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Gas Water Heater Energy Losses

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January 7, 2009

SUMMARY

A forty gallon residential gas-fired storage water heater was modeled under Department of Energy test procedure conditions using the TANK simulation program. The purpose was to determine heat flows in a typical residential storage water heater that meets the current minimum efficiency standards. Modeling showed that, without considering a condensing water heater design, the greatest potential efficiency gains can be made by reducing flue losses during the non-firing, non-recovery mode, i.e., during standby mode. The stack losses while in standby mode account for about 43% of heat losses (not including the energy added to deliver hot water), and 17% if hot water energy is included.

INTRODUCTION

The objective of this study was to provide background information to the SEGWHAI project, CEE and Energy Star who were considering promotion of an efficient "drop-in replacement" gas water heater. "Drop-in replacement" refers to a water heater that could replace a gas-fired storage water heater with a conventional vent and gas supply. The water heater would not be required to have special venting or an electrical outlet, so a condensing water heater or power venting would not be an option. With these restrictions the greatest efficiency gains can be made by reducing standby heat losses. This paper provides insight into:

- how high the efficiency of a natural draft tank type water heater can be without resorting to condensing flue gases or a power burner, and
- quantifying where the greatest standby losses in a conventional water heater occur, so that measures can be taken to reduce them.

We first defined a baseline gas-fired storage water heater that meets the current efficiency standard and modeled the heat flows, including delivered hot water and energy losses.

Water Heater Description

Figure 1 is a schematic of a typical gas-fired storage water heater. It shows the major components described below.

Tank: The tank is typically a glass-lined steel vessel which contains the heated water.

Insulation: Polyurethane foam insulation reduces the rate at which the heated water in the tank cools down.

Jacket: The jacket is a sheet metal or plastic covering over the tank insulation.

Burner: A burner enables and controls combustion by mixing air and gas and delivering the mixture to the flame.

Flue: The passage within the water heater through which combustion gases pass from the burner to the draft hood of the water heater.

Dip tube: The dip tube directs entering cold water to the bottom of the tank as hot water is drawn from the top of the tank.

Anode rod: A metal rod, usually of magnesium or aluminum, inserted into the water heater to delay corrosion of the tank.

Pilot: A pilot or pilot light is a small gas flame that is used to ignite gas at the main burner.

Vent: A metal or plastic (in case of some condensing water heaters) tube that conveys flue gases from the water heater to the outdoor air.

Thermostat: The thermostat senses and regulates the tank water temperature by controlling when the burner fires.

T&P Valve: Temperature and pressure valve--a safety valve that vents the water in the tank to ambient air when the pressure or temperature exceeds safe limits.

Flame arrestor: a design feature of a voluntary safety standard; also known as FVIR or "flammable vapor ignition resistant". The purpose of the FVIR is to prevent flammable vapors in the vicinity of the water heater from being ignited by the water heater burner or pilot.

Drain valve: a valve located at the bottom of the water heater used to drain water from the tank. This valve can be plastic or brass.

Baffle: The flue baffle is used to increase heat transfer from the combustion gases to the inside of the flue by increasing the turbulence of the gases as they leave the burner.

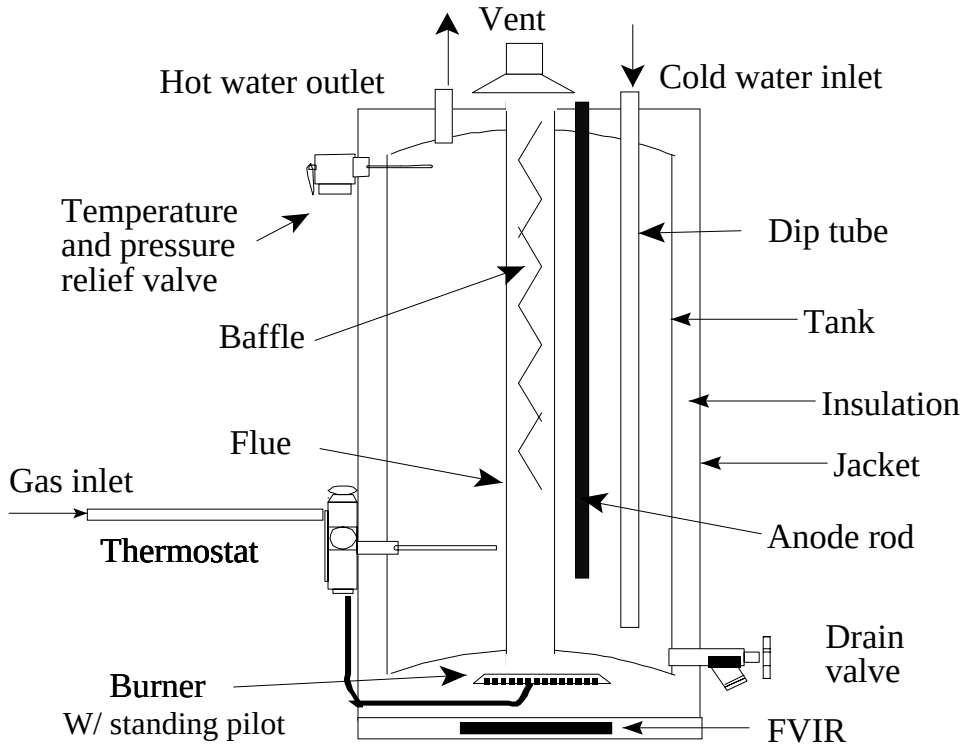

Figure 1: Diagram of Gas-Fired Storage Water Heater

Current Efficiency Standards

The U.S. Department of Energy issued a final rule on January 17, 2001, setting new minimum energy efficiency levels for water heaters.[1] These efficiency levels became effective on January 20, 2004. The required minimum efficiency is a function of the rated storage volume as specified by the manufacturer. For storage type gas-fired water heaters the minimum EF is:

$$EF = 0.67-(0.0019 \times \text{Rated Storage Volume in gallons})$$

For a 40 gallon water heater, an EF of 0.594 or higher is required. Prior to the 2001 efficiency rulemaking, a 40 gallon water heater was required to have a minimum EF of 0.544.

BACKGROUND

APPROACH

In this study we started with the baseline model from the DOE water heater rulemaking and added design options from the rulemaking to get a water heater that meets the current minimum efficiency standard. We then simulated the energy flows for this water heater operated under the DOE EF test procedure.

TANK Simulation Program

A computer simulation model, TANK, was developed by Battelle for the Gas Research Institute (GRI) to perform detailed thermal analyses of storage-type water heaters.[2] TANK models typical center-flue, gas-fired, storage-type water heaters. In addition to basic information on heat losses and water temperatures, this program determines the water heater Energy Factor (EF) based on the Department of Energy's 24-hour simulated use test. The TANK simulation program was used to model design options and combinations of design options that increase the efficiency of a water heater as part of the DOE rulemaking analysis.

We used the most current version of this model--version 2.0 Gas-Fired Water Heater Simulation Software, updated in 1993.[3] The program models draw patterns and temperatures according to the DOE water heater test procedure. TANK uses the test procedure protocol from 1990, which is consistent with the current test procedure.[4]

Appendix A shows the main input menu. Appendix B shows input tables of all parameters available to the program user. Appendix C shows all output parameters available to the program user.

TANK does not have the capability to model side-arm water heaters, indirect-fired water heaters, induced draft water heaters, water heaters with flue designs that are serpentine or other non-straight designs, or condensing water heaters.[1] It does not model tankless water heaters. However, it can model a submerged combustion chamber and water heaters with flue dampers. Flue dampers are modeled with an appropriate off-cycle pressure loss coefficient. Some water heaters have a rim or collar at the top of the flue reducing the diameter of the flue exit which reduces heat loss up the flue. This design feature cannot currently be modeled directly in TANK. An off-cycle pressure loss coefficient and flue heat transfer parameter (HX) would have to be determined experimentally for this design feature.

Test Procedure

The DOE test procedure is designed to simulate typical operation of a water heater by measuring water heater energy use over a 24 hour period. Water is drawn six times within the 24 hour period for a total draw of 64.3 gallons. After recovery from the initial draw, water is drawn at elapsed time intervals of one, two, three, four and five hours. Each draw removes an amount of water equivalent to one-sixth of 64.3 gallons. All draws are at flow rates of 3.0 gallons per minute. At the end of the recovery period after the sixth draw, a standby mode starts and continues until a total test duration of 24 hours is reached. The energy use during standby mode is measured as well as during the recovery periods. The energy added to the water is calculated for each draw.

The total amount of hot water drawn during the test is meant to be indicative of actual hot water use in a typical residence. Cold water inlet temperature is set at 58±2°F. Ambient air temperature is required to be between 65°F and 70°F. Natural draft is established with a 5 foot vertical vent

[1] Condensing operation starts to occur when the temperature of the combustion products is below the dewpoint and the water vapor condenses out as a liquid. For water heaters this happens at recovery efficiencies of approximately 82%. The efficiency at which condensing takes place is a function of several parameters including: excess combustion air, barometric pressure, ambient air temperature, water temperature, and ambient relative humidity.

pipe. The water heater thermostat is set so the maximum value of the mean tank temperature is 135±5°F after the thermostat cuts-out. The water temperature in the tank is measured with a probe that senses the temperature in the water heater at the center of 6 equal vertically divided volumes. The outlet water temperature is also measured and this, together with the gallons of water drawn, determines the hot water energy output.

The current test procedure stipulates that if heat traps, piping insulation, or pressure relief valve insulation are supplied with the water heater, they shall be installed for testing. The size and configuration of inlet and outlet plumbing is specified in the test procedure.

The test procedure efficiency metric is the EF, which is the ratio of the energy supplied as hot water to the heat content of the fuel used by the water heater. Selected parameters of the DOE test procedure are shown in Table 1.

Table 1: Key simulation parameters in DOE test procedure

Parameter	**Value**
Inlet water temperature	58°F
Ambient temperature	70°F
Relative humidity	50%
Nominal maximum mean tank temperature	135°F
Total time of simulated use test	24 hours
Number of draws	6
Total draw	64.3 gallons

Changes since the DOE Water Heater Rulemaking

Insulation Blowing Agents

Regulations limiting ozone depleting blowing agents have become effective since the residential water heater standard rulemaking analysis was completed in 2001. Because the blowing agent that was used in water heater jacket insulation, HCFC-141b, is now banned, other blowing agents had to be considered. There was a possibility that using a different blowing agent would affect the qualities of the insulation. Analyses done for DOE's rulemaking showed that for all three likely alternative blowing agents, the EFs were within 1% of each other for water heaters with the same thickness of insulation. For this reason, no change was made to the assumed R-value of the insulation in a currently conforming water heater.

Flammable Vapor Ignition Resistant Certification (FVIR)

New safety regulations include requirements to incorporate flammable vapor ignition resistant (FVIR) technology. Water heaters are now designed to prevent flammable vapors in the immediate vicinity of the water heater from igniting. This design feature includes a flame arrestor and a thermal cutoff switch. The arrestor screen could potentially collect lint and reduce air flow and thereby affecting airflow and draft.[5] This is not a feature that is directly modeled in TANK. No changes based on this feature were incorporated in the simulations discussed in this report. Parameters potentially affected by a FVIR include excess air and draft (i.e., greater resistance to air flow through the burner and flue).

Emission Considerations
In addition to meeting efficiency and safety requirements, water heaters in California's South Coast Air Quality Management District (SCAQMD) must comply with emissions regulations. Manufacturers must pay a mitigation fee for every water heater in sold in the district that does not meet the regulation. The requirements are detailed in Rule 1121. Nitrous oxide (NOx) emissions from each water heater must be no greater than 10 nanograms per joule output.[6] Similar rules have been adopted by the air quality district in the Houston area.

Model for Simulation

The assumed baseline water heater has a 40,000 Btu/hr main burner and a continuous burning pilot with an input of 400 Btu/hr. The water heater jacket consists of one inch of polyurethane insulation. The baseline water heater for the DOE rulemaking had an energy factor of 0.548 and a recovery efficiency (RE) of 75%.

Design options added to the baseline water heater to achieve the 2001 efficiency standard were heat traps, flue baffles and additional jacket insulation. Table 2 shows the EF and RE of the baseline and modified water heaters. Run number 4 provided the EF needed for a water heater that would meet the current efficiency standard requirements (0.594).

Table 2: Modifications to the baseline model and their effect

Run #	Modifications	Energy Factor (EF)	Recovery Efficiency (RE)
1	Baseline	0.548	75%
2	Added 1 inch of insulation to sides and top (from 1inch)	0.577	75.7%
3	Added plastic heat traps to inlet and outlet pipes	0.587	75.6%
4	Increased flue baffle effectiveness (Changed HX from 1.896 to 2.980)	0.603	78.0%

Important input parameters that describe the water heater being simulated are shown in Table 3. The burner firing rate includes the both main burner and the pilot.

Table 3: Important input parameters*

Parameter	**Value**
Tank volume	38 gallons
Pipe insulation	None
Burner firing rate	40,000 Btu/hr
Pilot input rate	400 Btu/hr
Heat Traps	Yes - plastic

*See Appendix B for all the input parameters.???

RESULTS

Energy Flows

All the energy in the simulation model ends up as useful hot water, heat stored or heat lost. Heat can be lost through the fittings and the jacket by conduction, convection and radiation and by hot combustion gases flowing up the flue. In addition, the uninsulated flue conducts heat from the water during standby hours which then moves up the flue by convection. The pilot energy consumption during standby is included in the energy input. Figure 2 shows the percentage of heat flow by each mechanism. The number of hours listed by each flow is how long it happens during the test.

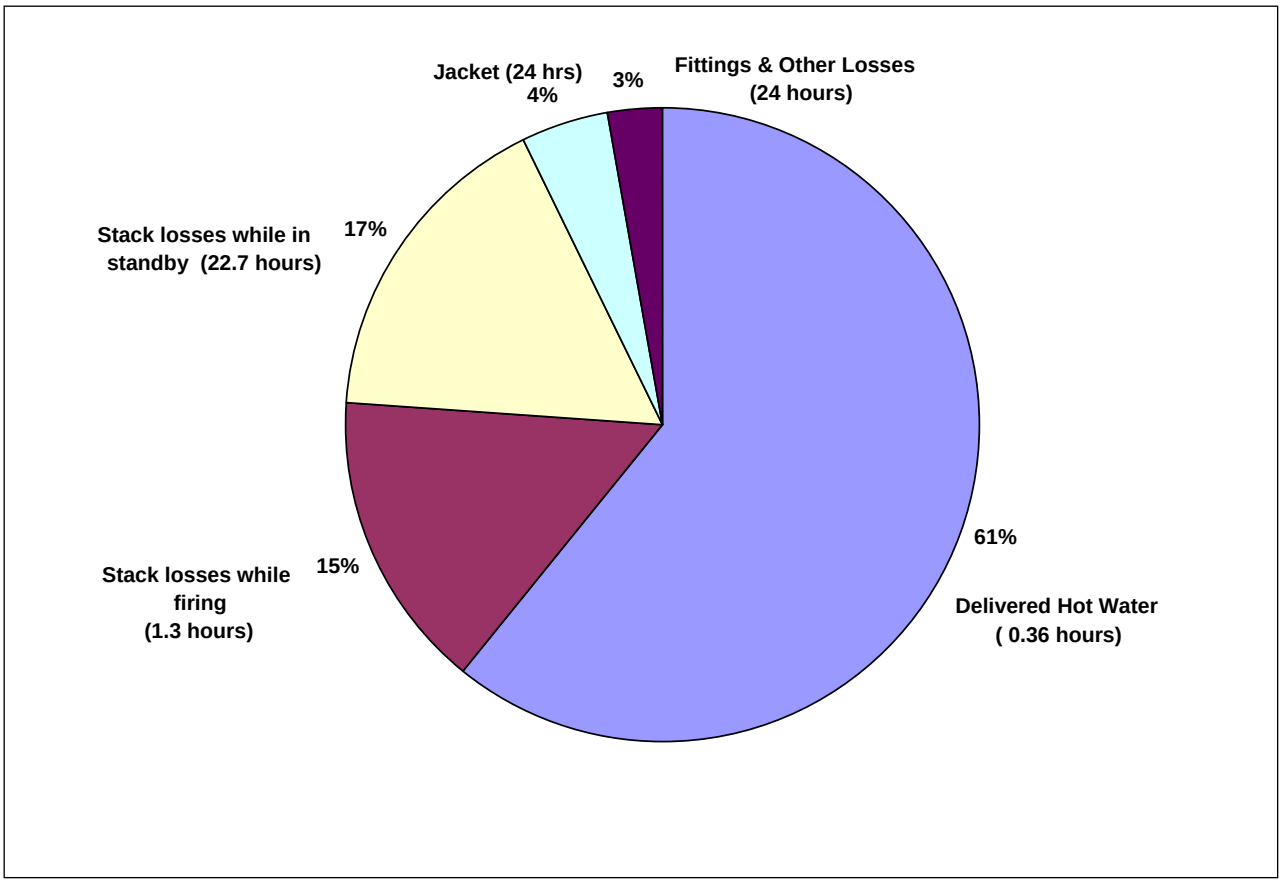

Figure 2: Energy Flows

The data in Figure 2 is from a simulation model run that had a lower water temperature at the end of the test than at the beginning. To correct for this, the test procedure subtracts the stored energy from the delivered hot water energy of 66% to provide the true net supplied efficiency of 61%.

Table 4 shows details of the energy flows in Figure 2. The losses are provided in Btu's as well as percentages of the total heat flows. The largest amount of input energy goes into heating the water. The next two largest heat flows are up the flue (stack loss) while in standby mode with only the pilot light on (17%) and while the burner is on and heating the water (15%). The standby mode represents the portion of the pilot light input that does not heat the water, i.e., is lost up the flue, as well as the heat transfer from the hot water in the tank through the uninsulated flue.

The heat losses through the 2 inches of insulation jacket are relatively small at 4%. Another 3% of total heat is lost through the fittings. The negative values for "storage" indicate that during this simulation some of the energy supplied to the delivered hot water was due to a drop in temperature (from the start of the test) of the water in the tank, the metal of the tank holding the water and the metal jacket protecting the tank insulation.

Table 4: Distribution of Energy

		Energy		
Energy Flow	**Parameter**	**BTU's**	**Percent**	**Time (hours)**
Input	Burner	52,552	85%	1.3
	Pilot	9,600	15%	24
Output	Delivered hot water	41,095	66%	0.36
	Stack loss on standby	10,404	17%	22.7
	Stack loss while firing	9,479	15%	1.3
	Jacket loss	2,771	4.5%	24
	Bottom skirt loss	998	1.6%	24
	Fitting losses	411	0.7%	24
	Inlet pipe (line) losses	307	0.5%	24
Temperature change	Water in tank	-2,971		
	Inner and bottom vessel metal	-64		
	Outer and top vessel metal	-55		
	Jacket metal	-35		

Figure 3 shows the percent heat losses (not including the delivered hot water), and not adjusting for the change in temperature of water in the tank of the metal tank and jacket.

Table 5 shows the TANK simulation results. Key results include an EF of 0.60, a recovery efficiency of 78.0% and a steady state efficiency of 81.6%. The efficiency is near the limit of what can be achieved without the water vapor in the flue gases condensing.

Table 5: Results of 24 Hour Simulated Use Test

Parameter	**Value**
Energy Factor	0.60
Recovery Efficiency	78.0%
Steady-state Efficiency	81.6%
Energy Consumption	
Gas (BTU)	62125

Electric (Watt-hr)	0
Hourly Standby Loss (BTU)	607.4
UA (BTU/hr*F)	10.472

The steady state efficiency is known as the flue loss efficiency, i.e., the ratio of heat energy not going up the flue to the energy entering the water heater. It does not include other losses. This is a pseudo-steady-state condition reached after about five minutes of burner on time.[7]

The UA value in Table 5 is the standby heat loss coefficient as defined in the DOE test procedure. This value includes the recovery efficiency. It is a calculation of energy needed to recover from heat lost during the standby period.[8]

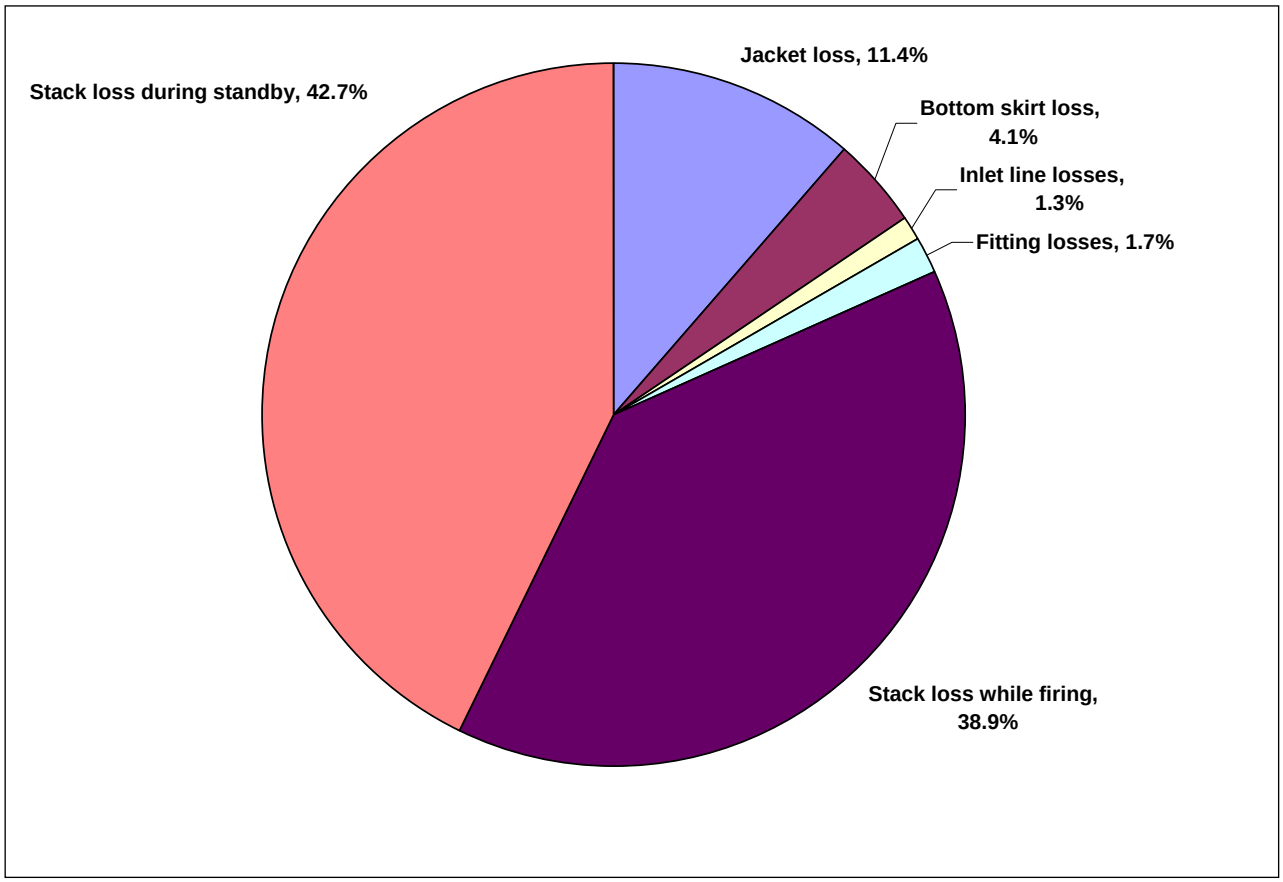

Figure 3: Percent Heat Losses from Tank

Impact on real versus test procedure energy use???
In actual operation water heaters operate at different water temperatures, ambient temperatures and humidity than specified in the test procedure. Other differences between laboratory and field conditions can be: the amount of hot water drawn; the number, length and timing of the draws; the height, diameter and configuration of the vent system; and the amount of excess air.

For a storage tank water heater, the greater the hot water use, the greater the efficiency. For example, if no hot water draws occurred, the water heater would still use energy to stay warm in standby mode. The output energy would be zero and the input energy is a finite number (pilot light and recovery of heat loss during standby) thus the efficiency would be zero.

Figure 4 shows how the average water temperature drops during the initial six water draws and how the flue temperature rises as the burner fires to reheat the water in the tank after a draw. After approximately 5.5 hours into the test, the flue outlet temperature tracks the water temperature but stays several degrees higher.

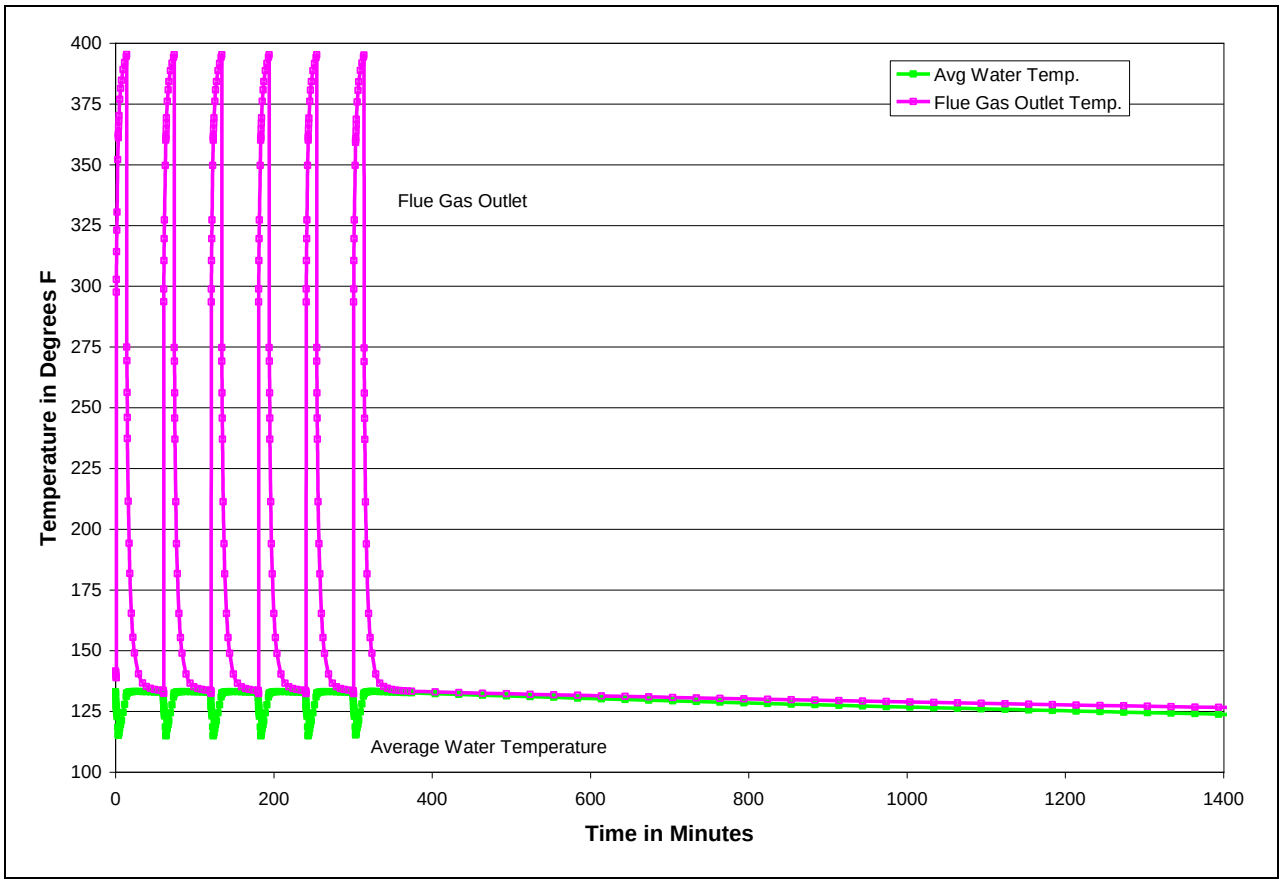

Figure 4: Water Heater Flue and Water Temperatures

OPTIONS TO INCREASE EFFICIENCY

Reduce Standby Losses Up the Flue

Standby losses occur up the flue when the burner is not firing. Based on the TANK simulation for a water heater meeting current minimum efficiency requirement and having a continuously burning pilot, the stack standby loss is slightly greater than the energy use of the pilot light. Standby heat loss up the flue could be reduced by:

- adding a flue damper,

- adding an induced draft blower that restricts flue gas flow when off, or
- using a side-arm water heater design.

Flue dampers close off the outlet to the flue when the burner is not firing. This prevents flue gases from convecting up the flue. They are commonly found on larger water heaters. After-market flue dampers may pose warranty issues.

An alternative to using a flue damper is to restrict flue gases during off cycles by using an induced draft blower. Induced draft blowers are located at the flue exit and are designed to pull combustion products through the flue and force them through the vent. Not all induced draft blowers adequately reduce off-cycle losses, but they could be specifically designed to reduce off-cycle losses by restricting air flow when the burner is not on. An additional benefit of an induced draft blower is to provide for a more controlled draft. It also allows for lower flue temperatures, such as can be found in condensing water heaters, because venting is not buoyancy induced. In addition, excess air requirements can be reduced by negating the need to design for variations in buoyancy due to factors external to the water heater.

The flue of a side arm water heater does not run through the tank but rather is attached external to the water heater insulation. Because the heat from the combustion chamber is transferred to the water tank indirectly, heat from the water is not lost up the flue during standby mode when the burner is not firing. It is important not to reduce possible efficiency advantages of a side arm design by allowing the heat from a continuously burning pilot to be lost up the flue.

Reduce other standby losses
Standby losses could also be reduced by:

- adding additional insulation to the water heater jacket,
- insulating fittings,
- reducing losses through the pipes by improving heat traps and by adding insulation to attached piping.

Increase Recovery Efficiency
Recovery efficiency is the efficiency to heat the water in the tank after a water draw. Increasing efficiency when the burner is firing without modifications to the vent and the flue can lead to excessive condensation. Condensation in the vent and flue become an issue when combustion efficiencies exceed approximately 82%. Condensation, while tolerated by the water heater for short durations, will corrode the flue over time until it leaks. The vent system can also become corroded.

Another method of increasing recovery efficiency is to decrease excess air. Excess air is the combustion air mixed with the fuel beyond what is required for combustion. In this model the excess air is set at 32%. While less excess air would increase the combustion efficiency, some excess air is necessary due to variability of the stack effect and restrictions to combustion air supply. Manufacturers must set excess air with a safety factor because field conditions will differ from test conditions in a laboratory. Some excess air is also necessary because of imperfect mixing of fuel and air. If the amount of excess air is not adequate, the combustion products will

produce carbon monoxide. Other regulated emissions such as NOx can also be effected. Radiant burners may increase combustion efficiencies and reduce emissions.

Pilot Lights
Efficiency measures include:

- low input pilot lights, and
- intermittent pilot lights or direct ignition.

Typical pilot lights have an input of approximately 400 Btu/hr. Lower input pilot lights are not recommended due to reliability reasons.[9] If energy from the pilot light is not used to heat water, eliminating the pilot light will increase efficiency. Intermittent and direct ignition designs typically require an external electrical power source. Energy from self-generated power by thermo-electric or water driven turbine designs are a possibility.

CONCLUSION

Reducing heat losses up the flue during standby mode has the greatest potential for increasing water heater efficiency. Reducing jacket and fitting losses, while possibly less complicated to achieve, offer only a modest potential for increases in efficiency.

References

[1] U.S. Department of Energy, Office of Energy Efficiency and Renewable energy, 10 CFR Part 430, Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters; Final Rule, January 17, 2001, Washington D.C.
[2] TANK Computer User's Manual With Diskettes: An Interactive Personal Computer Program to Aid in the Design and Analysis of Storage-Type Water Heaters, July 1993, GRI-93/0186. Prepared by Battelle for Gas Research Institute
[3] TANK Computer User's Manual With Diskettes: An Interactive Personal Computer Program to Aid in the Design and Analysis of Storage-Type Water Heaters, July 1993, GRI-93/0186. Prepared by Battelle for Gas Research Institute
[4] 10 CFR Part 430, Vol. 55, No. 201 pp. 42162-42177, October 17, 1990. Federal Register, Energy conservation Program for Consumer Products; Final Rule regarding Test Procedures and energy conservation Standards for Water Heaters
[5] Dolan, P., *FVIR Water Heater Technology: Past, Present, and Future*, IATC 2004
[6] SCAQMD, Rule 1121, *Control of Nitrogen Oxides From Residential Type, Natural Gas-Fired Water Heaters*, Section C(3), Ammeded September 3, 2004.
[7] Battelle, *Assessment of Technology for Improving the efficiency or Residential Gas water heaters*, Third Interim Task Report, November 1 4, 1991, p. 86, prepared for Gas Appliance Technology Center, Gas Research Institute.
[8] DOE, 10CFR Part 430, Subpart B, Appendix E, p. 163, January 1, 2005.
[9] Battelle, *Assessment of Technology for Improving the efficiency or Residential Gas water heaters*, Third Interim Task Report, November 1 4, 1991, p. 56, prepared for Gas Appliance Technology Center, Gas Research Institute.

Appendix A: Main Input Menu

SCREEN C: TANK VERSION 2.0 MAIN INPUT MENU
CURRENT INPUT FILE
Input Screen Choices:
1. WATER HEATER SPECIFICATIONS .. [ ]
2. COMBUSTION CHAMBER SPECS ..... [ ]
3. FLUE SPECIFICATIONS ..... [ ]
4. SUPPLY AND DRAW PIPE SPECS ... [ ]
5. HEAT XFER SPECS FOR FITTINGS . [ ]
6. MATERIAL PROPERTIES ..... [ ]
7. OPERATING CONDITIONS ..... [ ]
8. TEST CONDITIONS & ELEC. INPUT. [ ]
9. SUPPLY/DRAW INFORMATION ..... [ ]
10. SIMULATION CONTROL PARAMETERS [ ]
11. GRAPHICAL DISPLAY CONTROL .... [ ]
12. OUTPUT FILES CONTROL ... . [ ]
13. RUN SIMULATION/EXIT TANK ..... [*]

Appendix B: Input Screens

SCREEN D1: WATER HEATER SPECIFICATIONS
1. Tank Type: Standard Center Flue=1 1
Submerged Combustion=2
2. Tank Volume (gallons) 38.00
3. Internal Tank Diameter (in) 15.84
4. Pressure Vessel Wall Thickness (in) 0.0800
5. Outer Jacket Shell Thickness (in) 0.0190
6. Side Insulation Thickness (in) 1.981
7. Top Insulation Thickness (in) 1.981

SCREEN E1: STANDARD COMBUSTION CHAMBER SPECIFICATIONS

1. Combustion Chamber Height (in) 8.500
2. Comb. Chamber Inner Wall Thickness (in) 0.040
3. Distance Between Burner and Center Flue Entrance (in) 4.000
4. Addtl. Weight in Comb. Chamber (lb) 1.000
5. Heat Transfer Area Multiplier for Dome-shaped Combustion Chamber 1.150

SCREEN F1: FLUE SPECIFICATIONS FOR STANDARD COMBUSTION CHAMBER SYSTEMS
1. Number of Flues 1
2. Internal Flue Diameter (in) 3.840
3. Flue Wall Thickness (in) 0.0800
4. Flue Baffle Thickness (in) 0.0625
5. Avg. Flue Baffle HX Multiplier 2.980

NOTE: If you change the Average flue baffle HX multiplier, the same value will be used at each level of the flue. To specify a different HX multiplier at each level, use the table at the right.

6. Flue Baffle HX Multipliers

Level	HX Multiplier
Top = 1	2.980
2	2.980
3	2.980
4	2.980
5	2.980
6	2.980
7	2.980
8	2.980
Bottom = 9	0.000

0 indicates no baffle present

SCREEN G: WATER SUPPLY AND DRAW PIPE SPECIFICATIONS

1. Pipe Inside Diameter (in) 0.785
2. Pipe Wall Thickness (in) 0.045
3. Vert. Supply Pipe Height (in) 24.000
4. Vert. Supp. Pipe Insul. Thk. (in) 0
5. Addtl. Supply Pipe Length (in) 36.000
6. Addtl. Supp. Pipe Insul. Thk. (in) 0.000
7. Vert. Draw Pipe Height (in) 24.000
8. Vert. Draw Pipe Insul. Thk. (in) 0.000
9. Addtl. Draw Pipe Length (in) 36.000
10. Addtl. Draw Pipe Insul. Thk. (in) 0.000
11. Supply Pipe Heat Trap (0,1,-1)* -1
12. Draw Pipe Heat Trap (0,1,-1)* -1

* 0 = No heat trap
1 = Metal heat trap
-1 = Plastic heat trap

SCREEN H: HEAT TRANSFER SPECIFICATIONS FOR FITTINGS

Fitting	Exposed Area	R	Fitting Emissivity
	(in2)	(hr*ft2*F/Btu)	
Pressure Relief Valve	18.000	0.100	0.400
Drain	9.000	0.100	0.400
Thermostat	9.000	0.100	0.400
Cathodic Protection Tubes	0.000	0.100	0.400

SCREEN I1: PROPERTIES OF TANK MATERIALS

Material	Surface Roughness	Emissivity	Conductivity	Density	Specific Heat
	(ft)		(Btu/h-ft-F)	(lbm/ft3)	Btu/lbm-F
Tank & Flue	0.000500	0.950	30.0000	480.00	0.1000
Flue Baffle	-	0.950	0.0000	480.00	0.1000
Jacket Shell	-	0.920	30.0000	480.00	0.1000
Supply/Draw Pipes	-	0.380	196.0000		
Pipe Insulation	-	0.900	-	-	0.0200
Jacket Insulation	-	-	0.0155	2.00	0.3800
Skirt Insulation	-	-	0.0300	4.00	0.2300

SCREEN J: OPERATING CONDITIONS

1. Firing Rate (Btu/hr) 40000.00
2. Pilot Input Rate (Btu/hr) 400.00
3. Excess Air (%) 32.00
4. Off-cycle Pressure Loss Coeff. 14.0119
5. Thermostat Set Point (F) 128.50
6. Thermostat Dead Band (F) 20.00
7. Volume to Thermostat (gal) 4.05
8. Burner On Delay for EIDs (sec) 0.0
9. Supply Water Temperature (F) 58.00
10. Initial Water Temperature (F) 118.00
11. Ambient Temperature (F) 70.00
12. Relative Humidity (%) 50.00
13. Atmospheric Pressure (atm) 1.000
14. Higher Heating Value (Btu/SCF) 1028.0
15. Specific Gravity 0.58000

SCREEN K: TEST CONDITIONS & ELECTRIC INPUTS

1. Nominal Maximum Mean Tank Temp. (F) 135.00
2. Nominal Ambient Temperature (F) 67.50
3. Nominal Supply Temperature (F) 58.00
4. Total Time of Simulated Use Test (hr) (24 std) 24.00
5. Number of Draws in Simulated Use Test (6 std) 6
6. Water Temp. Drop in Rating Tests (F) 25.00
7. On-Cycle Power Consumption (W) 0.00
8. Off-Cycle Power Consumption (W) 0.00
9. Startup Energy Cons. (W-Hr) 0.0000
10. Additional Elec. Engy. (W-Hr) 0.0000
11. Elec.Conversion to Source Btus 1.000

SCREEN L: WATER SUPPLY/DRAW INFORMATION

Level:	Supply Rate (gal/min)	(%)
Top=1	0.000	0.000
2	0.000	0.000
3	0.000	0.000
4	0.000	0.000
5	0.000	0.000
6	0.000	0.000
7	0.000	0.000
8	0.000	0.000
Bottom = 9	3.000	100.000
Total Supply	3.000	100.000

	Draw Rate (gal/min)	Draw (gal)	Length of Draw (min:sec)	Time Between Start of Draws (hr:min:sec)
Precond	3.000	10.00	3:20	
Draw No.				
1	3.000	10.75	3:35	1: 0: 0
2	3.000	10.75	3:35	1: 0: 0
3	3.000	10.75	3:35	1: 0: 0
4	3.000	10.75	3:35	1: 0: 0
5	3.000	10.75	3:35	1: 0: 0
6	3.000	10.50	3:30	

Actual Supply Rates are Percent of Current Draw Rate

Total Draw 64.25 gallons

Appendix C: Program Control Selection

SCREEN M: SIMULATION CONTROL PARAMETERS

1. Select a Control Option (0-5): 0
    0:Simulated Use Test
    1:First Hour Rating Test
    2:Find flue loss coefficient
    3:Thermostat calibration
    4:Average Hour Rating Test
    5:Simulated Use Test with Specified
    Recovery Efficiency,% =

2. Simul.Test Precond Opts (0-1): 0
    0: 3 draws before test starts
    1: One heatup cycle
3. Select a Display Option (0-2): 0
    0: Minimal display (highest speed)
    1: Detailed on-screen temps. (text)
    2: Graphical temperature display

SCREEN N: GRAPHICAL DISPLAY CONTROL
1. Display Water Temperatures? (0-No/1-Yes) 1
2. Use Manual or Automatic Ranging for Water Temp. Display?
    (0-Manual/1-Autoranging) 0
    Manual Range for Water Temperatures: Lo 58.0 Hi 140.0
3. Display Flue Temperatures? (0-No/1-Yes) 0
4. Use Manual or Automatic Ranging for Flue Temp. Display?
    (0-Manual/1-Autoranging) 0
    Manual Range for Flue Temperatures: Lo 70.0 Hi 600.0

SCREEN P: OUTPUT FILES CONTROL
Generate Output Files (for possible plotting)? (0-No/1-Yes)
0. Flow Rates: Average and Outlet Temperatures 1
1. Zone 1 Jacket Wall Temperatures 0
2. Zone 2 Pressure Vessel Wall Temperatures 0
3. Zone 3 Wall and Water Temperatures 0
4. Zone 4 Wall and Water Temperatures 0
5. Zone 5 Center Flue Wall Temperatures 0
6. Zone 6 Flue Baffle Temperatures 0
7. Zone 7 Flue Gas Temperatures 0
8. Pipe and Fitting Surface Temperatures 0

Appendix D: Output (Modified Baseline Water Heater)

ENERGY BALANCE	
Gas input energy (BTU)	62,152
Jacket loss (BTU)	2,771
Bottom skirt loss (BTU)	998
Supply line losses (BTU)	307
Fitting losses (BTU)	411
Supply water heating (BTU)	41,095
Jacket metal storage (BTU)	-35
Outer and top vessel metal storage (BTU)	-55
Inner and bottom vessel metal storage (BTU)	-64
Water node storage (BTU)	-2,971
Stack loss while firing (BTU)	9,479
Stack loss on standby (BTU)	10,404

24 HOUR SIMULATED USE TEST SUMMARY	
Energy Factor	0.6029
Recovery Efficiency	0.7797
Steady-state Efficiency	81.57%
Energy Consumption	
Gas (BTU)	62125
Electric (Watt-hr)	0
Hourly Standby Loss (BTU)	607.4
UA (BTU/hr*F)	10.472

Appendix E: Glossary

Recovery efficiency – energy used to heat water in a storage water tank

Standby energy – energy lost while no water draws occur, excluding the energy to reheat the water after a water draw

Combustion efficiency - is basically how close the combustion is to stoichiometric conditions. This is limited by imperfect mixing, which then produces hydrocarbons, and carbon monoxide. To prevent this excess air (more air than theoretically needed for complete combustion) needs to be used. Because field conditions can vary from laboratory test conditions (draft may vary depending on stack height, ambient conditions), an additional amount of excess air must be added. Using an induced draft or forced draft burner can reduce the necessity of excess air.

Steady state conditions – because the water in the tank rises as heating occurs, steady state conditions are never reached. The temperature of the water in the tank effects the efficiency of the water heater.

Excess air – combustion air in excess of what is theoretically needed for complete combustion to occur. This is typically measured with a combustion analyzer measuring CO2 or Oxygen.

Draw pipe – this is the water heater outlet pipe which supplies hot water to the house.

Supply pipe – this is the water heater inlet pipe with refills the water heater with cold water

Note: The TANK program uses the terms “supply line” and “draw line” to designate the pipes transporting cold water to the water heater and hot water from the water heater, respectively. In this report, unless tables are directly copied from the TANK program output, we use the terms “inlet pipe” and “outlet pipe” for the pipes supplying water to and from the water heater.