ANALYSIS OF THE EFFECTIVENESS OF A SIMULATION MODEL FOR PREDICTING THE PERFORMANCE OF A TANKLESS WATER HEATER RETROFIT

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ABSTRACT

Utility data is compared to modeled pre- and post-retrofit energy and water consumption to assess the ability of a simulation model to accurately predict performance in a retrofit program. The program replaced tank type water heaters with tankless water heaters in 110 public housing units. BEopt version 1.1 energy simulation software was used to develop the estimates. Differences between the utility and simulated results are used to examine the performance predictions and resulting estimates of the economic feasability of the water heater retrofits. The statistical analyses of the utility data showed a statistically significant decrease in average gas use of 33% (minimum = 19%; maximum = 52%) when comparing the therms of gas used in the pre- and post-retrofit study periods. The simulation estimated energy savings of 39%. Although the utility and simulation energy savings percentages are similar, the economic analyses are not. Present value net savings and life cycle cost analyses indicate that the tank type water heater is preferred when using the simulation energy estimates and the tankless water heater is preferred when using the utility estimates. This is because actual average gas consumption was between 1.5 and 2 times the simulated estimates. Simulated hot water consumption was 60.6 gallons per day, which represents 35% of the actual average total water consumption. This is in line with a study of 1,188 homes that found that hot water consumption represented 34.2% of total water consumption.

INTRODUCTION

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.

The properties and performance characteristics of both tank type and tankless water heaters are generally well established and available. However, performance predictions do not always accurately represent how equipment will perform in real world conditions. Therefore, this study used longitudinal empirical utility data analysis to provide a point of comparison to the simulated pre- and post-retrofit performance estimates of a retrofit of tank-type water heating with tankless water heating in public housing units.

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.

In December 2010, the Alachua County Housing Authority in Gainesville, FL, USA initiated a retrofit program in 110 public housing units. The housing units had their gas-fired tank type water heaters replaced with gas-fired tankless water heaters as part of a federal program that targeted reduced energy use in public housing. 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. Ten units are in one housing development in the city of Gainesville, FL, ten are in Waldo, FL, and ninety are in the city of Alachua, FL. The units were built in stages and each stage consists 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, two strategies are used to estimate energy and water consumption pre- and post-retrofit:

1. Utility bill analysis: statistical analysis of energy and water consumption from the meter readings in the pre- and post-retrofit study periods as recorded in the utility bills for natural gas, propane, and potable water.

2. Simulation: energy and water consumption estimated using simulation.

LITERATURE REVIEW

BEopt (Building Energy optimization) was developed by NREL (National Renewable Energy Laboratory) to evaluate the design of residential buildings with regards to life cycle costs (LCC). BEopt provides a graphical interface to draw basic building models and specify project conditions such as building envelope, appliance efficiencies, and project location. BEopt uses Typical Meteorological Year 2 (TMY2) weather data. BEopt generates input files for energy simulation, runs the simulations, and collects the results for further analysis. Heat loss calculations and HVAC system simulation use either DOE-2 or EnergyPlus (Polly et al. 2012). Hot water events and simulations use TRNSYS, see Figure 1 (Christensen 2006, Backman et al. 2010). TRNSYS allows users to modify the mathematical models in the simulation routine (Klein et al. 2004, Malhotra 2009).
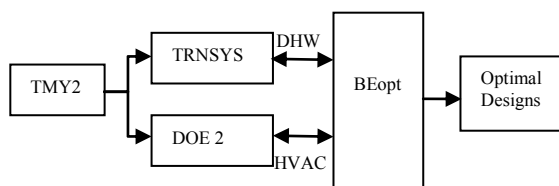

Figure 1. BEopt Simulation Process: Using TRNSYS and DOE 2

TRNSYS was developed by the University of Wisconsin, Madison's Solar Energy Laboratory and the University of Colorado. It has been commercially available since 1975 (Bradley 2005). BEopt uses TRNSYS to simulate hot water usage patterns thoughout the year so that the hourly consumption for hot water can be estimated along with system energy consumption. BEopt can also use TRNSYS to simulate solar water heater heating and photovoltaic systems (Christensen 2006, Gill 2008, Malhotra 2009).

Inputs into TRNSYS allow the user to specify the number of hot water appliances, flow rates for fixtures, occupancy schedules, water heater parameters, and distribution system parameters. The incoming water main temperature is estimated either by DOE-2 or EnergyPlus. These input parameters were set using actual project conditions with the exception of usage patterns. These were set according to the Building America House Simulation Protocols from Hendron et al. (2010).

A study by Wiehagen (2003) used TRNSYS to model water heater performance for electric tank type and tankless water heaters. The study modeled two types of piping systems based on hourly and weekly water draw data, and found that tankless water heaters inproved energy efficiency by 12 to 26%. A study conducted by Florida Solar Energy Center (FSEC) found that BEopt results were more accurate than EnergyGaugeUSA in certain areas (FSEC 2009). EnergyGaugeUSA is a software developed by FSEC for home energy rating and code compliance.

METHODOLOGY

The 110 units are in three areas, Gainesville, Alachua, and Waldo, FL, with each area having houses of the same construction, including similar appliances and fixtures provided and maintained by the Alachua County Housing Authority. 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 units consist 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.

As stated earlier, the utility-based statistical analyses use data from units that had the same occupants during the pre- and post-retrofit study. 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 and the simulated estimates are compared to assess the predictions from the energy simulation and used to calculate the economic feasibility of the tankless water heating system retrofit. The results from the two models were

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also compared to determine if any obvious differences could be found.

UTILITY ENERGY AND WATER CONSUMPTION

There were seven Gainesville units and thirty Alachua units that had the same tenants throughout the study period. During the study period of May through August, the only gas usage was for water heating in Gainesville and water heating along with cooking in Alachua. As gas for cooking will alter the results, the Gainesville and Alachua units are analysed separately.

Table 1 presents the study period gas and water consumption in Gainesville, and Table 2 presents the study period gas and water consumption in Alachua. The therms of gas consumption was computed from the utility meter data (1 therm = 0.11 gigajoule). The water utility data in Gainesville was recorded to the nearest 1,000 gallons by the utility (1 gallon = 3.785 liters). Construction details for the units were obtained through public records, interviews with the Alachua County Housing Authority, and site visits.

Table 1
Data from the Study Period for the Gainesville Units

[1]	[2]	[3]	[4]	[5]	[6]	[7]
Case Number	Bed Rooms	Bath Rooms	Gas (therms)	Water (gal)	Gas (therms)	Water (gal)
			May-July 2010		May-July 2011	
1	2	1	49	12,000	39	11,000
2	2	1	30	8,000	19	9,000
3	2	1.5	69	20,000	50	21,000
4	2	1.5	80	24,000	53	26,000
5	2	1.5	57	13,000	32	12,000
6	2	1.5	43	18,000	35	11,000
7	2	1.5	44	7,000	21	12,000
MEAN Gainesville			*53*	*14,571*	*36*	*14,571*

Table 2
Data from the Study Period for the Alachua Units

[1]	[2]	[3]	[4]	[5]	[6]	[7]
Case Number	Bed Rooms	Bath Rooms	Gas (therms)	Water (gal)	Gas (therms)	Water (gal)
			May-July 2010		May-July 2011	
8	3	1	46	13,660	30	10,520
9	3	1	74	36,370	42	25,420
10	3	1	25	21,990	23	16,700
11	2	1	53	23,170	12	3,540
12	3	1	23	7,240	16	7,050
13	4	1.5	68	24,590	44	19,560
14	5	1.5	58	36,160	65	58,890
15	2	1	31	7,630	18	9,870
16	4	1.5	55	16,580	38	15,270
17	4	1.5	63	31,300	40	25,030
18	2	1	36	11,010	16	5,700
19	4	1.5	21	5,160	37	14,460
20	4	1.5	42	22,360	52	27,550
21	4	1.5	64	11,750	33	11,530
22	4	1.5	53	13,700	29	14,830
23	2	1	31	11,040	22	16,600
24	4	1.5	65	29,280	45	22,650
25	3	1	25	6,030	18	6,910
26	3	1	26	5,310	24	7,310
27	5	1.5	76	32,330	58	28,690
28	2	1	24	22,400	21	14,390
29	2	1	50	21,430	28	15,900
30	2	1	30	7,280	27	22,730
31	4	1.5	55	21,810	40	15,480
32	3	1	33	18,740	46	12,250
33	3	1	48	14,500	37	14,550
34	4	1.5	51	58,620	77	58,570
35	4	1.5	47	15,630	34	19,690
36	2	1	32	9,740	29	11,090
37	5	1.5	43	23,220	44	23,580
Mean Alachua Units			*45*	*19,334*	*35*	*18,554*
Mean All Units			*46.5*	*18,433*	*35*	*17,792*

STATISTICAL ANALYSIS

A paired t-test with two tails was used to analyze utility data. 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 was 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 improves the likelihood that the 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 was 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. A 95% confidence level is used in the study. If there is confidence in the alternative hypothesis, the confidence interval is determined which is used to calculate 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 utility data gas savings percentage pre- and post-retrofit calculated for the units was statistically significant.

SIMULATED ENERGY AND WATER CONSUMPTION

The BEopt energy simulation protocols are based on the Building America House Simulation Protocols from Hendron et al. (2010) with the parameters adjusted to reflect actual project conditions.

Geometry screen tab

Figure 2 shows the input screen of BEopt for case 4, which is a 1,330 square foot house in Gainesville. Since the residential house is quadruplex, the model was separated into four different cases. Figure 2 represents the house at the west corner of the quadruplex for the foundation, first and second floor geometry. The number of bedrooms, bathrooms and stories are added to the model.

Figure 2 Geometry screen in BEopt software

Options screen tab

As this study is concerned with water heater performance, data on the building envelope and HVAC system were not used. Only values that impact the water heating simulation were entered, and are summarized in Table 3.

The BEopt simulation produces a wealth of data for analysis. Figure 3 represents the site source energy for water heating, and is graphed hourly, daily, monthly, and annually. This data is summarized in Tables 4 (pre-retrofit) and 5 (post-retrofit). Column [2] represents the Gainesville case in which natural gas is used and column [3] through [6] represent the Alachua cases where propane is used for water heating and cooking.

Table 3
Option Screen Input Summary for both cases

OPTION SCREEN INPUT SUMMARY						
Parameter	**Items**	**Existing Building**		**Post Retrofit**		
		Gainesville	Alachua	Gainesville	Alachua	
Miscellaneous Hot Water Loads		Benchmark[1]	Benchmark[1]	Benchmark[1]	Benchmark[1]	
	Cooking Range	Electric	Gas	Electric	Gas	
	Dishwasher	None	None	None	None	
	Clothes Washer	None	None	None	None	
	Clothes Dryer	None	None	None	None	
Water Heating	Water Heater	Gas Standard- $0.59^2/120^oF^4$	Gas Standard- $0.59^2/120^oF^4$	Gas Tankless- $0.82^3/120^oF^4$	Gas Tankless- $0.82^3/120^oF^4$	
	Distribution	Trunk Branch Copper[5]	Trunk Branch Copper[5]	Trunk Branch Copper[5]	Trunk Branch Copper[5]	

Note: [1] Refer to Building America House Simulation Protocols for fixtures input
    [2] Energy Factor for tank type water heater
    [3] Energy Factor for tankless water heater
    [4]Temperature input is set based on Alachua County Housing data
    [5] Trunk Branch refer to plumbing system which include header (trunk) and distribution pipe (branch) made from copper.

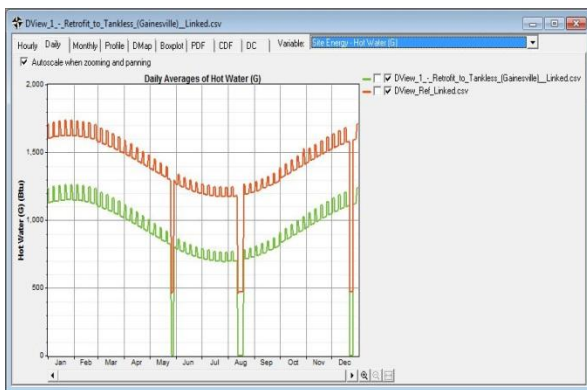**Simulated Gas Consumption**

Figure 3 Output screen in BEopt software: Site energy for water heater (natural gas consumption)

Table 4
Monthly simulated energy use for tank type water heaters (pre-retrofit) for the three month study period for two, three, four, and five bedroom units

[1]	[2]	[3]	[4]	[5]	[6]
	Simulated Gas Consumption (therms)				
Month	**Natural Gas**	**Propane**			
	2 Bed	**2 Bed**	**3 Bed**	**4 Bed**	**5 Bed**
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
TOTAL	*27.36*	*26.34*	*29.55*	*32.73*	*35.94*

Table 5
Monthly simulated energy use for tankless water heaters (post-retrofit) for the three month study period for two, three, four, and five bedroom units

[1]	[2]	[3]	[4]	[5]	[6]
	Simulated Gas Consumption (therms)				
Month	**Natural Gas**	**Propane**			
	2 Bed	**2 Bed**	**3 Bed**	**4 Bed**	**5 Bed**
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
TOTAL	*16.82*	*16.20*	*19.44*	*22.67*	*25.91*

Simulated Hot Water Consumption

BEopt's year-long water usage event schedules generated from TRNSYS include start time along with variable duration and flow rate for each fixture along with vacation schedules and seasonal variability. Using this event schedule, both hot and total water usage can be simulated. The results of the hot water simulation are given in Table 6 for all of the cases.

Table 6
Monthly-simulated hot water consumption for the three-month study period 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**
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
TOTAL	*3,808*	*4,566*	*5,327*	*6,087*

RESULTS

The utility gas savings percentage for the simulated and utility-based gas consumption estimates are summarized in Table 7 for Gainesville units and Table 8 for Alachua units. For the Gainesville units, the mean gas savings percentage for the simulated estimates is 39% and the mean utility-based estimate is 33% with a 95% confidence interval of 22-44%, see Table 9. The variability in utility-based estimates ranges from 19% to 52% gas consumption savings.

Table 7

Simulated-, and utility-based gas saving percentages for Gainesville units

| Case | Number of Bedrooms | Saving Percentage = (Gas$_{i\ pre\text{-}retrofit}$ - Gas$_{i\ post\text{-}retrofit}$) / Gas$_{i\ pre\text{-}retrofit}$ (%) | |
		Simulated	Utility
1	2	39%	20%
2	2	39%	37%
3	2	39%	28%
4	2	39%	34%
5	2	39%	44%
6	2	39%	19%
7	2	39%	52%
MEAN Gainesville		*39%*	*33%*

For the Alachua units, the mean simulated gas savings percentage is 33% and the utility-based estimate is 22% with a 95% confidence interval of 11-34%. The simulated estimates range from 28% to 38%, and the utility-based estimates range from 76% to 77%. The Alachua units have a lower mean simulation- and utility-based gas savings percentage compared to the Gainesville units. The greater variability in the Alachua units can be seen by comparing the utility gas savings percentages in Table 7 and Table 8. The negative values in Table 8 indicate an increase in post-retrofit gas use.

Table 8

Simulated-, and utility-based gas saving percentages for Alachua units

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

Compared with the Gainesville units, the Alachua utility-based gas savings percentages are not as similar to the simulation-based estimates.

Table 9 represents the summary of gas and water consumption for both cases. The top half of the table shows the results for the gas savings both in terms of percentage savings and in terms of mean savings.

Table 9

Simulated-, and utility-based estimates of pre-retrofit and post-retrofit gas and water consumption in the pre- and post-retrofit study periods.

| Location | Simulated | | | Utility | | | 95% CI | |
	Mean pre/post retrofit	Mean savings	%	Mean pre/post retrofit	Mean savings	%	Low	High
Gainesville Gas (therms)	27/17	10.5	39	53/36	17.6	33	22%	44%
Alachua Gas (therms)	30/20	10.1	33	45/35	10.1	22	11%	34%
All units Gas (therms)	30/20	10.2	34	47/35	11.5	25	16%	34%

The results show that the simulation tends to overestimate the gas savings percentage. However, simulation also underestimates the mean savings in the Gainesville units.

Total water use was compared to a study of residential water use in 1,188 homes by the American Water Works Association (AWWA) (Mayer et al. 1999). The average water use in gallons per day (gpd) found in this study are in line with the AWWA study (Table 10).

Table 10

Comparison of total water use in gallons per day compared with an American Water Works Association study of 1,188 homes.

	Pre-Retrofit (gpd)	Post-Retrofit (gpd)	AWWA (gpd)
Average	205	198	173
Standard deviation	123	132	94
Median	184	165	157

The simulated hot water values are based on the simulation protocol developed by the Building America program (Hendron 2010). From the simulation, the average hot water usage for sinks, showers, and baths was found to be 60.6 gpd. In the AWWA study, the sink, shower, and bath water consumption represented 34.2% of total water usage. The simulated hot water consumption represents 35% of the average water use from thee post-retrofit utility data. Two potential explanations are: 1.) The occupants are using a higher proportion of hot water to total water; and 2.) the WHAM model does not sufficiently represent the energy use related to the water use patterns in these cases. At this time, the empirical data needed to test these hypotheses is not available.

Figure 3 compares the ratio of utility therms to the simulated values for the Gainesville, Alachua, and combined data sets. The 95% confindence intervals are shown by the error bars. In summary, the Gainesville units consumed about twice the therms predicted by the simulation. In the Alachua units, gas consumption was about one and one half times the simulated estimates on average.
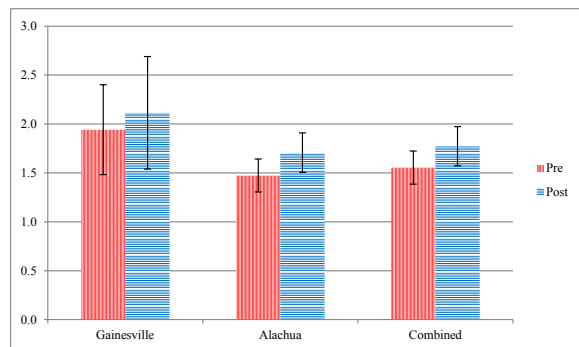

Figure 3 Ratio of the pre- and post-retrofit utility to simulated gas use in therms.

Occupancy data was obtained from the Alachua County Housing Authority. The occupancy data was analyzed to determine if the actual occpancy of the units was within the simulation protocol. The Build America housing simulation protocol (Hendron et al. 2010) estimates occupancy as:

$$\text{Occupancy} = 0.59 \times N_{br} + 0.87$$

where N_{br} = Number of bedrooms

Table 11 summarizes the occupancy data for the project, and shows that, on average, the simulation protocol underestimates the occupancy by a factor of 1.2. This is a likely reason for increased water heating energy use.

Table 11

Occupancy Table

Case	No. of Bed Rooms	Adult		Teens	Children	Total Actual Occupants	(0.59xNbr) + 0.87
		M	F	13-17	<13		
Gainesville							
1	2		1		2	3	2.05
2	2	1	1			2	2.05
3	2	1	1	1	4	7	2.05
4	2		1	3		4	2.05
5	2	1	1			2	2.05
6	2		1		1	2	2.05
7	2		1		2	3	2.05
Alachua							
8	3		1	1	1	3	2.64
9	3		2		1	3	2.64
10	3		2		2	4	2.64
11	2	1				1	2.05
12	3		1			1	2.64
13	4		1		3	4	3.23
14	5	2	2	1	2	7	3.82
15	2		1			1	2.05

Case	No. of Bed Rooms	Adult		Teens	Children	Total Actual Occupants	(0.59xNbr) + 0.87
		M	F	13-17	<13		
16	4		1		4	5	3.23
17	4		1		4	5	3.23
18	2		1			1	2.05
19	4		2	2		4	3.23
20	4	NA	NA	NA	NA	-	3.23
21	4	1		1		2	3.23
22	4		1		4	5	3.23
23	2		1	1		2	2.05
24	4	1	1		4	6	3.23
25	3	1				1	2.64
26	3		1		2	3	2.64
27	5	1	1	1	4	7	3.82
28	2		1			1	2.05
29	2		1			1	2.05
30	2	1	1			2	2.05
31	4		1	2	2	5	3.23
32	3	1			2	3	2.64
33	3	NA	NA	NA	NA	-	2.64
34	4		1	1	2	4	3.23
35	4	1	2		1	4	3.23
36	2		1		1	2	2.05
37	5	1	1	2		5	3.82
					Average	3.28	2.67

Impact on Underestimating Gas Consumption

Predictive models are often used to determine the economic feasability of performing energy upgrades. The Present Value Life Cycle Cost (PVLCC) and Present Value Net Savings (PVNS) were calculated for the simulated and utility based estimates (Ries et al. 2012). The alternative is judged favorable if the indicators satisfy these requirements:

→ If PVNS > 0 the alternative tankless water heater (TWH) is acceptable. However, the higher the PVNS the more favorable the alternative.

→ If PVLCC of the tankless water heater is lower than the PVLCC of the tank type water heater (TTWH), the tankless water heater is preferred.

All data were based on the actual project estimates in the year 2010. For example, in year 2010 the natural gas cost from the utility was $0.90/therm. The cost breakdown for the tankless system was based on Alachua County Public Housing contract documents. The economic analyses were calculated for a 30 year study period. The estimated replacement for the tank type water heater is 13 years and 20 years for the tankless water heater (DOE 2008). Maintanance cost for the tankless water heater is $45/year for annual descaling based on local cost. Three percent was used for the base discount and general inflation rates and four percent was used for the energy inflation rate base based on the likely rate for Florida (Rushing et al. 2010). Sensitivity analyses were also conduced for a range of discount, general inflation, and energy inflation rates.

The economic feasibility assessment based on the simulation energy use estimates showed that the tankless upgrade is not favorable, while the utility data indicates that the tankless system is preferred (Table 12). The difference is that, despite having similar predictions in gas savings percentage, the simulation underestimates gas consumption. The

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13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28

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underestimate reduces the cost savings of the tankless water heater to the point that the life cycle cost of the tankless system is higher than the tank-type.

Table 12

Life Cycle Costs of Simulated and Utility Estimates of Retrofitting to a Tankless Water Heater.

[1]	[2]	[3]	[4]	[5]
Economic analysis type	Simulated		Utility	
	TTWH	TWH	TTWH	TWH
PVLCC ($)	4616.61	5175.41	7365.01	7059.01
PVNS ($)	(557.03)		307.77	
	TTWH preferred		TWH preferred	

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 pre- and post-retrofit. The simulated results predict a higher percentage of energy savings compared to the utility-based estimates. However, simulation appears to underestimate gas usage and therefore underestimates the magnitude of the energy saved by the retrofit, which does impact the cost effectiveness of the retrofit.

The simulation protocol estimates water heater performance using the energy factor (EF). EF is a standard rating metric provided by the manufacturer so that consumers can make a comparison between the efficiency of different models. The EF is measured using a test that takes six draws of over ten gallons each at one hour intervals, followed by a 19 hour standby period. However, this draw pattern is not typical of actual usage. In a study by Bohac et. al (2010), actual draw patterns were frequently less than ten gallons and daily water consumption was less than 64 gallons. Further, the study found that the actual EF was less than the published EF, with the values approaching parity as hot water consumption increases.

As simulation estimates are used to determine the feasability of energy retrofits, further investigation is warranted to determine how best to improve estimates relative to actual performance. These investigations should include more realistic hot water draw patterns including variability in water use and improved occupancy estimates coupled with an improved model for predicting the actual EF.

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