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Dampers for Natural Draft Water Heaters: Technical Report

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Environmental Energy Technologies Division

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Preface

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Dampers for Natural Draft Water Heaters: Technical Report is a technical report for the Water Heating and Hot Water Usage in California Homes project (contract number 500-06-036,) conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to PIER's Buildings End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

Energy required for water heating accounts for approximately 40% of national residential natural gas consumption in California. With water heating contributing such a substantial portion of natural gas consumption, it is important to pay attention to water heater efficiencies.

This paper reports on an investigation of a patented, buoyancy-operated flue damper. It is an add-on design to a standard atmospherically vented natural-draft gas-fired storage water heater. The flue damper was expected to reduce off-cycle standby losses, which would lead to improvements in the efficiency of the water heater.

The test results showed that the Energy Factor of the baseline water heater was 0.576. The recovery efficiency was 0.768. The standby heat loss coefficient was 10.619 (BTU/hr-°F). After the damper was installed, the test results show an Energy Factor for the baseline water heater of 0.605. The recovery efficiency was 0.786. The standby heat loss coefficient was 9.135 (BTU/hr-°F). The recovery efficiency increased 2.3% and the standby heat loss coefficient decreased 14%.

When the burner was on, the baseline water heater caused 28.0 CFM of air to flow from the room. During standby, the flow was 12.4 CFM. The addition of the damper reduced the flow when the burner was on to 23.5 CFM. During standby, flow with the damper was reduced to 11.1 CFM.

The flue damper reduced off-cycle standby losses, and improved the efficiency of the water heater. The flue damper also improved the recovery efficiency of the water heater by restricting on-cycle air flows through the flue.

With or without the flue damper, off-cycle air flow up the stack is nearly half the air flow rate as when the burner is firing.

Keywords: water heater, gas-fired storage water heater, flue damper, recovery efficiency, energy factor, standby heat loss

Executive Summary

- Introduction

Energy required for water heating accounts for approximately 40% of national residential natural gas consumption in California. With water heating contributing such a substantial portion of natural gas consumption, it is important to pay attention to water heater efficiencies.

Efficiency improvements to baseline gas storage water heaters over the past two decades have been relatively minor. Currently, the gas storage water heater market is dominated by natural-draft units with an Energy Factor (EF) of 0.59. An EF of .59 means that over 40% of the gas energy input is not converted to heat in the hot water output.

Typical storage gas water heaters have a flue for combustion exhaust located along the center of the storage tank. The losses up the flue while in standby mode account for about 43% of heat losses.

- Purpose

This paper reports on an investigation of a patented, buoyancy-operated flue damper. It is an add-on design to a standard atmospherically vented natural-draft gas-fired storage water heater. The flue damper was expected to reduce off-cycle standby losses, which would lead to improvements in the efficiency of the water heater.

- Task Approach

The Department of Energy's 24 hour simulated use efficiency test was used to determine the energy factor of an off-the-shelf storage gas water heater. The flue damper was installed on the water heater and it was tested for efficiency. The 24 hour simulated use test was conducted three times before and after the flue damper was installed.

In addition to the impact of the flue damper on efficiency, we also determined the impact of the flue damper on air flow through the flue and the stack.

- Task Outcomes

The test results showed that the EF of the baseline water heater was 0.576. The recovery efficiency was 0.768. The standby heat loss coefficient was 10.619 (BTU/hr-°F). After the damper was installed, the test results show an EF for the baseline water heater of 0.605. The recovery efficiency was 0.786. The standby heat loss coefficient was 9.135 (BTU/hr-°F). The recovery efficiency increased 2.3% and the standby heat loss coefficient decreased 14%.

When the burner was on, the baseline water heater caused 28.0 CFM of air to flow from the room. During standby, the flow was 12.4 CFM. The addition of the damper reduced the flow when the burner was on to 23.5 CFM. During standby, flow with the damper was reduced to 11.1 CFM.

- Conclusions

The flue damper reduced off-cycle standby losses, and improved the energy factor of the water heater by .03 (from 0.576 to 0.605). The flue damper also improved the recovery efficiency of the

water heater 2.3% (from 0.768 to 0.786) by restricting on-cycle air flows through the flue. The efficiency improvement, while not as large as expected, is still significant.

With or without the flue damper, off-cycle air flow up the stack is nearly half the air flow rate as when the burner is firing.

- Recommendations

The test procedure calculations should depend on the recovery efficiency from all draws during the test. Calculating the recovery efficiency from the first draw and firing exaggerates the efficiency of the water heater.

Because of the impact stack air flow has on total house infiltration rates, this should be considered, especially in colder climates.

- Benefits to California

This flue damper for gas-fired storage water heaters did increase the efficiency of the water heater by 5%. Significant benefits would accrue to California from the deployment of increased efficiency water heaters. If this technology could be developed as a low-cost retrofit, considerable energy savings would be available for California residents.

1.0 Introduction

Energy required for water heating accounts for approximately 25% of national residential natural gas consumption. In California, because nearly all water heaters are gas-fired, that figure is closer to 40%. (California Energy Commission 2008) With water heating contributing such a substantial portion of natural gas consumption, it is important to pay attention to water heater efficiencies.

Efficiency improvements to baseline gas storage water heaters over the past two decades have been relatively minor. Currently, the gas storage water heater market is dominated by natural-draft units with an Energy Factor (EF) of 0.59. EF is a measure of efficiency according to the federal test procedure based on a 24 hour simulated use test. (U.S. Department of Energy 1998) This is the minimum efficiency allowed by federal standards for the typical 40 gallons gas storage water heater. (U.S. Department Of Energy 2001) An EF of .59 means that over 40% of the gas energy input is not converted to heat in the hot water output.

Typical storage gas water heaters have a flue for combustion exhaust located along the center of the storage tank. When the burner is firing, the combustion products are exhausted through the flue and vented out of the house through a chimney stack. When the burner is inactive, ambient air flows through the flue. The cooler air in the flue absorbs heat from the hot water in the storage tank and rises out of the flue. In many these water heaters, the pilot is still on and uses energy. However, even if the pilot were shut off, ambient air would rise out of the flue and remove heat from the water heater. More ambient air is drawn in through openings at the base of the heater. Consequently, fuel must be spent to maintain a store of hot water to keep up with these standby losses. The flue losses while in standby mode account for about 43% of heat losses. (Biermayer and Lutz 2006) In typical storage water heaters, the standing pilot makes up a significant part of these losses.

Figure 1 is a schematic of a typical gas-fired storage water heater. It shows the major components of a water heater. Several designs have been developed to reduce off-cycle standby losses caused by air flow through the flue. (Paul, Sheppard et al. 1991) This current work, to develop and evaluate three promising, alternative storage-type gas water heater technical concepts that reduce standby losses and thereby improve seasonal efficiency, represents the first element in a five-element multi-year State Technologies Advancement Collaborative (STAC) project titled "Reducing the Waste: Improved Fossil Water Heating Systems".

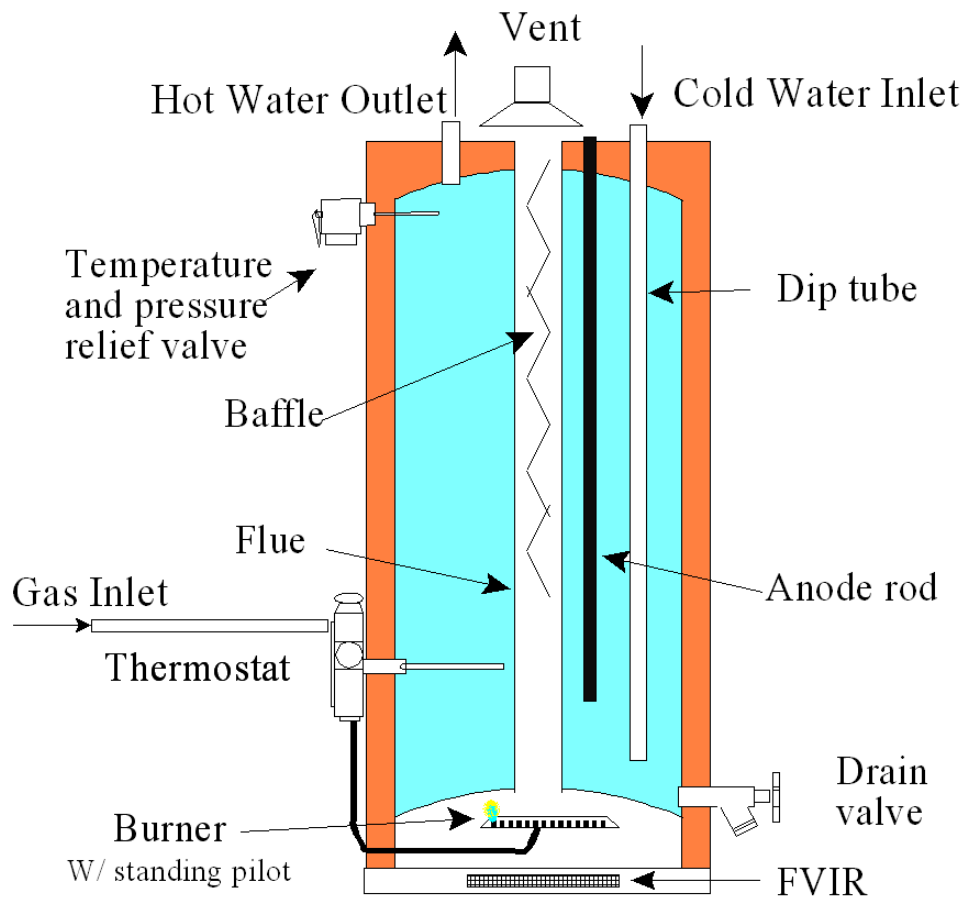


Figure 1: Diagram of Typical Gas-Fired Storage Water Heater

This paper reports on an investigation of a patented, buoyancy-operated flue damper.(Schimmeyer 2005) It is an add-on design to a standard atmospherically vented natural-draft gas-fired storage water heater. The flue damper was expected to reduce off-cycle standby losses, which would lead to improvements in the efficiency of the water heater.

The flue damper is installed at the top of the water heater flue, below the draft hood. It consists of two light-weight metal flaps. Each flap is balanced to pivot on a bar that extends across the flue. The damper is positioned in a cylindrical ceramic insulating material that surrounds the top of the flue. When the burner fires the flaps are pushed open by the buoyancy of the combustion gases rising through the flue. When the burner turns off, and only the pilot light remains lit, the flaps settle back into a nearly closed position. The damper closes almost all the way but the pilot light creates enough buoyancy to keep the damper slightly open. There is also a gap across the flue damper, between where the flaps pivot, that allows a small amount of combustion air from the pilot flame to exit the flue. Figure 2 is a photograph of the flue damper in the open position when the burner is operating.

The flue damper improves the efficiency of the water heater by reducing off-cycle standby losses. The design would be simple to manufacture and does not contain a large number of parts. Retail price of these flue dampers could be as low as \$20.

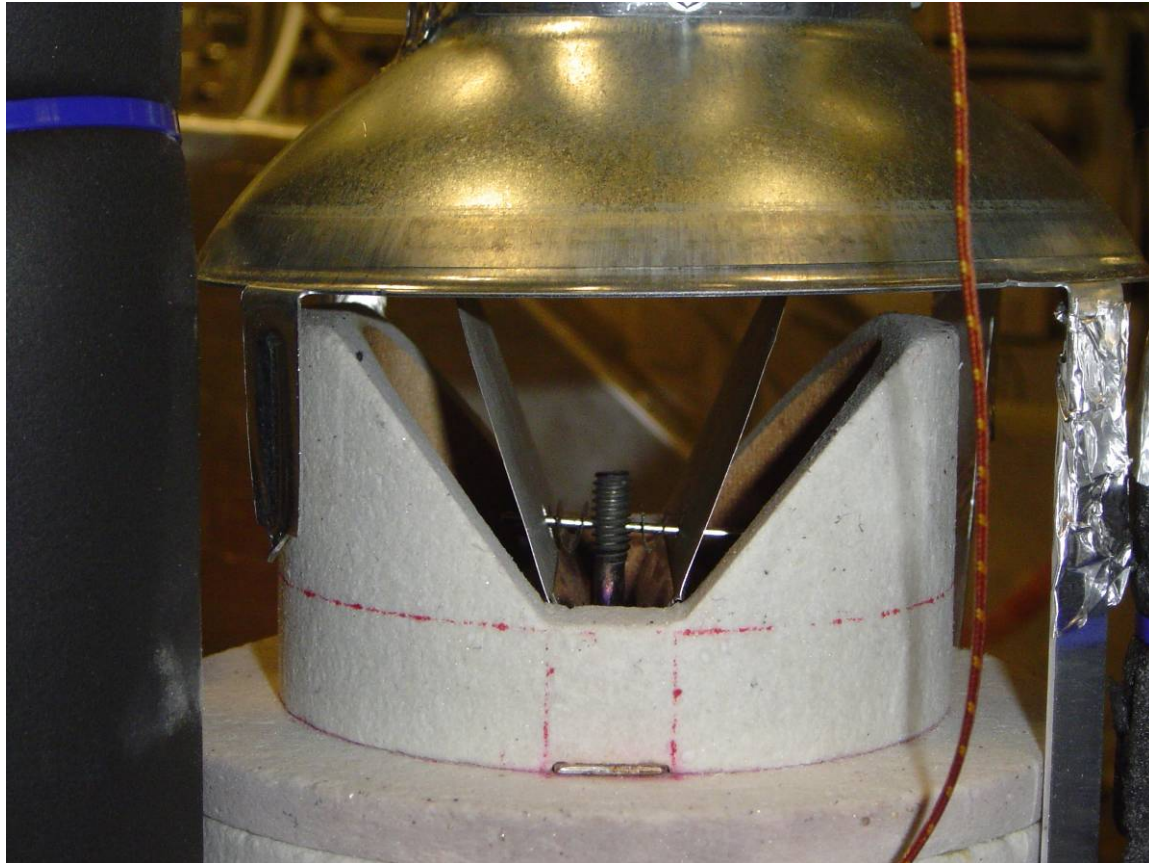


Figure 2: Buoyancy Operated Flue Damper in Open Position

2.0 Task Approach

To assess the impact of the flue damper this study compared the efficiency of a base case water heater before and after the addition of the flue damper. The Department of Energy's 24 hour simulated use efficiency test was used to determine the energy factor of an off-the-shelf storage gas water heater.(U.S. Department of Energy 1998) The flue damper was installed on the water heater and the water heater was tested again for efficiency. The 24 hour simulated use test was conducted three times before and after the flue damper was installed.

In addition to the impact of the flue damper on efficiency, we also determined the impact of the flue damper on air flow through the flue and the stack. The air flow through the flue was measured at the top of the flue. The flue gas consists of the combustion products and the excess air that was pulled into the combustion chamber. These gases pass through the water heater flue before mixing with ambient air at the draft hood and continuing to exit from the room

through the stack. The air flow through the stack consists of the flue gases and dilution air pulled in at the draft hood.

By measuring air flow and heat losses through the flue, we can directly assess the effectiveness of the flue damper to reduce the losses through the flue, especially while the water heater is in standby mode.

Air flow through the stack is important because in addition to the flue products being exhausted to the outside, additional room air is also exhausted by entering the draft hood. The total amount of air flow exhausted up the stack needs to be replaced by unconditioned air from outside the building. This air flow up the water heater vent will add to the infiltration load on the building. Depending on the temperature and humidity of the outside air this may increase the energy use by the building for heating, cooling or dehumidification.

2.1. Efficiency Testing

The efficiency test was performed using the DOE EF 24 hour simulated use test. The 24-hour simulated use test determines the amount of fuel used during a 24-hour period to heat 64.3 gallons of water. The water is heated from 58 °F to 135 °F. It is drawn in six equal draws of 10.7 gallons at one-hour intervals at the beginning of the test. After the draws, the water heater is left in standby mode for the remainder of the 24 hour test.

The main result of the test is an energy factor (EF) rating for the water heater. EF is the efficiency of the water heater defined as the ratio of energy output divided by energy input during the 24-hour simulated use test. The energy output is the energy in the heated water delivered by water heater. Energy input is the total energy content of the gas used by the water heater during the 24-hour simulated use test. Several calculations are applied to this ratio to correct various air and water temperatures if they are not at the specified values during the test.

Two other intermediate key parameters are calculated during the process of determining the EF. These are recovery efficiency and standby heat loss coefficient.

Recovery efficiency (RE) is the efficiency of the water heater at raising the temperature of the water supplied to the temperature of the hot water delivered during a draw. It is measured as the ratio of energy delivered as hot water during the first draw in the test to the total energy used by the water heater until the cut-out following the first draw, including auxiliary energy such as pilot lights, corrected for any net change of temperature of the water in the tank.

The standby heat loss coefficient (UA) is the ratio of the amount of energy consumed by the water heater during standby after the last draw to the product of temperature difference between the ambient air and the stored water and the length of time the water heater is in standby. It is also corrected for any net change of temperature of the water in the tank during the test.

2.2. Data Acquisition System

An automated test control and data acquisition system was built using National Instrument's LabVIEW system.¹ Data were acquired from the sensors at one second intervals using FieldPoint distributed input/output system modules.² The system was programmed to automatically run the entire 24 hour simulated use test.

Once the data from a test was collected it was analyzed using a custom computer program.³ The program calculated EF, RE, UA and several other parameters according to the calculation methodology in the test procedure.

2.3. Determining flue and stack air flow

There is no standard method of measuring air flow into a water heater. We considered several different methods before selecting the ones we used. The main options we considered were using a tracer gas, calculating excess air and using air temperatures.

The emissions data were collected in separate tests using a shorter procedure than the 24 hour simulated use test that was used to calculate efficiency. Approximately the same amount of hot water was drawn to initiate burner firing, but the flow rate was lower than in the EF test procedure. The emissions data were collected using protocols developed for a project to examine the potential impact of LNG on natural gas appliances.⁴

The natural gas flame in the combustion chamber used combustion air directly. Excess air is also entrained through the combustion chamber. The combustion products mixed with excess air rise through the flue. At the top of the flue is a draft hood. More dilution air is pulled in at the draft hood. It mixes with the combustion products and excess air as it rises through the stack. A schematic drawing of the air flows in a gas storage water heater is shown in Figure 3.

In the test laboratory the stack is five feet high and exhausts into the room at neutral pressure before it is removed by the ventilation system. In field installations, the stack may be much taller. Also during cold weather, the temperature difference between the stack gases and the outdoor air will be much greater than under test conditions. Because buoyancy forces are determined by a combination of stack height and temperature differences, in field applications, the flow through the stack will be higher than we measured in the laboratory.

¹. <http://www.ni.com/labview/whatis/>

². <http://sine.ni.com/nips/cds/view/p/lang/en/nid/1206>

³. The program was written in perl. Perl is a general-purpose programming language originally developed for text manipulation and now used for a wide range of tasks. <http://www.perl.org/>

⁴. Natural Gas Variability in California: Environmental Impacts and Device Performance, CEC Contract No. 500-05-026

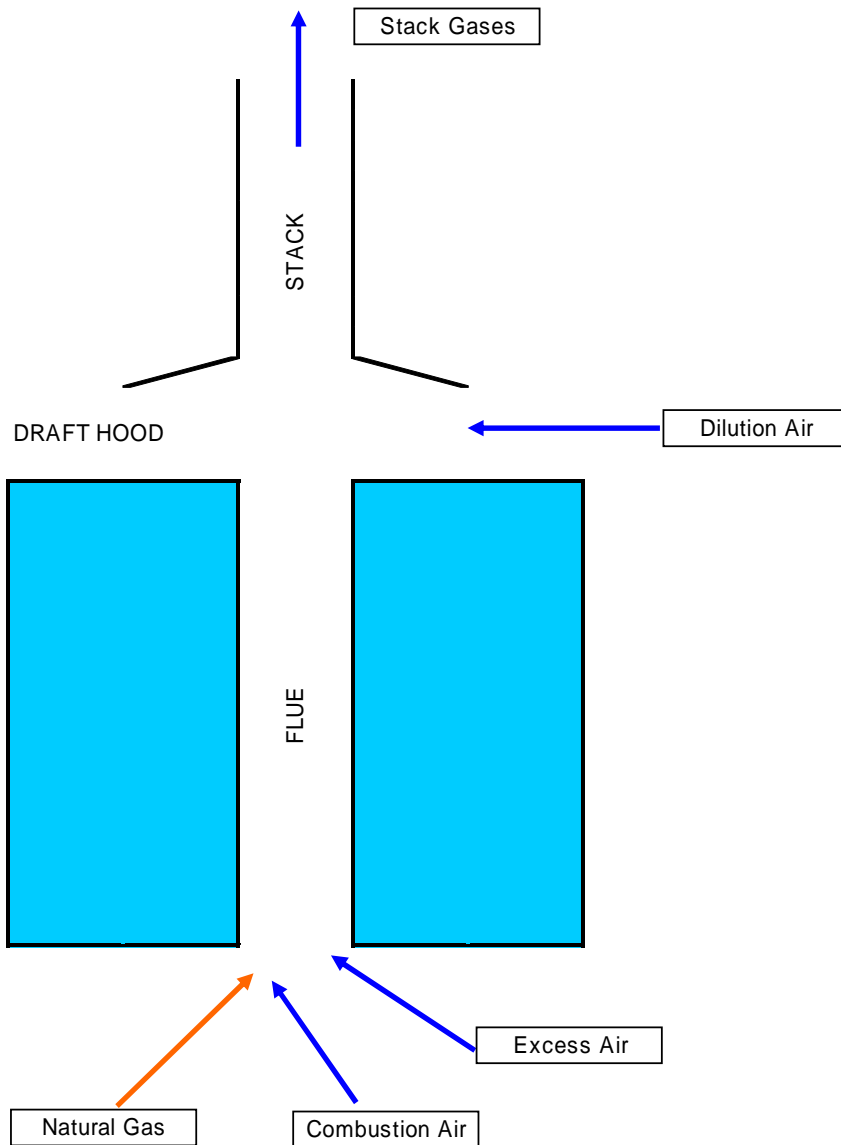


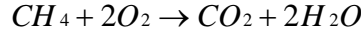
Figure 3: Schematic of Air Flows

2.3.1. Tracer gas method

This method entails injecting a small flow of a known amount of a gas into the combustion chamber that would not be destroyed by the flame. For the base case water heater, this would entail breaking the integrity of the sealed combustion chamber. All residential gas-fired storage water heaters are now required to have flammable vapor ignition resistant design. In the case of the water heater we tested, the combustion chamber is completely enclosed. To assure that all of the tracer gas is drawn through the water heater, we would have to inject the tracer gas directly into the combustion chamber. We did not use this method.

2.3.2. Excess air method

This method measures the concentrations of CO₂ or O₂ in the air streams. The combustion of natural gas generates CO₂ and depletes O₂. The combustion of natural gas in pure oxygen is described by the following equation.



The amount of fuel measured by the gas meter determines the amount of excess CO₂ in the combustion products. The combustion process consumes O₂, therefore the concentration of O₂ in the combustion products is reduced. To assure complete combustion, air in excess of the quantity of air needed for theoretical stoichiometric combustion is drawn into the combustion chamber. These effects can be measured as the different concentrations CO₂ and O₂ in the combustion products compared to the ambient air. Either gas can be used to determine the amount of excess air that is brought in either the combustion chamber or the draft hood. We used O₂ for both the burner-firing and the pilot-only operating modes.

2.3.3. Stack air flow – proportional temperature method

Another way of determining the amount of air moving up through the stack can be done by measuring the flue temperature, the ambient temperature and the temperature in the stack. The temperature in the stack is proportional to the amount and temperature of air and combustion gases from the flue and the amount and temperature of ambient air that enters the stack through the draft hood openings. It can be determined by solving the following equations.

$$\begin{aligned}\dot{M}_{stack} &= \dot{M}_{flue} + \dot{M}_{dil} \\ T_{stack} \times \dot{M}_{stack} &= T_{flue} \times \dot{M}_{flue} + T_{dil} \times \dot{M}_{dil}\end{aligned}$$

2.3.4. Additional checks on flue and stack airflow

The measurement of CO₂ and O₂ generated by combustion, when used to determine airflow in pilot mode can have significant error. This value was checked with other instrumentation. In pilot mode, the flow rates were also determined with a hot-wire anemometer, a vane type anemometer, and by using a smoke stick and visually observing the time it took for smoke to move up the five foot stack.

2.4. Test Setup

The water heater we tested is a nominal 40 gallon tank with a 40,000 Btu per hour gas input manufactured by American Water Heater Company. (Appendix 9.1 provides further information about the specific water heater used in these tests.) It has a flammable vapor ignition resistant design which reduces the risk of accidental fires involving flammable vapors from products such as gasoline, paint thinner, or solvents. The water connections are on the top with nominal 3/4" pipes. The gas connection is a nominal 1/2" pipe. The burner is an aluminized steel low-NO_x burner.

We tested the water heater according to the DOE 24 hour simulated use test.(U.S. Department of Energy 1998) Where not clearly described, the test procedure and test apparatus was supplemented according to the draft guidelines from the GAMA test method working group.(GAMA Test Method Working Group 2006)

The water heater was placed on a 3/4 inch thick plywood platform supported by three 2 X 4 inch runners. The temperature of the inlet and outlet water was measured by thermocouple probes inserted in the inlet and outlet pipes. The temperature of the water being supplied to the water heater was required to be between 56°F and 60°F during the test. Because the supply water in the test location was too warm, an air-cooled water chiller was used to cool the water to the specified temperature. The chilled water was stored in the tank of an un-fired electric water heater prior to any draws. A by-pass valve was used to purge the line between the chilled water storage tank and the water heater of warmed water prior to each draw during the 24 hour simulated use test. The supply water pressure was measured at approximately 50 psig when water was not being drawn.

The temperature of the water in the water heater was measured with six thermocouple probes positioned at the vertical midpoint of each of the six equal volume nodes within the tank. The temperature sensors were installed through an extra relief valve opening at the top of the tank. The thermocouples were located according to the draft guidelines from the GAMA test method working group. A more detailed explanation of determining the thermocouple location is contained in Appendix 9.3, Water Heater Tank Volume and Thermocouple Locations. The thermocouples were calibrated against platinum resistance temperature detectors as described in Appendix 9.4, Thermocouple Calibration.

All fittings added to the water heater to accommodate the temperature sensors were covered with thermal insulation having an R value of 4 h-ft²-°F/Btu. Water volume was measured by a flow meter in the outlet stream.

Ambient air temperature was measured at the vertical mid-point of the water heater approximately 2 feet from the surface of the water heater with a sensor shielded against radiation. The ambient air temperature was maintained between 65.0°F and 70.0°F during all tests.

Gas used in the test was from the local gas distribution company. The gas supply pressure was maintained at 7.4 to 8.0 inches of water column. The higher heating value of the natural gas was sampled before and after each test. Values ranged from 1010 to 1014 BTUs per standard cubic foot.

A 5-foot vertical vent pipe with a three inch diameter, equal to the size of the draft hood outlet, was connected to the draft hood outlet.

3.0 Task Outcomes

3.1. Efficiency

The results of the three 24-hour simulated use tests on the baseline water heater are shown in Table 1. The energy factor (EF), recovery efficiency (RE) and standby heat loss coefficient (UA) are listed for each test. A lower UA indicates lower standby heat loss and leads to a higher EF. A higher RE will also lead to a higher EF. The average values of each parameter, along with the standard deviation and size of the 95% confidence interval are also shown.

Table 1: Test Results-Baseline Water Heater

Test	1a (2007-10-12)	1b (2007-10-19)	1c (2007-10-20)	Average	Standard Deviation	95% Confidence Interval (\pm)
EF	0.575	0.574	0.578	0.576	0.0021	0.0024
RE	0.769	0.763	0.772	0.768	0.0046	0.0052
UA (BTU/hr-°F)	10.637	10.652	10.568	10.619	0.0448	0.0507

After the flue damper was installed, three more 24-hour simulated use tests were done. The results are shown in Table 2. The average EF, RE and UA values for these tests along with the standard deviation and 95% confidence interval are also shown.

Table 2: Test Results-Water Heater with Flue Damper

Test	2a (2007-10-25)	2b (2007-10-26)	2c (2007-10-27)	Average	Standard Deviation	95% Confidence Interval (\pm)
EF	0.609	0.607	0.599	0.605	0.0053	0.0060
RE	0.805	0.800	0.753	0.786	0.0287	0.0325
UA (BTU/hr-°F)	9.080	9.097	9.227	9.135	0.0804	0.0910

The differences for all test parameters for the water heater without and with the flue damper are statistically significant. The differences are shown in Table 3, Impact of Flue Damper.

Table 3: Test Results-Flue Damper Impact

Parameter	Baseline	Flue Damper	Difference From Baseline	%
EF	0.576	0.605	0.029	5.1%
RE	0.768	0.786	0.018	2.3%
UA (BTU/hr-°F)	10.619	9.135	-1.484	-14%

3.2. Air Flow

Air flows were calculated from measurements of oxygen concentration and measured directly in pilot only mode with anemometers. Gas concentration measurements were performed in both the burner on (firing) and pilot only (standby) modes. For both the burner-on mode and the pilot mode, measurements were conducted with hot water in the heater.

The flue, dilution and stack air flows are reported in Table 4, Air Flow in On-Cycle and Off-Cycle Modes. These air flows are reported for both on-cycle (burner on) and off-cycle (pilot only) for both the base case and the water heater with the flue damper.

Table 4: Air Flow in On-Cycle (Burner On) and Off-Cycle Modes (Pilot Only)

Water Heater Mode	Air flow	Base Case (CFM)	With Damper (CFM)
Burner On	Flue	16.2	13.4
	Dilution	12.6	10.8
	Stack	28.8	24.2
Pilot Only	Flue	5.0	2.6
	Dilution	7.4	8.5
	Stack	12.4	11.1

The heat contained in these air flows, as well as the heat content of the gas input during the tests is reported in Table 5, Heat Flow during On-Cycle and Off-Cycle Modes.

Since all of the excess combustion air and dilution air comes from the room where the water heater is located, heat losses for the flue and dilution air are based on loss of ambient room air. The heat flows in Table 5 are resulting from the temperature difference between ambient room air and the flue and stack temperatures.

Table 5: Heat Flow during On-Cycle and Off-Cycle Modes

Water Heater Mode	Air flow	Base Case (Btu/hr)	With Damper (Btu/hr)
Burner On	Burner	32601	32109
	Flue	4205	3172
	Dilution ⁵	0	0
	Stack	4205	3172
Pilot Only	Pilot	594	531
	Flue	301	169
	Dilution ⁵	0	0
	Stack	301	169

⁵ Since heat flows are calculated here relative to the room temperature and there is no heat added to the dilution air, the heat loss due to dilution air flow is zero. If it is colder outside than where the water heater is located, significant heat loss may be associated with the dilution air flow.

An alternate way of looking at this is to consider the total air going up the stack. This air started out as room ambient air and must be replaced by outside air. Air used for combustion, excess air into the combustion chamber and dilution air into the draft hood must all be included. How much this air would need to be conditioned (heated or cooled) depends on the outside conditions (temperature and humidity). This is shown in Table 6, Total Room Air Used.

Table 6: Total Room Air Used

Water Heater Mode	Base Case (CFM)	With Damper (CFM)
Burner On	28.0	23.5
Pilot Only	12.4	11.1

Alternate methods of measuring the stack and flue air flow listed in Table 7, Comparison of Off-Cycle Stack Air Flow on Base Case Water Heater, were used as a check against the results reported in Table 4.

Table 7: Comparison of Off-Cycle Stack Air Flow on Base Case Water Heater

Determination Method	CFM	
	Pilot Only	No pilot or burner
Excess Air / proportional temperature method	12.4	NA
Hot wire anemometer	9.2-10.6 (avg = 9.9)	5.9
Hot wire anemometer#2	10.0	-
Vane anemometer	10.4	5.5

3.3. Discussion

3.3.1. Efficiency

The results show the flue damper increased the efficiency of the water heater by 5%. The increase in EF was not as large as expected prior to this investigation. Unexpectedly, some of the increase was from an increase in off-cycle recovery efficiency. The flue damper restricted not only off-cycle flow of combustion gases through the flue, but on-cycle flow as well. This restriction of on-cycle flow increased the residency time combustion gases were in the flue. More heat was removed from the flue gases and put into the water in the storage tank, increasing the recovery efficiency.

3.3.2. Recovery Efficiency

The recovery efficiency of the water heater with the flue damper was higher than without the flue damper. However the recovery efficiency of the third test for the water heater with the flue damper was significantly lower than from the other two tests. Upon subsequent investigation we found that the recovery efficiency for the first draw in each test was significantly higher than for other draws in that test. See Figure 4, Recovery Efficiency by Draw Number During Tests. Tests 1 through 3 are for the water heater without the flue damper. Tests 4 through 6 are of the water heater with the flue damper. The higher recovery efficiency on the first draw of the test is

likely due to conditions at the beginning of the test being different than at the initiation of the subsequent draws.

The recovery efficiency for the first draw is used to calculate the EF for the entire test. This will give misleading results, since the recovery efficiency during the rest of the test is consistently lower.

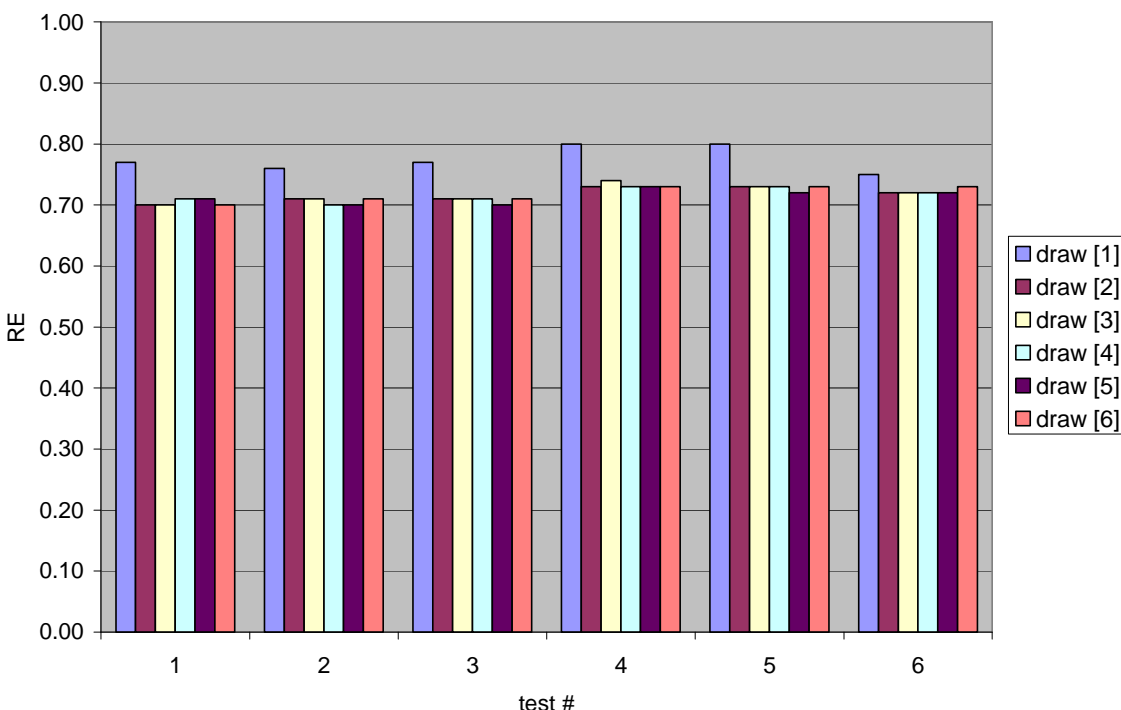


Figure 4: Recovery Efficiency by Draw Number During Tests

3.3.3. Actual versus Rated Input

An unexpected finding was that the gas consumption rate of the water heater when firing was much lower than the nominal firing rate. The rated input for model water heater is 40,000 BTU per hour. The measured firing rate was 33,000 BTU per hour. We installed the water heater in the laboratory according to the installation manual. We did not attempt to adjust the burner manifold pressure at the gas valve/ thermostat. It is not clear if plumbers would make, or even know how to make, any adjustments during installation. The installation manual seemed to recommend against making field adjustments. (American Water Heater Company 2005)⁶ It is

6. Only two references appear in the installation manual could refer to adjusting the gas valve/thermostat. One of them explicitly warns against tampering with the gas valve/thermostat.

GAS PRESSURE “The minimum supply pressure is for the purpose of input adjustment.” pg 6

“DO NOT tamper with the gas valve/thermostat, igniter, thermocouple, or temperature and pressure relief valve. Tampering voids all warranties. Only qualified service technicians should service these components.” pg 13

likely the efficiency would be higher in a water heater with a smaller burner than in the same heater with a larger burner.

3.3.4. Air Flow in On-Cycle and Off-Cycle Modes

The damper reduced the air flow up the flue during off-cycle mode as expected. Because of restrictions at the top of the flue, the damper also reduced on-cycle air flow.

Air flow out of the room where the water heater is located, has not been measured prior to this test. The flue damper we tested did not reduce total room air losses as much as we anticipated. The air flow through the flue was significantly reduced, however we measured increased dilution air flow through the flue with the damper.

We found that, in pilot mode, air flow up the stack was a significant fraction of stack air flow when the burner was on. Our measurements indicated that off-cycle air flow was nearly half the on-cycle air flow rate. Since the water heater is in pilot (off-cycle) mode most of the time, this means that a significant amount of room air is vented out of the house when the water heater is not firing.

4.0 Conclusions

The flue damper reduced off-cycle standby losses, and improved the energy factor of the water heater by .03. The flue damper also improved the recovery efficiency of the water heater 2.3% by restricting on-cycle air flows through the flue. The efficiency improvement, while not as large as expected, is still significant.

With or without the flue damper, off-cycle air flow up the stack is nearly half the air flow rate as when the burner is firing.

5.0 Recommendations

This flue damper for gas-fired storage water heaters did increase the efficiency of the water heater 5%. Significant benefits would accrue to California from the deployment of increased efficiency water heaters. If this technology could be developed as a low-cost retrofit, considerable energy savings would be available for California residents.

The test procedure calculations should depend on the recovery efficiency from all draws during the test. Calculating the recovery efficiency from the first draw and firing exaggerates the efficiency of the water heater.

Because of the impact stack air flow has on total house infiltration rates, this should be considered, especially in colder climates.

6.0 References

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- California Energy Commission (2008). Technology Innovations for Buildings and Communities Energy End-Use, Electricity Demand and GHG Emissions Reference, RFP Attachment 13, California Energy Commission.
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7.0 Glossary

BTU	British thermal unit
DOE	U.S. Department of Energy
EF	Energy Factor
GAMA	Gas Appliance Manufacturers Association
GPM	gallons per minute
PRTD	platinum resistance temperature detectors
RE	Recovery efficiency
STAC	State Technologies Advancement Collaborative
TC	thermocouple
UA	standby heat loss coefficient

8.0 Bibliography

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web.mit.edu/lienhard/www/ahtt.html

9.0 Appendices

9.1. Water Heater

American Water Heater Company

Model number: BFG 61 40 S 403 NO

Serial number: 0719105745

Product number: 0732032

Natural Gas

Energy Guide Label: 254 Therms per year

First Hour Rating: 67 gallons

Recovery rating: 33.9 gph

Rated Gas Input: 40,000 Btu/hr

Rated Storage: 40 gallons

Manifold pressure: 5 in. W.C.

Features: pilot, FVIR, low NOx, natural draft

9.2. Instrumentation & Calibration

GAS METER

American Meter Company

Model number: DTM-200A NON T.C.

Serial number: 06H865002

1 revolution per cubic foot

Pulse generator from IMAC: 500 pulses per cubic foot

Calibration: date: 7/11/2007

Calibrated at 200 CFH, 60 CFH, 17.5 CFH

All have corrected accuracy of 100.4 (multiply reading by 100.4)

AIRFLOW

Digital Vane Anemometer

Pacer Industries

Model number: DA 4000

Serial number: 4000-92-126749

Probe head -4F to 210°F

Accuracy $\pm 1\%$ of reading

Probe AP275 2 $\frac{3}{4}$ dia.

Calibration date: 4-11-98

Hot-Wire Anemometer

Alnor

Model number: 8500D-11

Temp. range 32 - 158°F

Air velocity 1 FPM from 20-700 FPM

Accuracy ($\pm 9\%$ or 9 FPM) ± 2 FPM whichever of the two is greater

If turbulence $< 1.5\%$ and temperature gradient is $< 0.1^\circ\text{C}$

WATER FLOW

Hoffer Flow Controls

Model number: HO1/2x3/8-0.75-7.5-B-1M-MS

Serial number: 91140

Min. 0.75gpm

Max. 7.5gpm

Calibrated: September 2007

Frequency to current transmitter

Model ACC18C Converts pulses to 4-20mA DC signal

Connected to FieldPoint FP-AI-111, National Instruments

Omega Flowmeter

Model number: FTB 4607

Serial number: 510160

Min. 0.22gpm

Max. 20.0gpm

Pulses per gallon: 75.7

¾ inch diameter

Calibration: new meter

Readout

Model number: DPF701-01

Serial number: 7210121

Connected to FieldPoint FP-AI-110, National Instruments

TEMPERATURE

Omega Thermocouples

For Inlet and Outlet water temperature and gas temperature

Type T, 1/8th inch diameter, ungrounded

For water heater probe

Type T, 0.04 inches diameter, ungrounded

Ambient temperature is type T, 0.04 inches probe

PRESSURE

Barometric Pressure

NOVA Lynx Digital Barometer / Altimeter

Model number: 355-AIO900-04103003

Serial number: 966910-S1

Note: calibrated against a mercury barometer at a single point

Gas pressure (at gas meter)

U-tube manometer (the primary pressure reference)

Resolution to 0.05 inches W.C.

Dwyer Magnehelic Differential Pressure Gauge ($\pm 2\%$ of full scale); full scale = _

Setra pressure transducer with 0-5 volt output, calibrated to the U-tube manometer

Water Pressure

March Gauge 0-160 psig

9.3. Water Heater Tank Volume and Thermocouple Locations

The methods in the GAMA draft test guidelines were used for guidance in these measurements.(GAMA Test Method Working Group 2006)

Total storage volume was measured using the weight of the water in the water heater divided by the density of water for the corresponding temperature. Weight was measured using a Cardinal RW-1000 scale, and water temperature was measured with a 0.040 inch diameter 47 inch long type-T thermocouple which output to an Omega HH-23 digital thermometer. Visual observation of the water level and insertion of the thermocouple probe was done through an unused alternate temperature and pressure relief valve location or through the hot water outlet.

Each water heater was fitted with pipe-to-hose connections. The drain was fitted with a tee, where a long clear $\frac{1}{4}$ inch internal diameter acrylic tube was attached. With no other attachments, a dry weight was measured. After the inlet and drain hoses were attached, water was allowed to pass through the storage tank (both inlet and drain were open). The thermocouple probe was lowered into the water at the bottom of the tank. Once the water temperature stabilized to within one degree, the drain was closed and the tank filled until water reached the unused opening at the top of the water heater.

With all hoses detached, a new weight measurement was obtained. The weight of water was then found by subtracting the dry weight from the filled weight. The water temperature was checked again, and the appropriate density was used to convert the water weight into volume. This water weight was also used to determine each of the six thermocouple locations.

Water levels were observed using the clear acrylic tube extending from the drain to above the top of the water heater. With the storage tank filled, a "Top" mark was placed on the exterior at the height seen in the clear tube. The uppermost thermocouple location was found by removing

1/12 of the total water weight and marking the water level. The five remaining thermocouple locations were subsequently found by removing 1/6 of the total water weight and marking each water level.

The thermocouples were attached to a rod inserted into the storage tank. To determine the placement of the thermocouples, a series of measurements was taken. First, a reference was set by placing a level across two identical pipe nipples from the inlet and outlet openings on the water heater. The thermocouple locations were then measured from the bottom of that level (which extended beyond the edge of the water heater) to the marks on the side of the water heater. Next, the distance from the level to the top of the water heater adjacent to where the thermocouple rod would be inserted was found. The thermocouple feed-through, including all necessary fittings, was tightened into place. For consistency, the number of turns was recorded and an alignment mark was made for future reference. Once tightened, the height of the thermocouple feed-through from the top of the water heater was measured. Thermocouple locations on the rod were then calculated.

The side-arm water heater had an alternate temperature and pressure relief valve opening in the top center of the storage tank and directly over the peak of the bottom tank dome. The top of the dome was about 3 cm higher than the bottom thermocouple location. The bottom thermocouple in this tank was therefore displaced upwards by about 5.5 cm, which included a 2.5 cm clearance above the dome.

The volume of water heaters is shown in Table 9, Water Heater Volumes.

Table 8: Water Heater Volumes

Water Heater	Gallons
Baseline	38.16
Side-arm	35.57
Power Vented	38.15

9.4. Thermocouple calibration

Type-T thermocouples were used for water and ambient air temperature measurements. Calibration factors were included in the Labview program. These factors were obtained from a calibration done using a Neslab RTE-221 temperature controlled bath and three Azonix calibrated (on 10/5/04) platinum resistance temperature detectors (PRTD) and ITS-90 thermometer.

The PRTD temperature data was read by serial cable from the ITS-90 thermometer every 30 seconds, and thermocouple data was read every second using National Instruments' Labview software and Fieldpoint FP-TC-120 hardware modules. Analysis was done in Microsoft Excel.

The ends of the PRTDs and thermocouples were immersed in the bath. The thermostat on the Neslab temperature controlled bath was adjusted in increments of 10 °C, ranging from 10 °C to 70 °C. Ample time was allowed for the bath temperature to stabilize between thermostat adjustments. Each setting was maintained for at least 5 minutes.

Figure 5, PRTD Reference Temperatures, shows the temperature of the bath versus time. The red boxes indicate the time intervals for which the thermocouples were calibrated to the PRTD data.

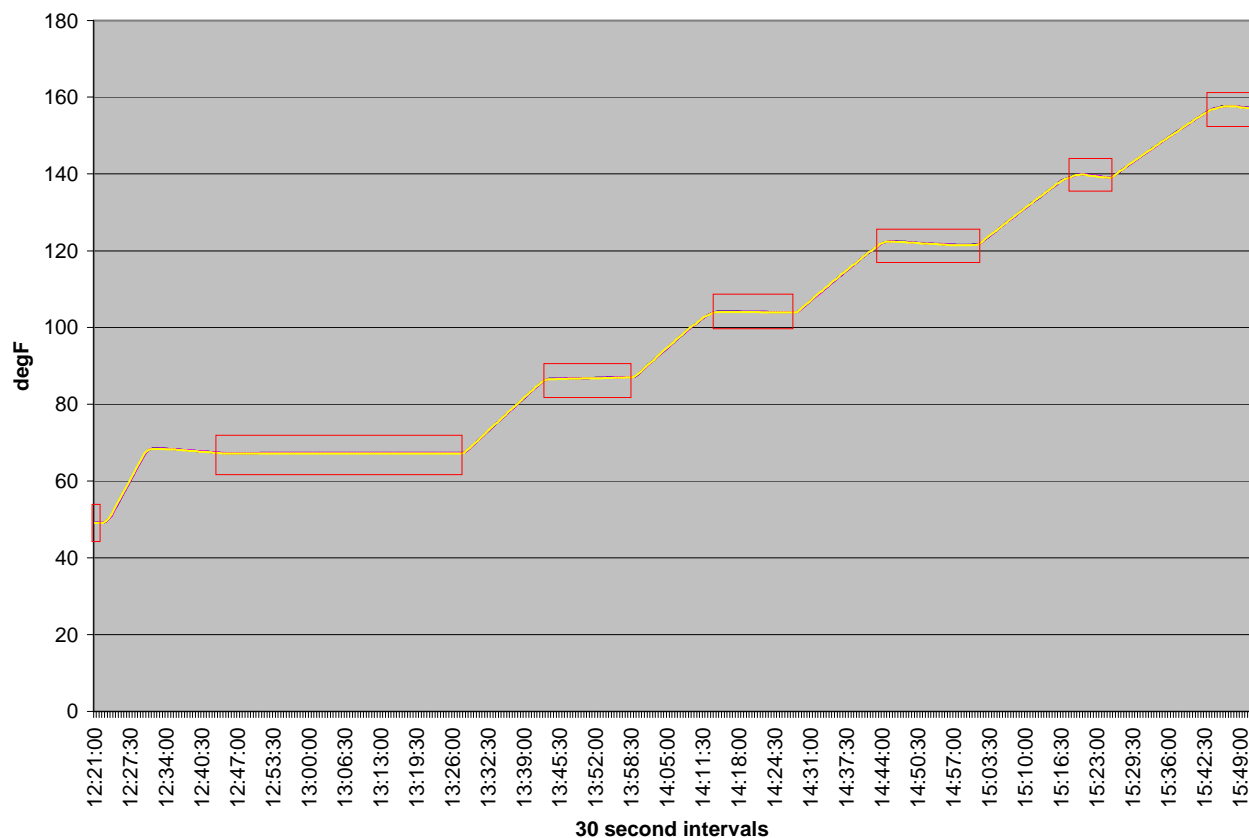


Figure 5: PRTD Reference Temperatures

The reference temperature at each 10 °C setting was obtained by averaging the three PRTD values together. Data for each thermocouple was independently averaged over the same time intervals used for the PRTDs. A linear regression fit was done to bring each thermocouple's average temperatures to the reference temperatures. The slope, intercept and R^2 for each regression are shown in Table 9, Thermocouple Calibration Coefficients. The linear equation for each thermocouple calibration was written directly into the 24 hour test procedure data acquisition program.

Table 9: Thermocouple Calibration Coefficients

Location	Tank Top	In Tank 2	In Tank 3	In Tank 4	In Tank 5	Tank Btm	WH Inlet	WH Outlet
	TC 1-0	TC 1-1	TC 1-2	TC 1-3	TC 1-4	TC 1-5	TC 2-0	TC 2-1
Slope	0.9946	0.9957	0.9962	0.9961	0.9957	0.9955	0.9983	0.9922
Intercept	0.6750	0.5340	0.4330	0.3990	0.4667	0.5733	0.6161	0.8211
R^2	0.9865	0.9861	0.9762	0.9696	0.9887	0.9639	0.8689	0.9781

A plot of corrected and uncorrected thermocouple temperature minus the reference temperature, the residuals, is shown in Figure 9, Residuals for Thermocouple Compared to Reference Temperatures.

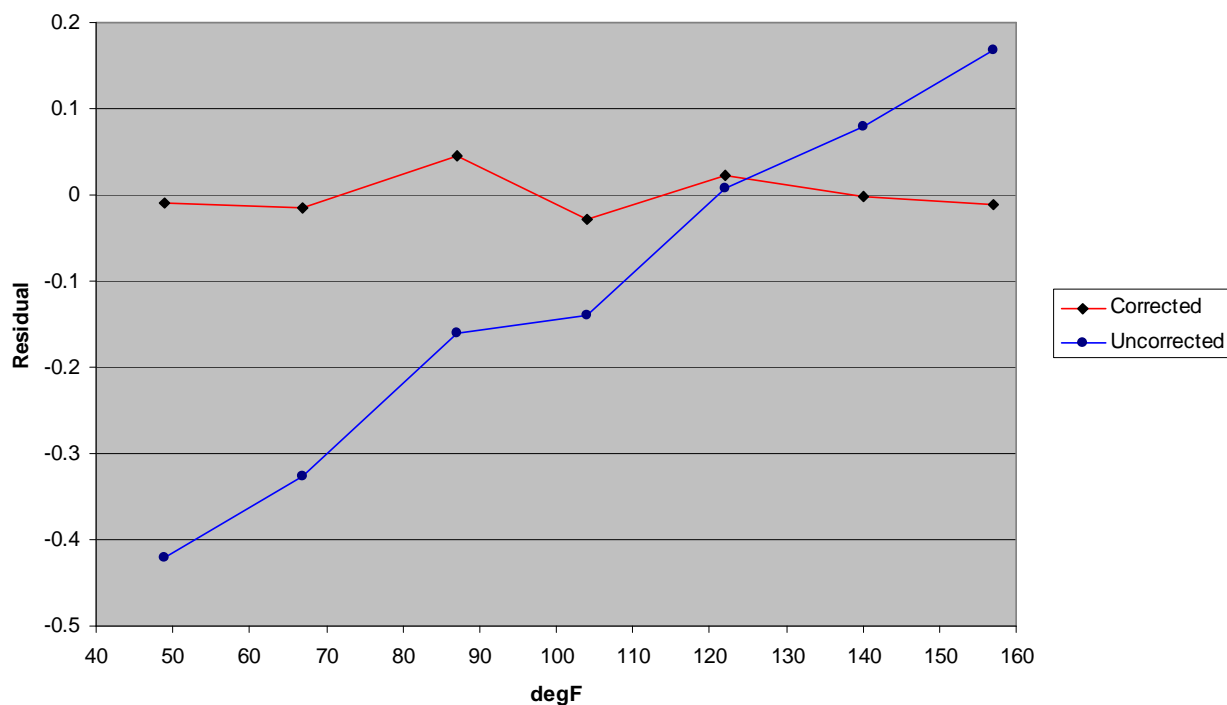


Figure 6: Residuals for Thermocouple Compared to Reference Temperatures