

Life Cycle Cost Analysis of Tankless Water Heaters

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In 2011, one hundred and ten public housing units in Alachua County, Florida were retrofitted with gas tankless water heaters . 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. A cost effectiveness analyses using utility-based energy savings estimates for calculating present value life cycle cost, present value net savings, and the savings to investment ratio showed that the tankless water heaters were cost effective. 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.

Key Words: Life Cycle Cost, Energy Retrofit, Tankless Water Heater, Case Study

Introduction

Residential water heating represents about 20% of total residential energy consumption (Energy Information Administration 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. 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 over-sized to accommodate the times of the day with the heaviest demand. This requires energy 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 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 with different use patterns. Therefore, this study includes estimates based on a longitudinal empirical utility data analysis.

In December 2010, the Alachua County Housing Authority 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 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, and an analysis of the utitlity bills from the pre- and post-retrofit data can be used as the basis of determining the cost effectiness of the upgrade.

Methodology

Of the one hundred and ten units in the Alachua County Housing Authority retrofit program, 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. 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 30 units in Alachua met these criteria, for a total of 37 units for the study. 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.

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.

Utility-based Energy Consumption

Energy use in the pre-retrofit and the post-retrofit periods are estimated using the meter readings in the pre- and post-retrofit study periods 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.

Evaluation of Cost Effectiveness

Present value life cycle cost (PVLCC), present value net savings (PVNS), and the savings to investment ratio (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. 2011). 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.

Results

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. 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 ($Gas_{pre\text{-}retrofit} – Gas_{post\text{-}retrofit}$, Column 6) and the percentage reduction in gas use (($Gas_{pre\text{-}retrofit} – Gas_{post\text{-}retrofit}$) / $Gas_{pre\text{-}retrofit}$, Column 7) are shown in Table 1.

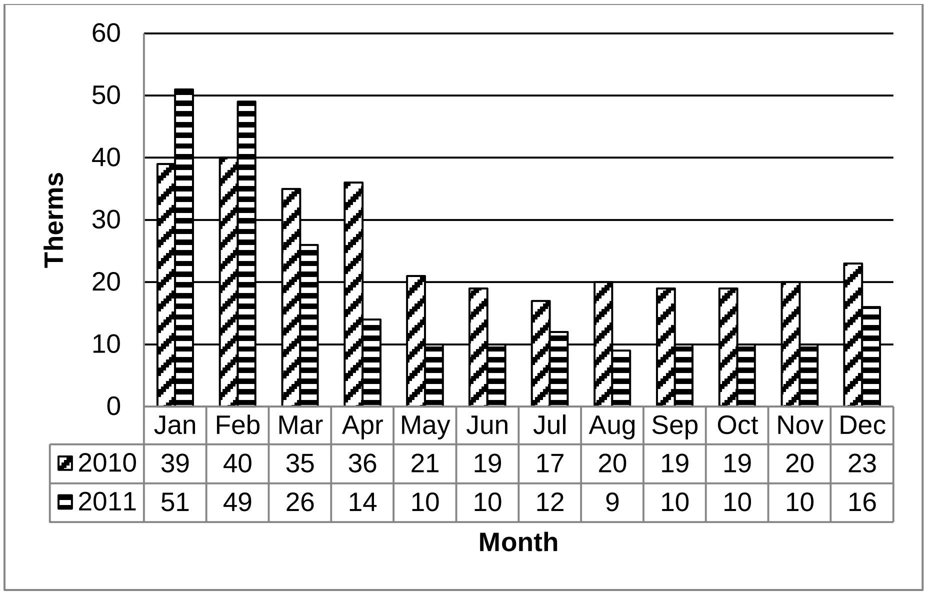


Figure 20. Monthly gas usage pre-retrofit (2010) and post-retrofit (2011) for one Gainesville unit.

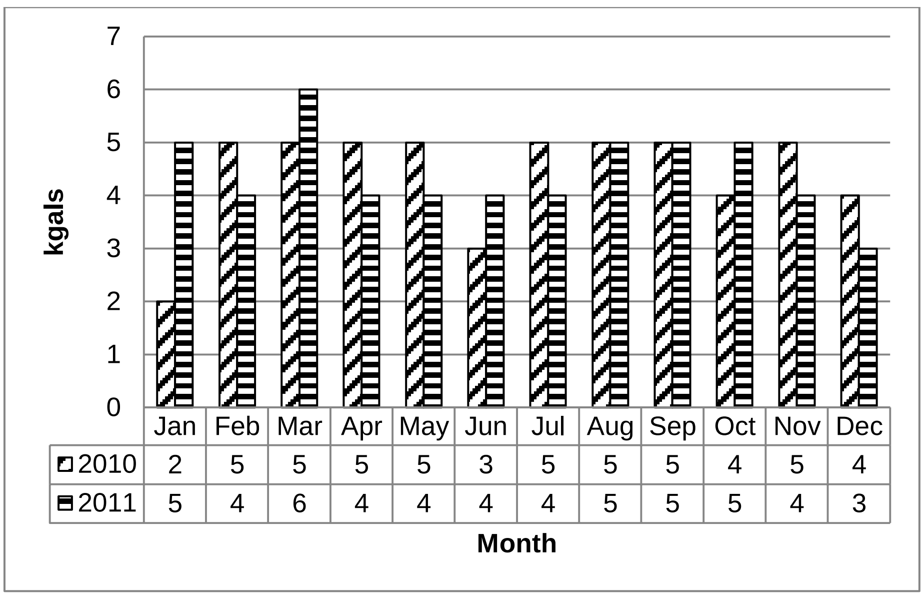


Figure 2. Monthly water consumption pre-retrofit (2010) and post-retrofit (2011) for one Gainesville unit.

Summary of the pre- and post-retrofit study period data for the Gainesville and Alachua units.

[1] Case Number	[2] Gas (therms)	[3] Water (gal)	[4] Gas (therms)	[5] Water (gal)	[6] Difference in gas use (therms)	[7] Reduction in gas use (%)
	May – July 2010		May – July 2011			
Gainesville	*53*	*14,571*	*36*	*14,571*	*17.6*	*33%*
Alachua	*45*	*19,334*	*35*	*18,544*	*10.1*	*19%*
All units	*46.5*	*18,433*	*35*	*17,792*	*11.5*	*21%*

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. The gas savings 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 0) 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%.

One-tailed t-test results of non-normalized energy savings percentage over the study period for all units in the study.

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

Evaluation of the Cost Effectiveness of the Measures

To demonstrate the sensitivity of the cost analysis to the energy consumption estimate, the PVLCC, PVNS, and SIR were calculated for the two bedroom Gainesville units. 0 and 0 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. The annual energy costs are based on utility data. Annual gas costs are $191.31 and $128.06 for the tank type and the tankless water heaters, respectively.

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 actual project costs.

Installation cost estimates for tank type water heaters.

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*

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.

Installation cost estimates for tankless water heaters.

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*

Present value life cycle cost

The summary PVLCC for the tank type and tankless water heaters in the two bedroom Gainesville units are shown in 0. The tank type and the tankless heaters have differing lifespans of 13 and 20 years respectively. The analysis period was for cost analysis was 30 years, and included replacing the tankless unit once and the tank type unit twice. Salvage values for the units were subtracted at the end of the 30 year period to account for the differing unit lifespans. Energy and inflation rates were adjusted according to the indices published by the National Institute of Standards and Technology (Rushing et. al). 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.

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 0. The PVNS for the utility energy consumption estimate is $307.77, and therefore the tankless system is the preferred alternative.

Savings to investment ratio

The SIR of the tankless system is 1.61 for the utility-based energy consumption estimates. The summary of SIR is shown in 0.

Summary PVLCC, PVNS, and SIR for the tank type and tankless water heaters in the Gainesville units.

Economic analysis type	Utility TTWH	TWH
PVLCC ($)	7365.01	7059.01
PVNS ($)	307.77	
SIR	1.61	

Impact of tankless water heater electricity use on cost effectiveness

A gas tankless water heater 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 tankless water heaters. In a study performed for the Okaloosa Gas District of Florida (Exelon Services Federal Group 2002), the tankless system 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 were monitored, including two Rheem models of the type used in this study. Table 6 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.

Natural gas usage, electricity usage, and the electricity to gas usage ratio for a non-condensing Rheem tankless water heater (Bohac et al. 2010).

	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 electricity cost calculation uses the average kWh/therm ratio from the Bohac et al (2010) study. Multiplying the annual utility gas usage estimates in therms by the kWh/therm ratio and the $/kWh electricity charge results in an estimated annual electricity cost of $9.68 per year or about 7.6% of gas cost in this study. The electricity rate is based on utility data for 2011 in Gainesville, where tenants paid an average of $0.101/kWh.

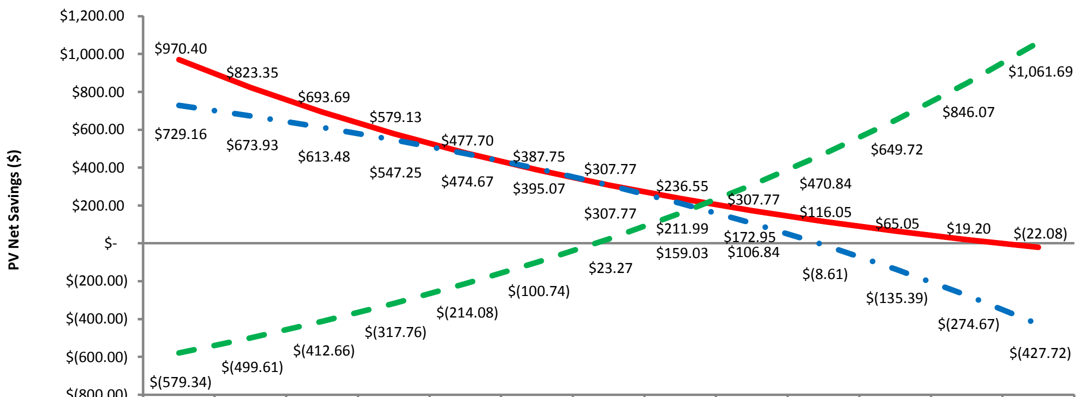
Adding this estimate to the calculated PVLCC, PVNS, and SIR equations increases the PVLCC of the tankless water heater to about equal to the tank type heater, decreases the PVNS to $25.83, and decreases the SIR to 1.05. Including the electricity cost reduces the benefit of the of the tankless water heater.

Impact of fan and controls electricity use on PVLCC, PVNS, and the SIR for the tank type and tankless water heaters in the Gainesville units.

Economic analysis type	Utility TTWH	TWH
PVLCC ($)	7,365.01	7,340.95
PVNS ($)	25.83	
SIR	1.05	

Sensitivity analyses for discount, general inflation, and energy inflation rates

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. 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.



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	$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

Rate (%)

Figure 5. Sensitivity analysis of the discount, general inflation, and energy inflation rates on present value net savings.

Conclusions

Upgrades to energy efficient appliances should be made using a whole cost approach such as life cycle costing. In this study, utility data and project costs were used to analyze the effectiveness of upgrading from tank type to tankless water heaters. The cost effectiveness of upgrading to a tankless water heater was evaluated using PVLCC, PVNS, and SIR, with energy cost estimates derived from utility data. The economic analyses were favorable, but the return was considerably lower when electricity costs for the tankless water heaters were included. 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 methodology described in this paper could also be in the analysis of other energy upgrades.

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