914	58	36160	0.0016
15	2	38	12241	0.0031	30	3809	0.007876	31	7630	0.004
16	4	47	20401	0.0023	33	5326	0.006196	55	16580	0.0033
17	4	47	20401	0.0023	33	5326	0.006196	63	31300	0.002
18	2	38	12241	0.0031	30	3809	0.007876	36	11010	0.0033
19	4	47	20401	0.0023	33	5326	0.006196	21	5160	0.0041
20	4	47	20401	0.0023	33	5326	0.006196	42	22360	0.0019
21	4	47	20401	0.0023	33	5326	0.006196	64	11750	0.0055
22	4	47	20401	0.0023	33	5326	0.006196	53	13700	0.0039
23	2	38	12241	0.0031	30	3809	0.007876	31	11040	0.0028
24	4	47	20401	0.0023	33	5326	0.006196	65	29280	0.0022
25	3	43	16321	0.0026	31	4566	0.006789	25	6030	0.0041
26	3	43	16321	0.0026	31	4566	0.006789	26	5310	0.005
27	5	52	24481	0.0021	36	6087	0.005914	76	32330	0.0023
28	2	38	12241	0.0031	30	3809	0.007876	24	22400	0.0011
29	2	38	12241	0.0031	30	3809	0.007876	50	21430	0.0023
30	2	38	12241	0.0031	30	3809	0.007876	30	7280	0.0041
31	4	47	20401	0.0023	33	5326	0.006196	55	21810	0.0025
32	3	43	16321	0.0026	31	4566	0.006789	33	18740	0.0018
33	3	43	16321	0.0026	31	4566	0.006789	48	14500	0.0033
34	4	47	20401	0.0023	33	5326	0.006196	51	58620	0.0009
35	4	47	20401	0.0023	33	5326	0.006196	47	15630	0.003
36	2	38	12241	0.0031	30	3809	0.007876	32	9740	0.0033
37	5	52	24481	0.0021	36	6087	0.005914	43	23220	0.0019
		Average	*17545*	*0.0026*			*0.006774*		*19334*	*0.0028*

Table I.3. Results Comparison in May, June and July 2011 Gainesville Units

Case	No of Bedroom	2011 Summer-Gas and Water								
		Calculated			Simulated			Utility		
		Gas	Total Water	Normalized	Gas	Hot Water	Normalized	Gas	Total Water	Normalized
		(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)
1	2	21	12241	0.0018	17	3809	0.004463	13	11000	0.0011
2	2	21	12241	0.0018	17	3809	0.004463	19	9000	0.0021
3	2	21	12241	0.0018	17	3809	0.004463	50	21000	0.0024
4	2	21	12241	0.0018	17	3809	0.004463	53	26000	0.0021
5	2	21	12241	0.0018	17	3809	0.004463	32	12000	0.0027
6	2	21	12241	0.0018	17	3809	0.004463	35	11000	0.0031
7	2	21	12241	0.0018	17	3809	0.004463	21	12000	0.0017
		Average	*12241*	*0.0018*			*0.004463*		*14571*	*0.0022*

Table I.4. Results Comparison in May, June and July 2011 Alachua Units

Case	No of Bedroom	2011 Summer-Gas and Water								
		Calculated			Simulated			Utility		
		Propane	Total Water	Normalized	Propane	Hot Water	Normalized	Propane	Total Water	Normalized
		(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)	(Therm)	(gallons)	(Therm/gallon)
8	3	26	16321	0.0016	21	4566	0.004599	30	10520	0.0028
9	3	26	16321	0.0016	21	4566	0.004599	42	25420	0.0017
10	3	26	16321	0.0016	21	4566	0.004599	23	16700	0.0014
11	2	21	12241	0.0018	19	3809	0.004988	12	3540	0.0035
12	3	26	16321	0.0016	21	4566	0.004599	16	7050	0.0022
13	4	30	20401	0.0015	23	5326	0.004318	44	19560	0.0023
14	5	34	24481	0.0014	26	6087	0.004271	65	58890	0.0011
15	2	21	12241	0.0018	19	3809	0.004988	18	9870	0.0019
16	4	30	20401	0.0015	23	5326	0.004318	38	15270	0.0025
17	4	30	20401	0.0015	23	5326	0.004318	40	25030	0.0016
18	2	21	12241	0.0018	19	3809	0.004988	16	5700	0.0028
19	4	30	20401	0.0015	23	5326	0.004318	37	14460	0.0026
20	4	30	20401	0.0015	23	5326	0.004318	52	27550	0.0019
21	4	30	20401	0.0015	23	5326	0.004318	33	11530	0.0029
22	4	30	20401	0.0015	23	5326	0.004318	29	14830	0.0020
23	2	21	12241	0.0018	19	3809	0.004988	22	16600	0.0013
24	4	30	20401	0.0015	23	5326	0.004318	45	22650	0.0020
25	3	26	16321	0.0016	21	4566	0.004599	18	6910	0.0027
26	3	26	16321	0.0016	21	4566	0.004599	24	7310	0.0033
27	5	34	24481	0.0014	26	6087	0.004271	58	28690	0.0020
28	2	21	12241	0.0018	19	3809	0.004988	21	14390	0.0015
29	2	21	12241	0.0018	19	3809	0.004988	28	15900	0.0018
30	2	21	12241	0.0018	19	3809	0.004988	27	22730	0.0012
31	4	30	20401	0.0015	23	5326	0.004318	40	15480	0.0026
32	3	26	16321	0.0016	21	4566	0.004599	46	12250	0.0037
33	3	26	16321	0.0016	21	4566	0.004599	37	14550	0.0025
34	4	30	20401	0.0015	23	5326	0.004318	77	58570	0.0013
35	4	30	20401	0.0015	23	5326	0.004318	34	19690	0.0017
36	2	21	12241	0.0018	19	3809	0.004988	29	11090	0.0026
37	5	34	24481	0.0014	26	6087	0.004271	44	23580	0.0019
		Average	*17545*	*0.0016*			*0.004567*		*18544*	*0.0022*

Table I.5. Comparison of Difference in Normalized Energy Use for Pre-retrofit (May-July 2010) and Post-retrofit (May-July 2011) Periods Gainesville Units

Case	Difference = post retrofit (2011) - pre retrofit (2010)		
	Calculated	Simulated	Utility
	Therm/gal	Therm/gal	Therm/gal
1	-0.003203	-0.002625	-0.002957
2	-0.003203	-0.002625	-0.001701
3	-0.003203	-0.002625	-0.001061
4	-0.003203	-0.002625	-0.001261
5	-0.003203	-0.002625	-0.001644
6	-0.003203	-0.002625	0.000756
7	-0.003203	-0.002625	-0.004535
MEAN	*-0.003203*	*-0.002625*	*-0.001772*

Table I.6. Comparison of Difference in Normalized Energy use for Pre-retrofit (May-July 2010) and Post-retrofit (May-July 2011) Periods Alachua Units

Case	Difference = post retrofit (2011) - pre retrofit (2010)		
	Calculated	Simulated	Utility
	Therm/gal	Therm/gal	Therm/gal
8	-0.002670	-0.002190	-0.000506
9	-0.002670	-0.002190	-0.000371
10	-0.002670	-0.002190	0.000250
11	-0.003203	-0.002888	0.001203
12	-0.002670	-0.002190	-0.000914
13	-0.002284	-0.001878	-0.000507
14	-0.002121	-0.001643	-0.000501
15	-0.003203	-0.002888	-0.002167
16	-0.002284	-0.001878	-0.000867
17	-0.002284	-0.001878	-0.000414
18	-0.003203	-0.002888	-0.000499
19	-0.002284	-0.001878	-0.001539
20	-0.002284	-0.001878	-0.000005
21	-0.002284	-0.001878	-0.002570
22	-0.002284	-0.001878	-0.001898
23	-0.003203	-0.002888	-0.001466
24	-0.002284	-0.001878	-0.000243
25	-0.002670	-0.002190	-0.001413
26	-0.002670	-0.002190	-0.001723
27	-0.002121	-0.001643	-0.000317
28	-0.003203	-0.002888	0.000407
29	-0.003203	-0.002888	-0.000570
30	-0.003203	-0.002888	-0.002913
31	-0.002284	-0.001878	0.000016
32	-0.002670	-0.002190	0.001953
33	-0.002670	-0.002190	-0.000738
34	-0.002284	-0.001878	0.000437
35	-0.002284	-0.001878	-0.001242
36	-0.003203	-0.002888	-0.000635
37	-0.002121	-0.001643	0.000009
MEAN	*-0.002616*	*-0.002207*	*-0.000658*

Appendix J: Detailed Water Usage in the Study Period for All Units.

Table J.1. Actual Water Use for Case 1 - Gainesville

Case 1 – Gainesville							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	7000	32	218.75	May	2000	29	68.97
June	3000	29	103.45	June	4000	30	133.33
July	2000	30	66.67	July	5000	33	151.52
Average (gal/day)			129.63	Average (gal/day)			117.94

Table J.2. Actual Water Use for Case 2 - Gainesville

Case 2 – Gainesville							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	3000	32	93.75	May	4000	29	137.93
June	3000	29	103.45	June	4000	30	133.33
July	2000	30	66.67	July	1000	25	40
Average (gal/day)			87.95	Average (gal/day)			103.75

Table J.3. Actual Water Use for Case 3 - Gainesville

Case 3 – Gainesville							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	8000	32	250	May	7000	29	241.38
June	6000	29	206.9	June	7000	30	233.33
July	6000	30	200	July	7000	33	212.12
Average (gal/day)			218.96	Average (gal/day)			228.94

Table J.4. Actual Water Use for Case 4 - Gainesville

Case 4 – Gainesville							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	7000	32	218.75	May	9000	29	310.34
June	9000	29	310.34	June	7000	30	233.33
July	8000	30	266.67	July	10000	33	303.03
Average (gal/day)			265.25	Average (gal/day)			282.23

Table J.5. Actual Water Use for Case 5 - Gainesville

Case 5 - Gainesville							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	5000	32	156.25	May	4000	29	137.93
June	3000	29	103.45	June	4000	30	133.33
July	5000	30	166.67	July	4000	33	121.21
Average (gal/day)			142.12	Average (gal/day)			130.82

Table J.6. Actual Water Use for Case 6 - Gainesville

Case 6 - Gainesville							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	6000	32	187.5	May	3000	29	103.45
June	9000	29	310.34	June	3000	30	100
July	3000	30	100	July	5000	33	151.52
Average (gal/day)			199.28	Average (gal/day)			118.32

Table J.7. Actual Water Use for Case 7 - Gainesville

Case 7 - Gainesville							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	2000	32	62.5	May	4000	29	137.93
June	2000	29	68.97	June	4000	30	133.33
July	3000	30	100	July	1000	33	30.3
Average (gal/day)			77.15	Average (gal/day)			100.52

Table J.8. Actual Water Use for Case 8 – Alachua

Case 8 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	4810	31	155.16	May	4060	32	126.88
June	4580	30	152.67	June	3000	30	100.00
July	4270	30	142.33	July	3460	29	119.31
Average (gal/day)			150.05	Average (gal/day)			115.40

Table J.9. Actual Water Use for Case 9 – Alachua

Case 9 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	11230	31	362.26	May	9220	32	288.13
June	12480	30	416.00	June	7340	30	244.67
July	12660	30	422.00	July	8860	29	305.52
Average (gal/day)			400.09	Average (gal/day)			279.44

Table J.10. Actual Water Use for Case 10 – Alachua

Case 10 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	9460	31	305.16	May	5080	32	158.75
June	7870	30	262.33	June	4480	30	149.33
July	4660	30	155.33	July	7140	29	246.21
Average (gal/day)			240.94	Average (gal/day)			184.76

Table J.11. Actual Water Use for Case 11 – Alachua

Case 11 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	7660	31	247.10	May	1710	32	53.44
June	8250	30	275.00	June	860	30	28.67
July	7260	30	242.00	July	970	29	33.45
Average (gal/day)			254.70	Average (gal/day)			38.52

Table J.12. Actual Water Use for Case 12 – Alachua

Case 12 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	2670	31	86.13	May	2670	32	83.44
June	2450	30	81.67	June	2090	30	69.67
July	2120	30	70.67	July	2290	29	78.97
Average (gal/day)			79.49	Average (gal/day)			77.36

Table J.13. Actual Water Use for Case 13 – Alachua

Case 13 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	7430	31	239.68	May	8010	32	250.31
June	9300	30	310.00	June	6100	30	203.33
July	7860	30	262.00	July	5450	29	187.93
Average (gal/day)			270.56	Average (gal/day)			213.86

Table J.14. Actual Water Use for Case 14 – Alachua

Case 14 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	14090	31	454.52	May	17470	32	545.94
June	10500	30	350.00	June	19330	30	644.33
July	11570	30	385.67	July	22090	29	761.72
Average (gal/day)			396.73	Average (gal/day)			650.66

Table J.15. Actual Water Use for Case 15 – Alachua

Case 15 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	2390	31	77.10	May	4070	32	127.19
June	2720	30	90.67	June	2680	30	89.33
July	2520	30	84.00	July	3120	29	107.59
Average (gal/day)			83.92	Average (gal/day)			108.04

Table J.16. Actual Water Use for Case 16 – Alachua

Case 16 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	4940	31	159.35	May	5290	32	165.31
June	6910	30	230.33	June	4570	30	152.33
July	4730	30	157.67	July	5410	29	186.55
Average (gal/day)			182.45	Average (gal/day)			168.07

Table J.17. Actual Water Use for Case 17 – Alachua

Case 17 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	8310	31	268.06	May	9990	32	312.19
June	10710	30	357.00	June	8360	30	278.67
July	12280	30	409.33	July	6680	29	230.34
Average (gal/day)			344.80	Average (gal/day)			273.73

Table J.18. Actual Water Use for Case 18 – Alachua

Case 18 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	3590	31	115.81	May	2970	32	92.81
June	2930	30	97.67	June	1850	30	61.67
July	4490	30	149.67	July	880	29	30.34
Average (gal/day)			121.05	Average (gal/day)			61.61

Table J.19. Actual Water Use for Case 19 – Alachua

Case 19 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	1920	31	61.94	May	5770	32	180.31
June	2700	30	90.00	June	4370	30	145.67
July	540	30	18.00	July	4320	29	148.97
Average (gal/day)			56.65	Average (gal/day)			158.31

Table J.20. Actual Water Use for Case 20 – Alachua

Case 20 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	8370	31	270.00	May	9410	32	294.06
June	6930	30	231.00	June	8070	30	269.00
July	7060	30	235.33	July	10070	29	347.24
Average (gal/day)			245.44	Average (gal/day)			303.43

Table J.21. Actual Water Use for Case 21 – Alachua

Case 21 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	3690	31	119.03	May	4610	32	144.06
June	4210	30	140.33	June	4070	30	135.67
July	3850	30	128.33	July	2850	29	98.28
Average (gal/day)			129.23	Average (gal/day)			126.00

Table J.22. Actual Water Use for Case 22 – Alachua

Case 22 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	3820	31	123.23	May	7080	32	221.25
June	4930	30	164.33	June	3940	30	131.33
July	4950	30	165.00	July	3810	29	131.38
Average (gal/day)			150.85	Average (gal/day)			161.32

Table J.23. Actual Water Use for Case 23 – Alachua

Case 23 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	3770	31	121.61	May	6550	32	204.69
June	4100	30	136.67	June	4810	30	160.33
July	3170	30	105.67	July	5240	29	180.69
Average (gal/day)			121.32	Average (gal/day)			181.90

Table J.24. Actual Water Use for Case 24 – Alachua

Case 24 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	9430	31	304.19	May	7950	32	248.44
June	10490	30	349.67	June	7190	30	239.67
July	9360	30	312.00	July	7510	29	258.97
Average (gal/day)			321.95	Average (gal/day)			249.02

Table J.25. Actual Water Use for Case 25 – Alachua

Case 25 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	1720	31	55.48	May	3440	32	107.50
June	1880	30	62.67	June	1990	30	66.33
July	2430	30	81.00	July	1480	29	51.03
Average (gal/day)			66.38	Average (gal/day)			74.96

Table J.26. Actual Water Use for Case 26 – Alachua

Case 26 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	1170	31	37.74	May	3190	32	99.69
June	2040	30	68.00	June	2360	30	78.67
July	2100	30	70.00	July	1760	29	60.69
Average (gal/day)			58.58	Average (gal/day)			79.68

Table J.27. Actual Water Use for Case 27 – Alachua

Case 27 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	9750	31	314.52	May	9360	32	292.50
June	11790	30	393.00	June	9320	30	310.67
July	10790	30	359.67	July	10010	29	345.17
Average (gal/day)			355.73	Average (gal/day)			316.11

Table J.28. Actual Water Use for Case 28 – Alachua

Case 28 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	6630	31	213.87	May	5520	32	172.50
June	8050	30	268.33	June	3970	30	132.33
July	7720	30	257.33	July	4900	29	168.97
Average (gal/day)			246.51	Average (gal/day)			157.93

Table J.29. Actual Water Use for Case 29 – Alachua

Case 29 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	6310	31	203.55	May	6060	32	189.38
June	7450	30	248.33	June	4950	30	165.00
July	7670	30	255.67	July	4890	29	168.62
Average (gal/day)			235.85	Average (gal/day)			174.33

Table J.30. Actual Water Use for Case 30 – Alachua

Case 30 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	2610	31	84.19	May	9080	32	283.75
June	2720	30	90.67	June	6730	30	224.33
July	1950	30	65.00	July	6920	29	238.62
Average (gal/day)			79.95	Average (gal/day)			248.90

Table J.31. Actual Water Use for Case 31 – Alachua

Case 31 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	7190	31	231.94	May	5130	32	160.31
June	7740	30	258.00	June	4980	30	166.00
July	6880	30	229.33	July	5370	29	185.17
Average (gal/day)			239.76	Average (gal/day)			170.49

Table J.32. Actual Water Use for Case 32 – Alachua

Case 32 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	4980	31	160.65	May	4540	32	141.88
June	7020	30	234.00	June	4570	30	152.33
July	6740	30	224.67	July	3140	29	108.28
Average (gal/day)			206.44	Average (gal/day)			134.16

Table J.33. Actual Water Use for Case 33 – Alachua

Case 33 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	4790	31	154.52	May	5540	32	173.13
June	4760	30	158.67	June	4620	30	154.00
July	4950	30	165.00	July	4390	29	151.38
Average (gal/day)			159.39	Average (gal/day)			159.50

Table J.34. Actual Water Use for Case 34 – Alachua

Case 34 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	14330	31	462.26	May	14860	32	464.38
June	22110	30	737.00	June	21170	30	705.67
July	22180	30	739.33	July	22540	29	777.24
Average (gal/day)			646.20	Average (gal/day)			649.09

Table J.35. Actual Water Use for Case 35 – Alachua

Case 35 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	4660	31	150.32	May	6750	32	210.94
June	5610	30	187.00	June	6330	30	211.00
July	5360	30	178.67	July	6610	29	227.93
Average (gal/day)			172.00	Average (gal/day)			216.62

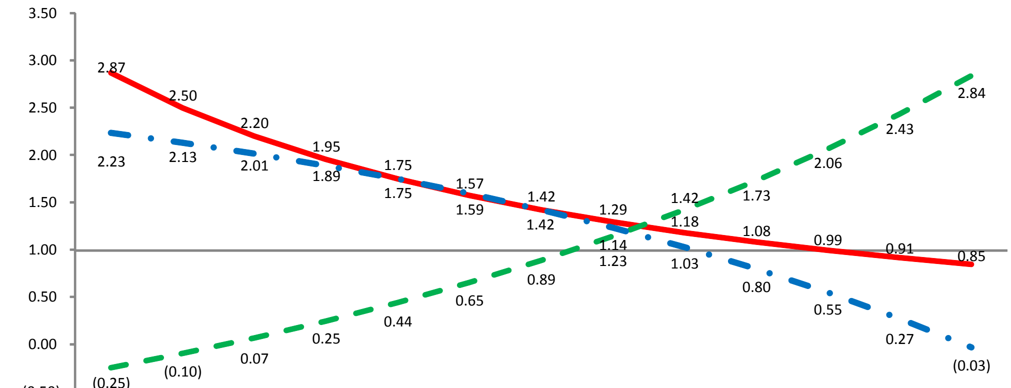
Table J.36. Actual Water Use for Case 36 – Alachua

Case 36 – Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	2930	31	94.52	May	4760	32	148.75
June	3650	30	121.67	June	2850	30	95.00
July	3160	30	105.33	July	3480	29	120.00
Average (gal/day)			107.17	Average (gal/day)			121.25

Table J.37. Actual Water Use for Case 37 – Alachua

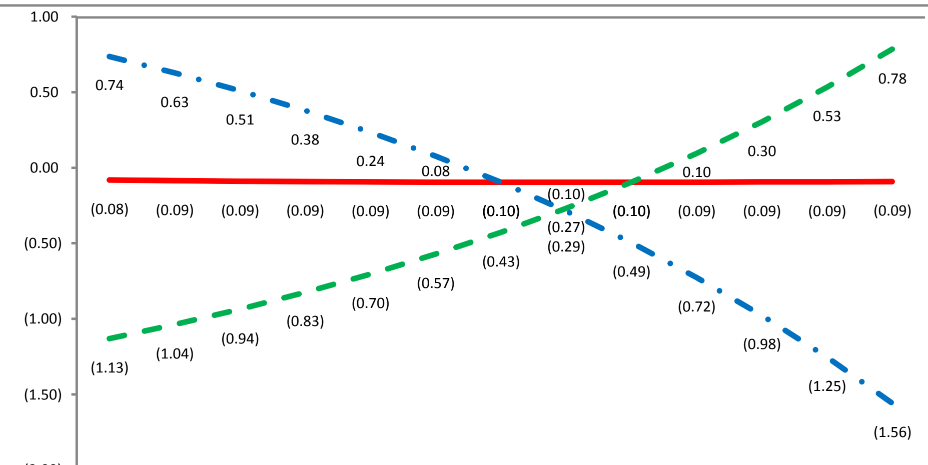
Case 37 - Alachua							
2010				2011			
Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)	Month	Water Usage (gallon)	Days of Service	Daily Usage (gallon/day)
May	6780	31	218.71	May	7360	32	230.00
June	8510	30	283.67	June	7460	30	248.67
July	7930	30	264.33	July	8760	29	302.07
Average (gal/day)			255.57	Average (gal/day)			260.25

Appendix K: Sensitivity Analysis Graphs for the SIR



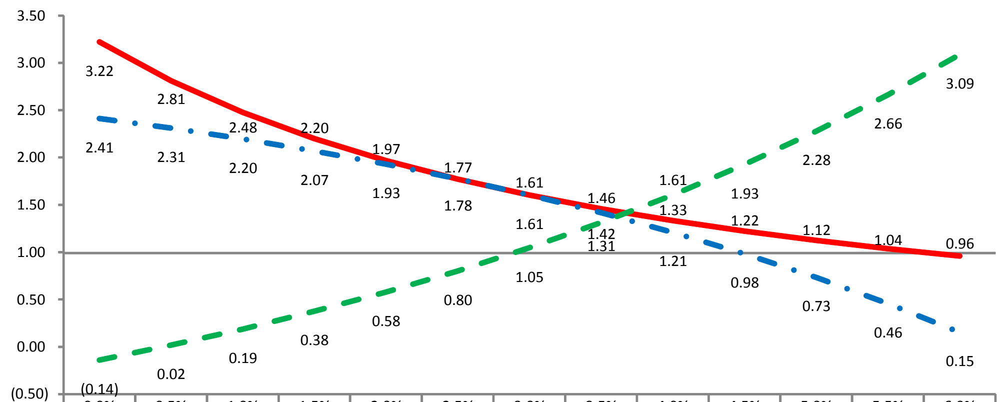
	0.0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%
Discount	2.87	2.50	2.20	1.95	1.75	1.57	1.42	1.29	1.18	1.08	0.99	0.91	0.85
Energy	(0.25)	(0.10)	0.07	0.25	0.44	0.65	0.89	1.14	1.42	1.73	2.06	2.43	2.84
General	2.23	2.13	2.01	1.89	1.75	1.59	1.42	1.23	1.03	0.80	0.55	0.27	(0.03)

Figure K.1. Sensitivity analysis of the PVNS for the calculated energy consumption estimate versus the discount, general inflation, and energy inflation rates



	0.0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%
Discount	(0.08)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.10)	(0.10)	(0.10)	(0.09)	(0.09)	(0.09)	(0.09)
Energy	(1.13)	(1.04)	(0.94)	(0.83)	(0.70)	(0.57)	(0.43)	(0.27)	(0.10)	0.10	0.30	0.53	0.78
General	0.74	0.63	0.51	0.38	0.24	0.08	(0.10)	(0.29)	(0.49)	(0.72)	(0.98)	(1.25)	(1.56)

Figure K.2. Sensitivity analysis of the SIR for the simulated energy consumption estimate versus the discount, general inflation, and energy inflation rates



Rate	0.0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%
Discount	3.22	2.81	2.48	2.20	1.97	1.77	1.61	1.46	1.33	1.22	1.12	1.04	0.96
Energy	(0.14)	0.02	0.19	0.38	0.58	0.80	1.05	1.31	1.61	1.93	2.28	2.66	3.09
General	2.41	2.31	2.20	2.07	1.93	1.78	1.61	1.42	1.21	0.98	0.73	0.46	0.15

Rate

Figure K.3. Sensitivity analysis of the SIR for the utility bill-based energy consumption estimate versus the discount, general inflation, and energy inflation rates

Appendix L: Photographs of Retrofits

Figure L.1. Tankless hot water heater unit

Figure L.2. Actual vertical venting assembly attached to the roof

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