Development and Field Testing of a Hybrid Water Heating and Dehumidification Appliance

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Abstract

A dual-service dehumidifier water heater (WHD) appliance has been researched and developed by Western Carolina University, Asheville-Buncombe Community College, and Sci-Cool Incorporated through a partnership with Oak Ridge National Laboratory (ORNL). Prior research on a similar appliance, a heat pump water heater (HPWH), has demonstrated the unit's increased performance and energy saving, and through collaboration, development of the WHD into a potentially marketable product has yielded favorable field testing results.

The two major types of residential water heaters are direct gas fired (~55%) and electric resistance (~45%) [1]. The maximum efficiency of a standard electric resistance water heater is 1 (100%), and progress has been made to increase the efficiency of the current standard heaters to approximately 95 percent (DOE 2004), which is roughly the maximum available with today's technology. However, if the standard system is replaced by a Heat Pump Water Heater (HPWH), the performance can be increased by 140 percent [2]. The WHD operates as a HPWH while heating water and as a dedicated dehumidifier when water heating is not necessary.

This paper will present the design, laboratory analysis, and field testing results of a WHD. Performance data reveal coefficient of performances (COP) of approximately 2.2 during water heating. Similarly, field testing showed a significant potential energy savings for residential water heating compared to the traditional electric units. With continued soaring energy costs and job losses to overseas markets, opportunities to revive American manufacturing may lie in producing improved energy efficient products such as the WHD.

Introduction

With continued job losses to overseas markets and increased awareness of energy costs, opportunities to revive American manufacturing may lie in producing improved energy efficient products. Prior research sponsored by the Department of Energy (DOE) has resulted in a demonstrated proof of concept for a new hybrid energy saving product. A call for proposals addressing the transfer of energy conservation and efficiency technologies into a workable prototype was issued by the Department of Energy with the ultimate goal to stimulate regional economical development and promote job growth. Resulting from an awarded contract to Western Carolina University, a partnership was formed among Oak Ridge National Laboratory, Western Carolina University, Asheville-Buncombe Technical Community College, and a Sci-Cool, Incorporated to develop a marketable energy efficient hybrid water heating and dehumidifying product. This partnership was made possible by securing funding from the Department of Energy's Office of Energy Efficiency and Renewable Energy through a competitive request for proposals.

Based on previous work of engineers, scientists, and technologists at Oak Ridge National Laboratory, 18 percent of residential energy utilization is consumed by water heating.[1] Laboratory results have shown the efficiency ratings of test units to be approximately 90 percent of the maximum achievable operating efficiency.[2] Further research conducted by the national laboratory suggests that substantial improvement can be made by implementing a heat pump type unit for supplementing a standard electric water heater. The heat pump water heater field tests have demonstrated that the overall energy costs of heating water can be reduced by 50 percent [3]. The project addressed the monitoring, development, and testing needed to prototype a similar product with added dehumidification capability. Thus, the project focused on developing a hybrid Water Heater and Dehumidifier (WHD) product. This project included two major phases. *Phase I* involved product development and laboratory testing. *Phase II* involved product refinement and field testing.

Product Development

Phase I of the project involved the development of a working prototype that demonstrates energy conservation through improved use of efficient technology. WHD units were designed, fabricated and laboratory tested during *Phase I*. A significant potential for reducing energy costs has been demonstrated during *Phase I* with observed reductions near 50 percent when compared to a conventional electric water heater. The basic theory of operation is depicted in Figure 1.

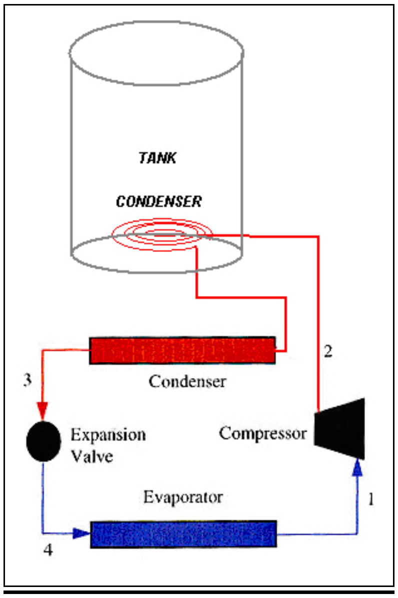
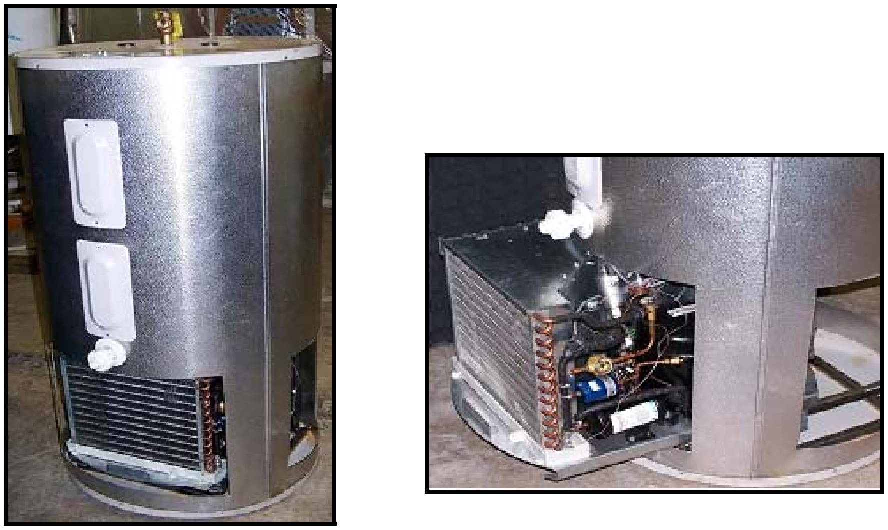


Figure 1: WHD Simplified Operation

The WHD operates on the theoretical vapor-compression refrigeration cycle. Supplemental water heating is provided by heat transfer from the refrigeration unit to stored tank water through the spiral heat exchanger. A high pressure super-heater saturated vapor is produced by the compressor and is discharged to the tank condenser. As the refrigerant passes through the tank condenser/air condenser, the super-heated refrigerant condenses into a sub-cooled saturated liquid. During the condensing phase change, heat is released and transferred to the stored water through thermal conduction. The sub-cooled saturated liquid passes through an expansion device to produce a significant pressure drop and lower temperature. When the refrigerant passes through the evaporator, heat energy is absorbed and the cycle repeats. During the water heating mode, the top electrical element and refrigeration system are activated until water temperature reaches the desired set point. Combined current drawn for the electric element and refrigeration unit is below 23 amps. When the top element deactivates, the refrigeration unit continues to operate. In other words, the conventional lower electric element is replaced by the tank condenser coil and refrigeration cycle during this mode of operation.

When water inside the storage tank reaches the set temperature point and the ambient humidity is above the humidity control set point, the WHD unit switches to dehumidifying mode. During this mode, air passes through the air condenser coil to provide heat rejection into the room environment. Water temperature is maintained to the set point since minimum condensation by the refrigerant occurs within the tank condenser.

As a result of the hybrid WHD unit, a more efficient method of heating water is obtained since “waste heat” from the refrigeration system is used to provide supplemental water heating. A major benefit is also recognized in the form of dehumidification. Near 50 percent savings in electrical power consumption has been observed during laboratory testing when compared to a conventional electric water heater [3]. Image 1 displays prototype A*lpha 1* of *Phase I.*



Evaporator Side Service Drawer

Image 1: *Phase I* Prototype - *Alpha 1*

After proof of concept was established with *Alpha 1* prototype, *Alpha 2* prototype was constructed to refine the design of the WHD and establish a basis for analysis and testing. Image 2 presents the Phase I Alpha 2 prototype. Table 1 presents the product specifications for the Alpha 1 and 2 prototypes.

Table 1: Product Specifications for *Phase I - Alpha 1* and *2* Prototypes

Product	Specification
Water Tank Capacity	47 Gallons (U.S.)
Refrigerant type	R-134 A
Compressor	Hermitically sealed reciprocating
Tank Condenser	Co-axial leak path enhanced copper tubing
Fan	230 v. 3 watt, 300 CFM (nominal)
Electrical service connection	230 v., single phase,60 hz, 30 amp
Plumbing connections	¾ NPT pipe
Noise level	57db (nominal)
Condensate drain	ABS pan, gravity (optional condensate pump)
Dimensions	Diameter: 24 inches Height: 54 inches
Maximum Water Temp	140 Deg

Evaporator Side View

Compressor Side View

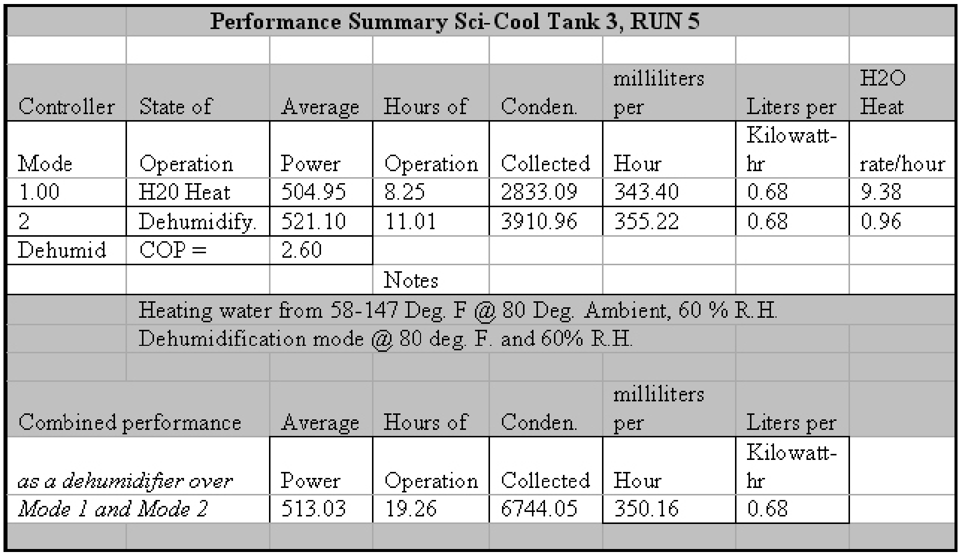
Image 2: *Phase I* Prototype – *Alpha 2*

Phase II goals included design refinement and field testing for the WHD product with funding secured from the Department of Energy through Oak Ridge National Laboratory. Units were re-engineered and refined in an attempt to further enhance performance. A UL review was also conducted during the re-engineering process in order to establish criteria for preparation of launching the product to market. Field tests were conducted at least 8 residential dwellings to evaluate operational performance and were compared to a referenced laboratory model. Each WHD unit was compared to a referenced electric unit at each respective site. Customer Satisfaction surveys were also conducted during the field testing in order to assess acceptance of characteristics and performance. Since this appliance installs and operates in the same manner as an electric water heater, there were no known or foreseen risks that would go beyond those expected with an electric unit. Duration of actual field testing was three months. Similar field tests have been conducted on Heat Pump Water Heaters (HWPH) with no known liability issues [2], [3].

Laboratory Analysis

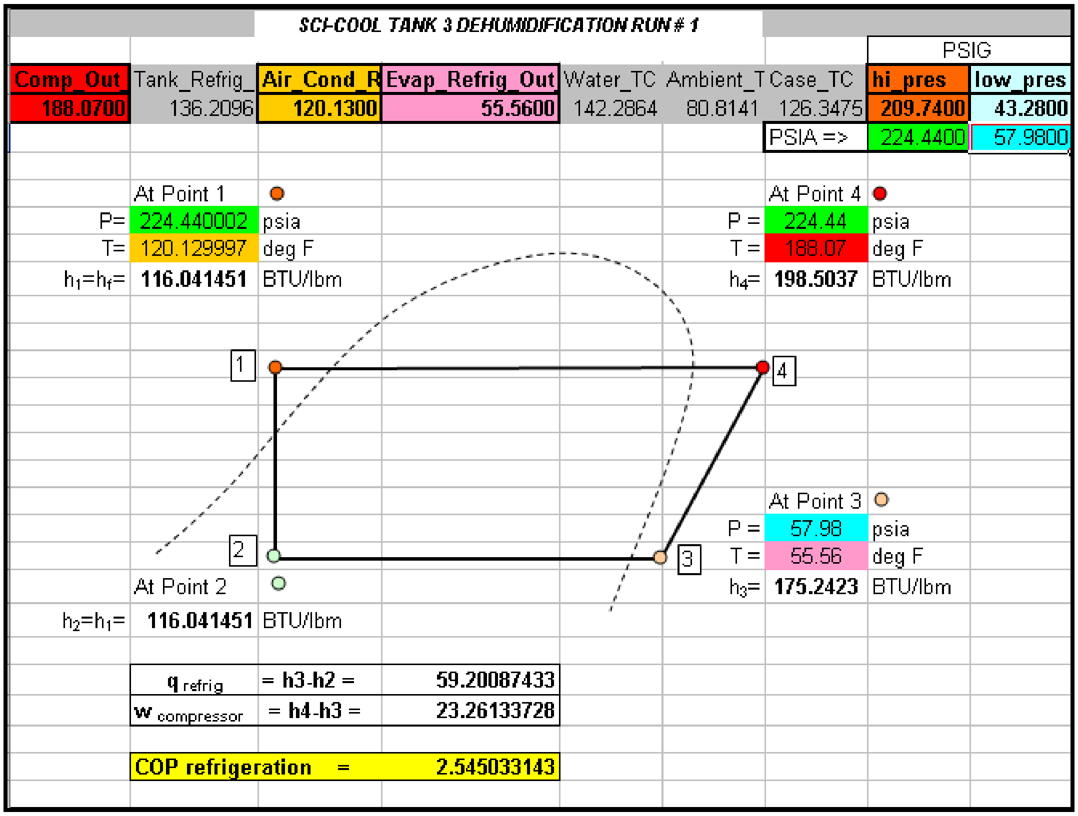
Phase II included production engineering plan development, fabrication, laboratory testing, and field testing of WHD units. The contract specified 6 field test units to be produced with two backup units. The project team installed and tested 8 units in 7 residences in western North Carolina and one at a Habitat for Humanity test site in eastern Tennessee. The purpose of the field tests was to evaluate operational performance and customer satisfaction during household usage. Additionally, laboratory tests were conducted under controlled conditions to compare performance to a standard electric water heater of similar capacity to the WHD laboratory unit. Further testing was conducted to evaluate dehumidification capability of the WHD. Tests conducted included the federal test for water heaters based on the Federal Register Vol. 63 No. 90, Part III, 10 CFR Part 430 standard and dehumidification testing as outlined under Energy Star guidelines (Energy Star Program Requirements for Dehumidifiers, Version 2.0). Table 2 presents a typical performance summary of the Alpha 2 WHD prototype.

Table 2: Typical Performance Summary of the Alpha 2 WHD Prototype



	Performance Summary Sci-Cool Tank 3, RUN 5						
Controller Mode	State of Operation	Average Power	Hours of Operation	Conden. Collected	milliliters per Hour	Liters per Kilowatt-hr	H2O Heat rate/hour
1.00	H20 Heat	504.95	8.25	2833.09	343.40	0.68	9.38
2	Dehumidify.	521.10	11.01	3910.96	355.22	0.68	0.96
Dehumid	COP =	2.60					
			Notes				
	Heating water from 58-147 Deg. F @ 80 Deg. Ambient, 60 % R.H.						
	Dehumidification mode @ 80 deg. F. and 60% R.H.						
Combined performance *as a dehumidifier over*		Average Power	Hours of Operation	Conden. Collected	milliliters per Hour	Liters per Kilowatt-hr	
Mode 1 and Mode 2		513.03	19.26	6744.05	350.16	0.68	

Laboratory test results based on the federal test standards revealed that the first hour rating for the WHD averaged 55 gallons as compared to 52.4 gallons for a standard Electric Water Heater (EWH) of the same volume capacity and tank type. The 24 hour simulated use test results showed an average Energy Factor (EF) of 113.5 % for the WHD and 85.1% for the EWH. Image 3 shows a typical laboratory test analysis output for theWHD prototype



SCI-COOL TANK 3 DEHUMIDIFICATION RUN # 1

							PSIG	
Comp_Out	Tank_Refrig_	**Air_Cond_R**	**Evap_Refrig_Out**	Water_TC	Ambient_T	Case_TC	**hi_pres**	**low_pres**
188.0700	136.2096	**120.1300**	**55.5600**	142.2864	80.8141	126.3475	**209.7400**	**43.2800**
						PSIA =>	224.4400	57.9800

At Point 1 ●
P= 224.440002 psia
T= 120.129997 deg F
$h_1=h_f=$ **116.041451** BTU/lbm

At Point 4 ●
P = 224.44 psia
T = 188.07 deg F
$h_4=$ **198.5037** BTU/lbm

At Point 3 ○
P = 57.98 psia
T = 55.56 deg F
$h_3=$ **175.2423** BTU/lbm

At Point 2 ○
$h_2=h_1=$ **116.041451** BTU/lbm

q_{refrig}	**= h3-h2 =**	**59.20087433**
$w_{compressor}$	**= h4-h3 =**	**23.26133728**

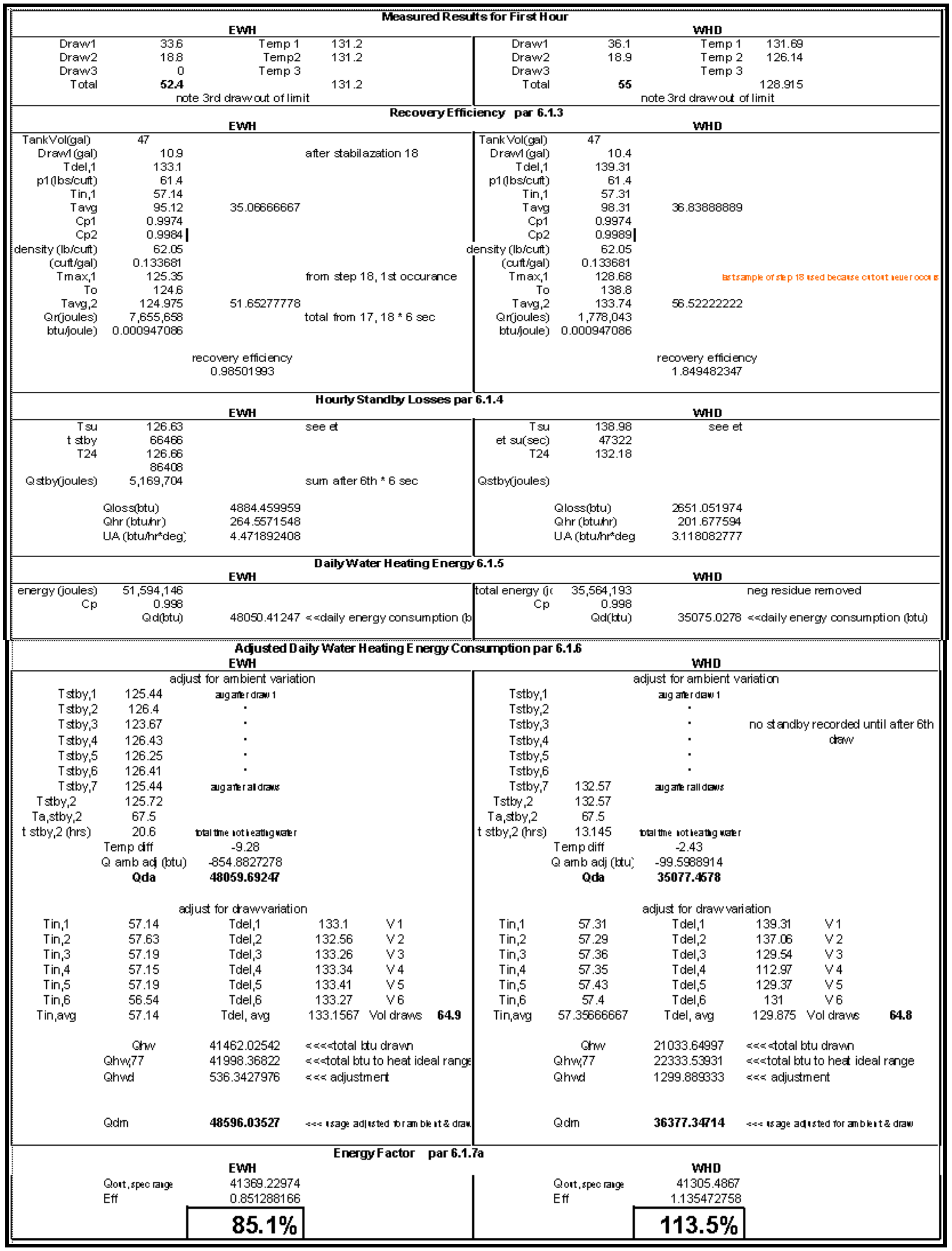
COP refrigeration = 2.545033143

Image 3: Typical Laboratory Test Analysis Output for the WHD Prototype

The WHD dehumidification capability based on laboratory test data did not meet the requirements for Energy Star under the current standard. An average performance of 1.007 Liters per kilowatt-hour (L/kwh) was observed when adhering to the Energy Start standard which requires 1.20 L/kwh to qualify. However, when condensate collected during the water heating mode was also included and considered as “free” the dehumidification factor for the WHD was determined to be 1.5 L/kwh (which will meet Energy Star standards under the current version).

The current Energy Star standard for dehumidifiers does not provide an adequate and true evaluation of the performance of the WHD with respect to dehumidification since no provision is made for considering condensate collected during the water heating mode. An argument can be made that condensate collected during water heating mode is “free” dehumidification since it is simply a by-product of water heating. Further, by including the condensate generated during water heating mode, Energy Star performance standards are within the performance range of the WHD. It is recommended that further efforts be made to solicit a new standard for the WHD unit should full-scale marketing and manufacturing be implemented. Tables 3 and 4 present the results from the federal tests.

Table 3: Results from Federal Tests (First Hour and 24 Hour Simulated Use)



Measured Results for First Hour

EWH				WHD			
Draw1	33.6	Temp 1	131.2	Draw1	36.1	Temp 1	131.69
Draw2	18.8	Temp2	131.2	Draw2	18.9	Temp 2	126.14
Draw3	0	Temp 3		Draw3		Temp 3	
Total	**52.4**		131.2	Total	**55**		128.915
	note 3rd draw out of limit				note 3rd draw out of limit		

Recovery Efficiency par 6.1.3

EWH				WHD			
TankVol(gal)	47			TankVol(gal)	47		
Drawl (gal)	10.9		after stabilazation 18	Drawl (gal)	10.4		
Tdel,1	133.1			Tdel,1	139.31		
p1(lbs/cuft)	61.4			p1(lbs/cuft)	61.4		
Tin,1	57.14			Tin,1	57.31		
Tavg	95.12	35.06666667		Tavg	98.31	36.83888889	
Cp1	0.9974			Cp1	0.9974		
Cp2	0.9984			Cp2	0.9989		
density (lb/cuft)	62.05			density (lb/cuft)	62.05		
(cuft/gal)	0.133681			(cuft/gal)	0.133681		
Tmax,1	125.35		from step 18, 1st occurance	Tmax,1	128.68		lastsample of step 18 used because cutout never occurs
To	124.6			To	138.8		
Tavg,2	124.975	51.65277778		Tavg,2	133.74	56.52222222	
Qr(joules)	7,655,658		total from 17, 18 * 6 sec	Qr(joules)	1,778,043		
btu/joule)	0.000947086			btu/joule)	0.000947086		
		recovery efficiency				recovery efficiency	
		0.98501993				1.849482347	

Hourly Standby Losses par 6.1.4

EWH				WHD			
Tsu	126.63		see et	Tsu	138.98	see et	
t stby	66466			et su(sec)	47322		
T24	126.66			T24	132.18		
	86408						
Qstby(joules)	5,169,704		sum after 6th * 6 sec	Qstby(joules)			
	Qloss(btu)	4884.459959			Qloss(btu)	2651.051974	
	Qhr (btu/hr)	264.5571548			Qhr (btu/hr)	201.677594	
	UA (btu/hr*deg)	4.471892408			UA (btu/hr*deg	3.118082777	

Daily Water Heating Energy 6.1.5

EWH				WHD			
energy (joules)	51,594,146			total energy (j	35,564,193		neg residue removed
Cp	0.998			Cp	0.998		
	Qd(btu)	48050.41247	<<daily energy consumption (b		Qd(btu)	35075.0278	<<daily energy consumption (btu)

Adjusted Daily Water Heating Energy Consumption par 6.1.6

EWH				WHD			
adjust for ambient variation				adjust for ambient variation			
Tstby,1	125.44	avg after draw 1		Tstby,1		avg after draw 1	
Tstby,2	126.4	·		Tstby,2		·	
Tstby,3	123.67	·		Tstby,3		·	no standby recorded until after 6th draw
Tstby,4	126.43	·		Tstby,4		·	
Tstby,5	126.25	·		Tstby,5		·	
Tstby,6	126.41	·		Tstby,6		·	
Tstby,7	125.44	avg after all draws		Tstby,7	132.57	avg after all draws	
Tstby,2	125.72			Tstby,2	132.57		
Ta,stby,2	67.5			Ta,stby,2	67.5		
t stby,2 (hrs)	20.6	total time not heating water		t stby,2 (hrs)	13.145	total time not heating water	
	Temp diff	-9.28			Temp diff	-2.43	
	Q amb adj (btu)	-854.8827278			Q amb adj (btu)	-99.5988914	
	Qda	**48059.69247**			**Qda**	**35077.4578**	

EWH						WHD					
adjust for draw variation						adjust for draw variation					
Tin,1	57.14	Tdel,1	133.1	V 1		Tin,1	57.31	Tdel,1	139.31	V 1	
Tin,2	57.63	Tdel,2	132.56	V 2		Tin,2	57.29	Tdel,2	137.06	V 2	
Tin,3	57.19	Tdel,3	133.26	V 3		Tin,3	57.36	Tdel,3	129.54	V 3	
Tin,4	57.15	Tdel,4	133.34	V 4		Tin,4	57.35	Tdel,4	112.97	V 4	
Tin,5	57.19	Tdel,5	133.41	V 5		Tin,5	57.43	Tdel,5	129.37	V 5	
Tin,6	56.54	Tdel,6	133.27	V 6		Tin,6	57.4	Tdel,6	131	V 6	
Tin,avg	57.14	Tdel, avg	133.1567	Vol draws	**64.9**	Tin,avg	57.35666667	Tdel, avg	129.875	Vol draws	**64.8**

EWH			WHD		
Qhw	41462.02542	<<<<total btu drawn	Qhw	21033.64997	<<<<total btu drawn
Qhw,77	41998.36822	<<<total btu to heat ideal range	Qhw,77	22333.53931	<<<total btu to heat ideal range
Qhwd	536.3427976	<<< adjustment	Qhwd	1299.889333	<<< adjustment
Qdm	**48596.03527**	<<< usage adjusted for ambient & draw	Qdm	**36377.34714**	<<< usage adjusted for ambient & draw

Energy Factor par 6.1.7a

EWH		WHD	
Qout,spec range	41369.22974	Qout,spec range	41305.4867
Eff	0.851288166	Eff	1.135472758
	85.1%		**113.5%**

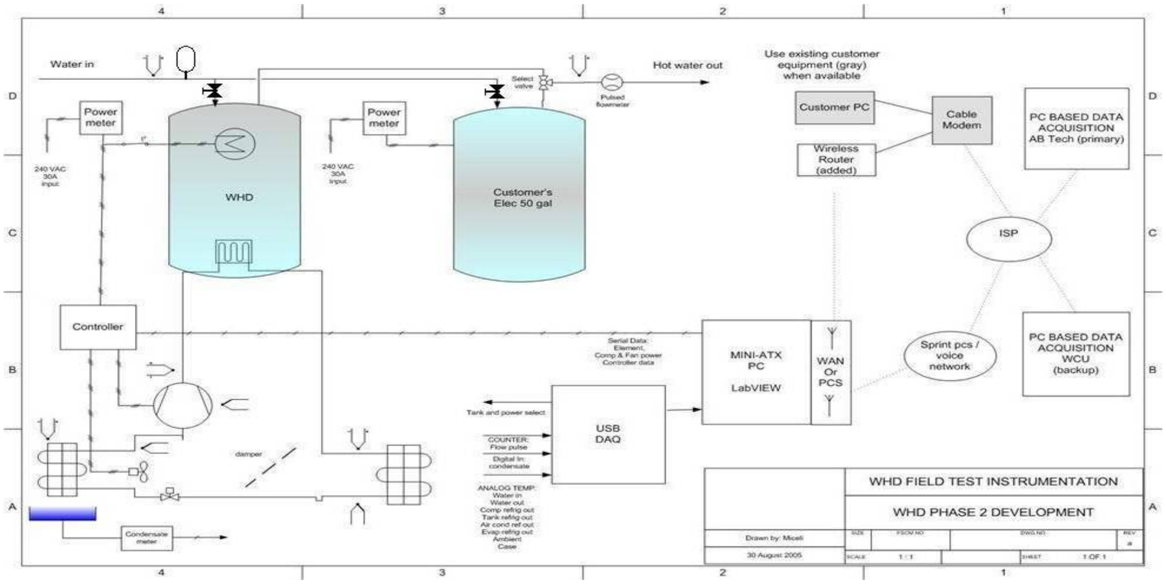
Pro/Engineer 3D Solid Model of WHD

Phase II Field Test WHD Unit

Image 4: Pro/Engineer Model of WHD and Phase II WHD Field Test Unit

Field Testing Results

Data was gathered from 7 field test sites for both WHD and EWH field units. Side by side comparisons were made based on water heating rates with respect to kilowatt hours per gallon across field test sites. Methods used for data collection followed a similar model developed by AIL Research, Russell Johnson, and the Northeast Utilities Commission for field testing of Heat Pump Water Heaters [7]. A typical field test site configuration and installation is shown in Figure 2 and Image 5.



Figures 2: Field Test Plan and Layout

Image 5: Typical Field Test Layout

In order to more accurately track the status of each site, a field test site tracking calendar was developed. Each site was monitored continuous, and data was logged each hour with a sample frequency each minute. However, in some cases communication problems occurred and the site in question marked as being "off-line". Incomplete daily files were not included in the field test daily summaries and analysis.

Due to the sampling period and number of field test sites, a large quantity of data files was generated. Over 8,000 files were logged during the field test period. Further, each file for each site was checked to determine which unit was operating during the day and hour. If the WHD unit was in operation, the actual controller data must be extracted and evaluated for operation during water heating (Mode 1), dehumidification (Mode 2), or standby (Mode 0). In order to make the task manageable, a procedure was developed to merge hourly files into single daily files and compile one summary file for each site. Site summary files by day were generated for both the WHD operation and EWH operation. Formulas were developed and placed into a master file that was copied to the last row of merged data. Averages for water temperatures, ambient temperature, relative humidity, demand, power, condensate, and controller data (for WHD units) were calculated. Further, the controller data were extracted to numerical data to determine the mode of operation (Mode1 = water heating, Mode 2 = dehumidification, and Mode 0 = standby). Summary calculations were made to determine overall daily average power, daily power during water heating, and daily demand in gallons. Similarly, appropriate data were collected to evaluate dehumidification performance with respect to condensate produced relative to power requirements. Ambient temperature, relative humidity, condensate and power were tabulated in order to determine the liters per kilowatt-hour factor during Mode 2 (dehumidification mode) of the WHD. An adjusted l/kwh ratio was also calculated to include condensate collected during water heating (Mode 1).

From the intermediate calculations during water heating, the power rate per day for hot water produced was determined. Regression equations were also developed across each site for both the WHD and EWH units with respect to daily demand (gallons) and power (kilowatt-hours per day). Summaries of regression analysis results are presented in Image 6.

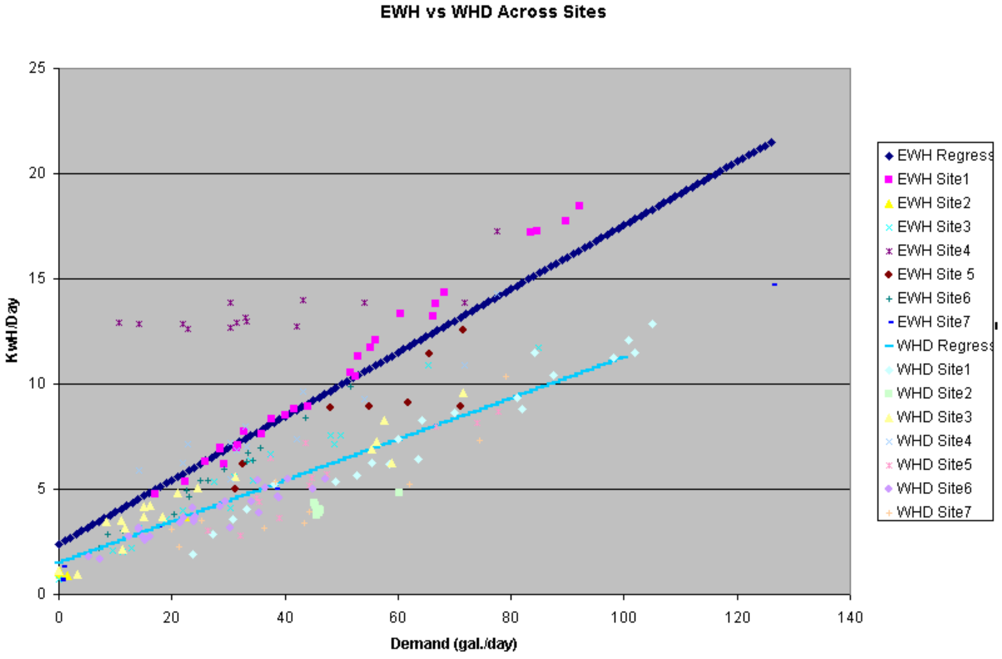


Image 6: Summaries of Regression Analysis

Due to incomplete data, data for site 8 was not included in the regression run. For sites one through seven, regression analysis yielded the following equation for the EWH units:

$$Y = .15141\ X + 2.40379$$

Likewise, a regression analysis was conducted for the WHD field units and yielded the following:

$$Y = .09774\ X + 1.4866.$$

Further analysis showed site 4 as being different from the other WHD field units, and a third regression analysis was conducted with site 4 removed. The resulting equation was determined as follows:

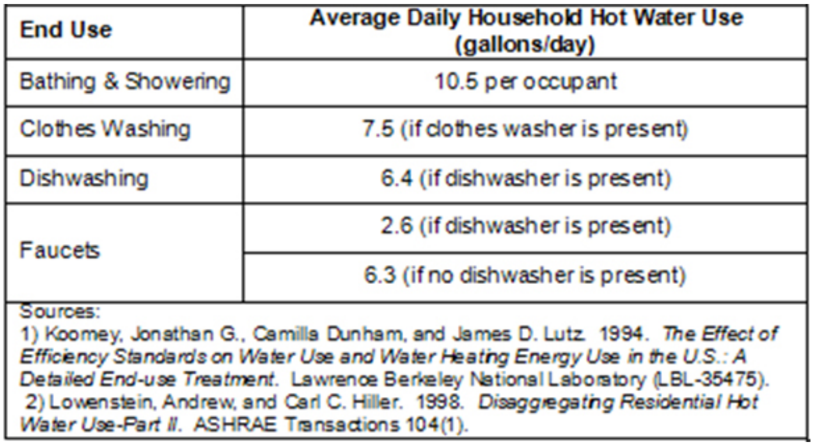
$$Y = .0978 + 1.1078.$$

However, site 4 was included in the composite comparison analysis.

The plotted regression equations and field test data show that the WHD units consistently performed better with respect to the EWH units with respect to daily demand and power requirement. As demand levels rise, the difference between the EWH and WHD is reflected by observing the diverging regression lines. Simple stated, the greater the demand, more energy savings can be recognized when the WHD unit is operating. Assuming national average demands for a family of four at nearly 60 gallons per day, the potential difference in kwh/day is approximately 4.5.

Further analyses were conducted to compare composite field test results to a control reference unit. The reference unit had previously served as a laboratory unit. The reference unit WHD had insulated refrigeration lines and better seals for the damper control system. Performance analyses were conducted to compare the performance of the field test units to the control unit for both WHD and EWH operation. Annual operating cost estimates were also derived using an assumed utility rate in dollars per kilowatt-hour. The multiplier factor used for the analysis was .091 (the approximate current rate in effect by Progress Energy). National demand data for household hot water consumption were also used for evaluating specific household costs. Tables 4 and 5 present the referenced national data for hot water consumption and a sample hot water consumption calculation.

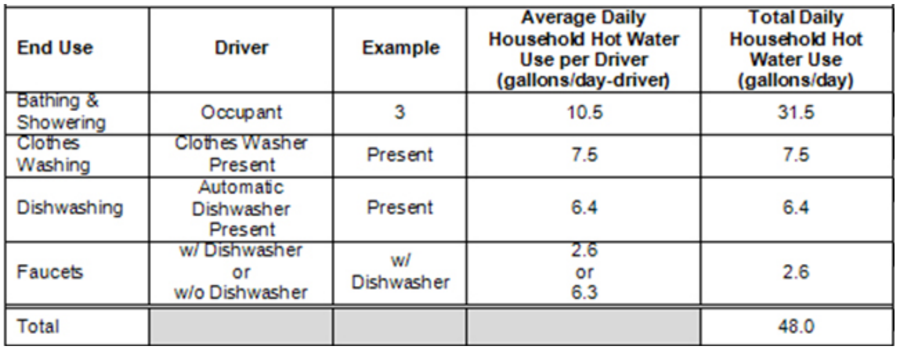
Table 4: National Data for Hot Water Consumption



End Use	**Average Daily Household Hot Water Use (gallons/day)**
Bathing & Showering	10.5 per occupant
Clothes Washing	7.5 (if clothes washer is present)
Dishwashing	6.4 (if dishwasher is present)
Faucets	2.6 (if dishwasher is present)
	6.3 (if no dishwasher is present)

Sources:
1) Koomey, Jonathan G., Camilla Dunham, and James D. Lutz. 1994. *The Effect of Efficiency Standards on Water Use and Water Heating Energy Use in the U.S.: A Detailed End-use Treatment.* Lawrence Berkeley National Laboratory (LBL-35475).
2) Lowenstein, Andrew, and Carl C. Hiller. 1998. *Disaggregating Residential Hot Water Use-Part II.* ASHRAE Transactions 104(1).

Table 5: Sample Hot Water Consumption Calculation



End Use	**Driver**	**Example**	**Average Daily Household Hot Water Use per Driver (gallons/day-driver)**	**Total Daily Household Hot Water Use (gallons/day)**
Bathing & Showering	Occupant	3	10.5	31.5
Clothes Washing	Clothes Washer Present	Present	7.5	7.5
Dishwashing	Automatic Dishwasher Present	Present	6.4	6.4
Faucets	w/ Dishwasher or w/o Dishwasher	w/ Dishwasher	2.6 or 6.3	2.6
Total				48.0

As shown, typical daily water consumption for the average household with modern conveniences are approximately 48.0 gal/day. Performance of WHD units was based on national hot water demands for determining annual cost and savings. By comparing the kwh/gallon ratio of EWH to WHD, a Relative Rate of Performance factor (RROP) was calculated for field test sites and the control site. Results of these calculations are provided in Image 7, and relevant regression analysis results are provided in Table 6.

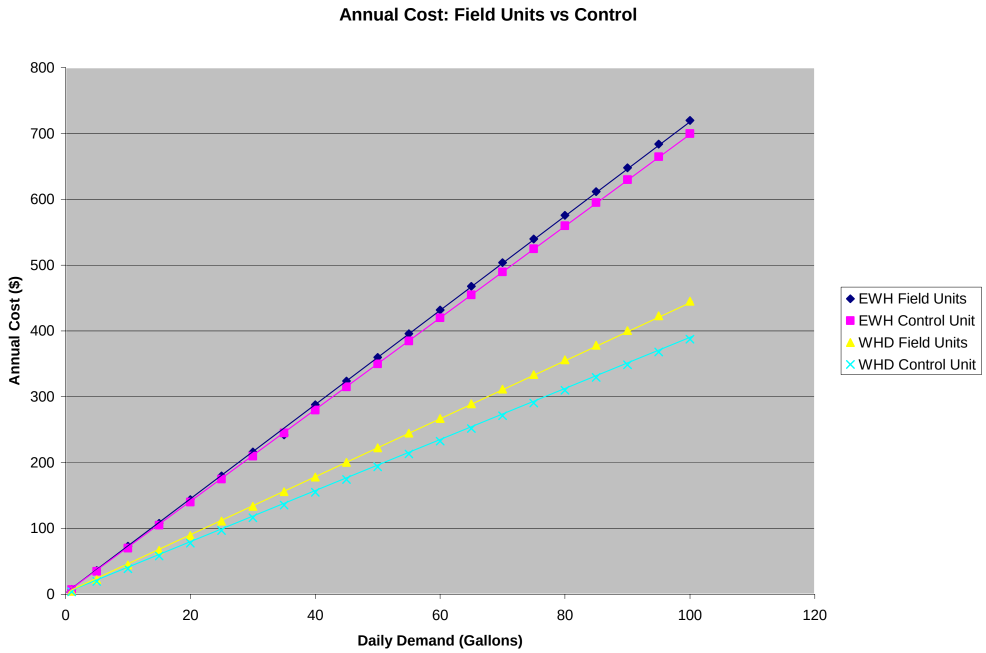
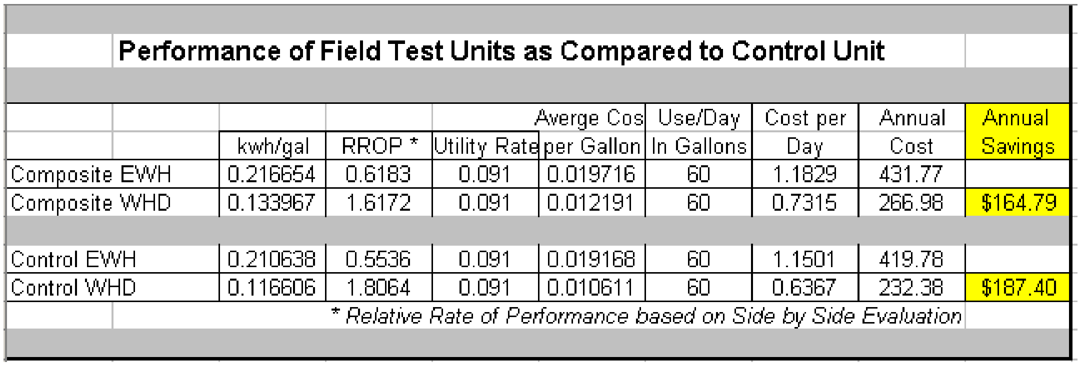


Image 7: EWH vs. WHD across Field Test Sites and WHD Control Unit

Table 6: Summary of all Data Sites

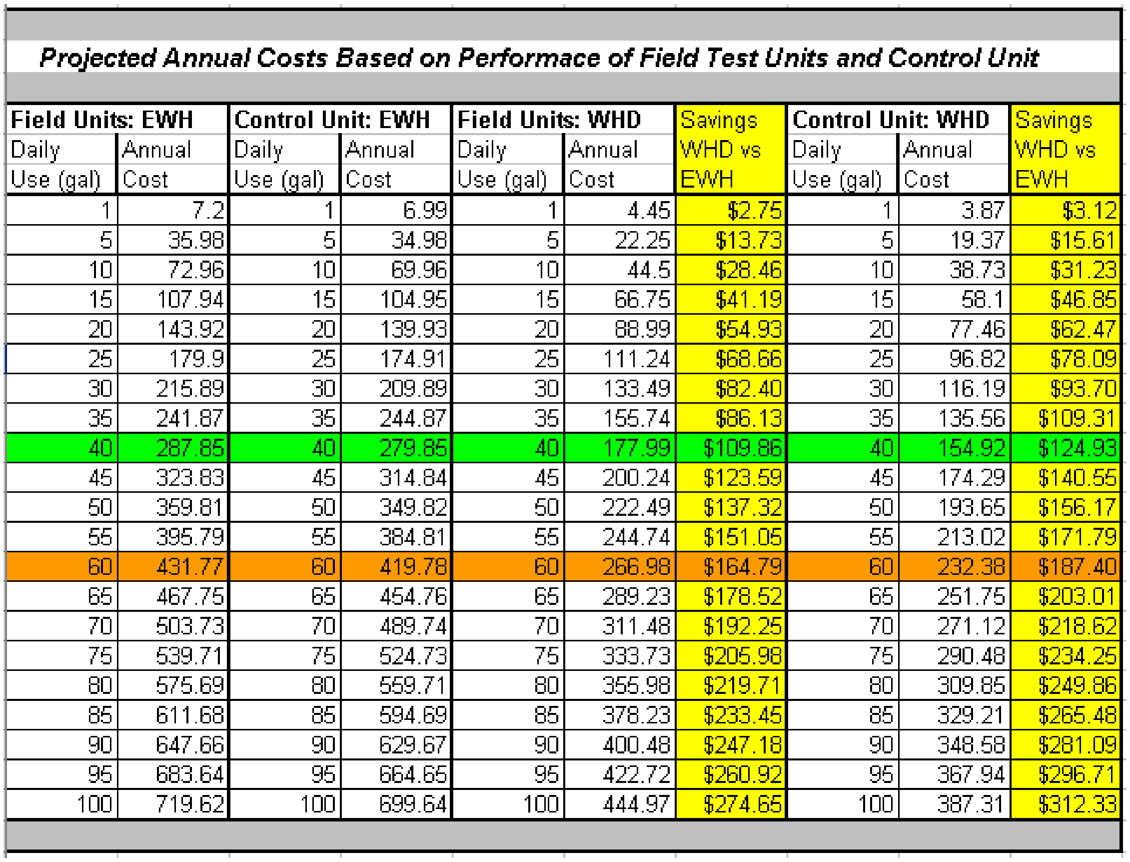


	Performance of Field Test Units as Compared to Control Unit							
	kwh/gal	RROP *	Utility Rate	Averge Cos per Gallon	Use/Day In Gallons	Cost per Day	Annual Cost	Annual Savings
Composite EWH	0.216654	0.6183	0.091	0.019716	60	1.1829	431.77	
Composite WHD	0.133967	1.6172	0.091	0.012191	60	0.7315	266.98	$164.79
Control EWH	0.210638	0.5536	0.091	0.019168	60	1.1501	419.78	
Control WHD	0.116606	1.8064	0.091	0.010611	60	0.6367	232.38	$187.40

* Relative Rate of Performance based on Side by Side Evaluation

As evidenced by the regression models, greater savings would occur with higher demands. These savings were quantified based on the values shown in the chart above across a range of daily demands. A table showing the potential savings based on field test data and the control unit is shown in Table 7.

Table 7: Potential Annual Savings WHD and Control Unit



Projected Annual Costs Based on Performace of Field Test Units and Control Unit

Field Units: EWH		**Control Unit: EWH**		**Field Units: WHD**		Savings WHD vs EWH	**Control Unit: WHD**		Savings WHD vs EWH
Daily Use (gal)	Annual Cost	Daily Use (gal)	Annual Cost	Daily Use (gal)	Annual Cost		Daily Use (gal)	Annual Cost	
1	7.2	1	6.99	1	4.45	$2.75	1	3.87	$3.12
5	35.98	5	34.98	5	22.25	$13.73	5	19.37	$15.61
10	72.96	10	69.96	10	44.5	$28.46	10	38.73	$31.23
15	107.94	15	104.95	15	66.75	$41.19	15	58.1	$46.85
20	143.92	20	139.93	20	88.99	$54.93	20	77.46	$62.47
25	179.9	25	174.91	25	111.24	$68.66	25	96.82	$78.09
30	215.89	30	209.89	30	133.49	$82.40	30	116.19	$93.70
35	241.87	35	244.87	35	155.74	$86.13	35	135.56	$109.31
40	287.85	40	279.85	40	177.99	$109.86	40	154.92	$124.93
45	323.83	45	314.84	45	200.24	$123.59	45	174.29	$140.55
50	359.81	50	349.82	50	222.49	$137.32	50	193.65	$156.17
55	395.79	55	384.81	55	244.74	$151.05	55	213.02	$171.79
60	431.77	60	419.78	60	266.98	$164.79	60	232.38	$187.40
65	467.75	65	454.76	65	289.23	$178.52	65	251.75	$203.01
70	503.73	70	489.74	70	311.48	$192.25	70	271.12	$218.62
75	539.71	75	524.73	75	333.73	$205.98	75	290.48	$234.25
80	575.69	80	559.71	80	355.98	$219.71	80	309.85	$249.86
85	611.68	85	594.69	85	378.23	$233.45	85	329.21	$265.48
90	647.66	90	629.67	90	400.48	$247.18	90	348.58	$281.09
95	683.64	95	664.65	95	422.72	$260.92	95	367.94	$296.71
100	719.62	100	699.64	100	444.97	$274.65	100	387.31	$312.33

Dehumidification performance was also evaluated across the field test sites and compared to the control unit. It should be noted that the projected savings only reflect water heating, and dehumidification was not included in these calculations. The dehumidification performance data is not a valid measure based on Energy Star guidelines since wide variation was observed with respect to both temperature and humidity. The Energy Star standard required a controlled level of humidity at 60% and temperature at 80 degrees F. These conditions can only be met in laboratory chamber testing. Therefore, the data was only reviewed for general relative performance and to compare against the control unit (Site 1).

The performance factor was calculated while the WHD units were operating in MODE 2 (dehumidification). However, condensate collected while units were operating in MODE 1 (water heating) was not considered. Therefore, an adjusted performance factor (l/kwh) was calculated considering the volume of condensate as “free” since it was collected while heating water. The control unit (Site 1) performed better than did other field test units, and can most likely be explained by the insulated refrigeration lines and better damper seals. Field test dehumidification results are presented in Table 8.

Table 8: Field Test Dehumidification Results

Site No.	Average R.H.	Average Ambient Temperature	L/Kwh in mode 2	Adjusted Liters per KWH
1*	57.31	68.43	0.84	1.13
2	52.25	73.07	0.37	0.41
3	59.91	79.60	0.48	0.55
4	68.69	74.02	0.34	0.42
5	51.31	76.51	0.41	0.65
6	54.85	78.16	0.55	0.66
7	62.23	77.40	0.58	0.83
* Control Site				

Feedback data from survey participants were obtained through a survey instrument. Based on responses from homeowners participating in the field tests, a high degree of satisfaction was reported with respect to the dehumidification and water heating capability of the WHD. Homeowners also indicated a willingness to pay for this performance in the range of $500 to $1100. Some interest was also expressed in regard to added features to the product such as enhanced air filtration, electrostatic air cleaning, and ducting to supplement existing HVAC utilities.

Conclusions

In the current energy crises this product potential is great. Rising energy cost and green technology heightened awareness. As energy cost continue to rise, the WHD product will become more viable as an alternative to current available technologies. Further research will include side-by side tests against on-demand hot water units.

The WHD project has helped to build stronger ties with industry, better community relations, and stronger relationships with government agencies. Both educational institutions look forward to future engagement projects so they may continue to serve the local community, students, and industry. Partnerships among government agencies (ORNL), regional industry, and regional educational institutions offer an excellent opportunity for advancing professional development, enhancing student learning, and promoting economic development. The foundation for potential for economic development in western North Carolina has been demonstrated through collaboration with Sci-Cool, Incorporated and coordinated by ORNL. The WHD unit has demonstrated acceptable performance during field testing both as a water heating appliance and a dehumidifier. The manufacturer must make the ultimate decision as to the economic risk and profitability potential associated with the WHD.

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