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Hydronic Baseboard Thermal Distribution System with Outdoor Reset Control to Enable the Use of a Condensing Boiler

Dr. Thomas A. Butcher

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Energy Sciences and Technology Department
Brookhaven National Laboratory
P.O. **Box** 5000
Upton, **NY** 11973-5000
www.bnl.gov

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Abstract

Use of condensing boilers in residential heating systems offers the potential for significant improvements in efficiency. For these to operate in a condensing mode the return water temperature needs to be about 10 degrees below the saturation temperature for the flue gas water vapor. This saturation temperature depends on fuel type and excess air and ranges from about 110 F to 135 F. Conventional baseboard hydronic distribution systems are most common and these are designed for water temperatures in the 180 F range, well above the saturation temperature. Operating strategies which may allow these systems to operate in a condensing mode have been considered in the past. In this study an approach to achieving this for a significant part of the heating season has been tested in an instrumented home. The approach involves use of an outdoor reset control which reduces the temperature of the water circulating in the hydronic loop when the outdoor temperature is higher than the design point for the region. Results showed that this strategy allows the boiler to operate in the condensing region for 80% of the winter heating season with oil, 90% with propane, and 95% with gas, based on cumulative degree days. The heating system as tested combines space heating and domestic hot water loads using an indirect, 40 gallon tank with an internal heat exchanger. Tests conducted during the summer months showed that the return water temperature from the domestic hot water tank heat exchanger is always below a temperature which will provide condensing operation of the boiler.

In the field tests both the condensing boiler and the conventional, non-condensing boiler were in the test home and each was operated periodically to provide a direct performance comparison.

Acknowledgements

The author would like to acknowledge Yusuf Celebi, George Wei, and Dave Elling of the BNL team who contributed a great deal to the experimental effort. Appreciation is also expressed to Pete Caruso and the technical group at Monitor Products who provided the condensing boiler for this work and helped with planning the operating conditions for the tests. Finally the author would like to acknowledge the support and guidance of Arun Vohra, technical representative overseeing this work for the **U.S.** Department of Energy, the project sponsor.

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1. INTRODUCTION

Condensing boilers offer the potential to significantly improve efficiency in home heating systems by reducing the amount of energy discarded with exhaust. This includes both sensible heat in flue gas and the latent heat of flue gas water vapor. Table 1 shows the magnitude of just the latest loss for gas, propane, and heating oil.

Gas-fired condensing boilers currently have a substantial market in Europe and the **U.S.** Oil-fired condensing boilers are starting to capture market share in Europe and have recently been introduced to the North American market.

Fuel	Latent Heat Loss (% of Input Based on Higher Heating Value)
Natural Gas	9.55
Propane	7.99
Heating: Oil	6.50

The saturation temperature of water vapor in flue gas depends upon fuel hydrogen content, excess air, and, to a smaller degree, ambient air humidity. Figure 1 shows saturation temperature vs. excess air for gas, propane, and oil at an ambient humidity level of 70% at 70 F. To illustrate humidity impacts Figure 2 shows saturation temperature vs. humidity for propane at high and low excess air.

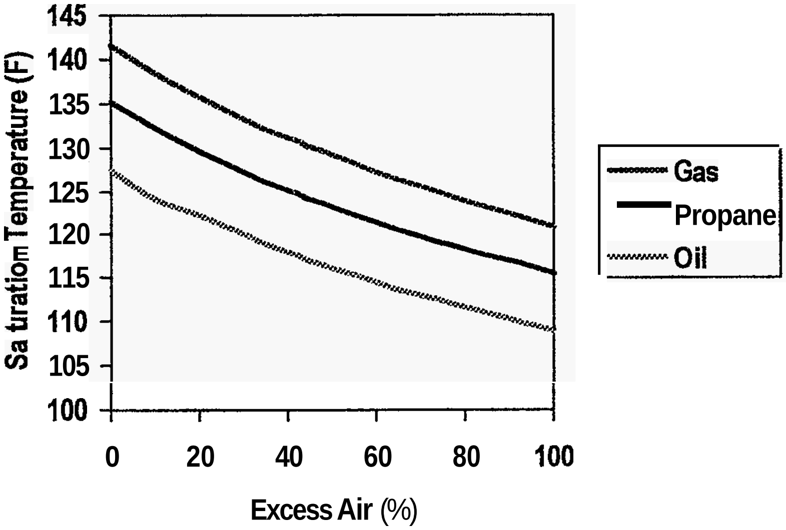

Figure 1 Saturation temperature of the water vapor in flue gas as a function of excess air for different fuel types

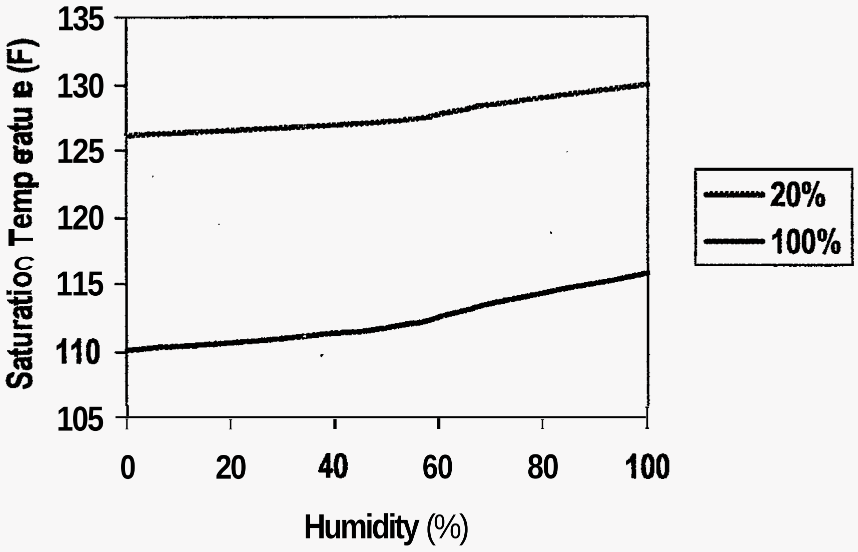

Figure 2 Saturation temperature of the water vapor in flue gas as a function of ambient humidity (at 70 F) for propane at two excess air levels

In a specific installation, condensation depends strongly on the heat exchanger surface temperatures and, to a lesser extent on the average flue gas temperature. It is very common for condensation to occur in these boilers at flue gas temperatures above the saturation temperature. These boilers are typically configured with a counterflow-type arrangement and return water temperature below the saturation temperature is critical for condensation. Radiant flow heating systems are designed for operation with low circulating water temperatures and are a good match for condensing boilers. While these systems are gaining popularity they clearly represent only a small fraction of the current home population. Another option gaining popularity in some new home markets is hydro-air systems. While these could be designed with large heat exchangers and low return water temperatures they typically are not and return water temperatures are above the saturation temperature.

In North America the dominant residential hydronic heat delivery mode is baseboard radiators, typically designed for operation at higher water temperatures. In homes the installed length of baseboard is planned based on high temperature circulating water. Under the **ASHRAE** standard for rating the efficiency of heating boilers, supply and return water temperatures of 140°F/120°F are assumed [1]. Boilers which also provide domestic hot water generally operate at higher temperatures – 180°F. Figure 3 shows the manufacturers rated capacity data for one very common baseboard radiator product.

Methods of modifying a baseboard heating system to achieve significant flue gas latent heat recovery were addressed in a study by Krajewski and Andrews [2]. Strategies evaluated included:

1. Reduced flow through the baseboards to reduce return water temperature.
2. Strategy 1 above with periodic flow reversal to reduce the impacts of uneven space heating.
3. Addition of baseboard to a conventional system to increase the heat delivery capacity at low circulating water temperatures.
4. Addition of fan-coil unit heaters or radiant panels to reduce the return water temperatures with conventional systems.
5. Use of two speed circulators with conventional baseboards.

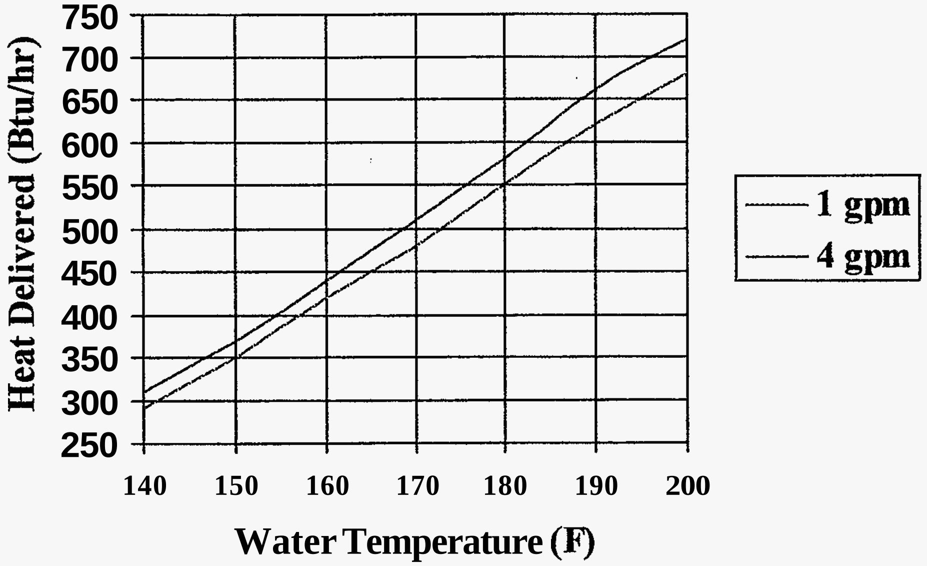

Figure 3 Nominal rated heat delivery capacity for typical residential baseboard convectors (3/4 inch)

The strategy of reducing the circulating water flow can be very effective in increasing the difference between the supply and return temperatures but can lead to uneven heating of the space. The second strategy listed above addresses this but requires the addition of control and actuator components which add cost and may be difficult to implement on a refit basis. The addition of baseboard or fan-coil units also adds cost and may not be practical on an existing home. Two speed circulators are available and offer the advantage of relatively easy installation in an existing home. These could operate at low speed for most of the heating season and high speed, for full delivery capacity only during the coldest parts of the heating season.

The operating strategy tested in the field during this project is related to this last approach. **As** discussed in Section **3**, an outdoor reset control was integrated with a condensing boiler to have supply and return water temperature which increases as the outdoor temperature decreases. The circulating water flow rate was kept within a normal range to provide uniform space heating at all outdoor conditions. This approach is used commonly in Europe with condensing boilers.

With a conventional boiler, where the supply water temperature is fixed, the cyclic efficiency of the boiler decreases as the load on the boiler decreases (increasing outdoor temperature). This is caused by off cycle and jacket losses which are an increasing fraction of the total heat input rate. With condensing boilers with outdoor reset a completely opposite efficiency-load relation occurs. **As** the load decreases with increasing outdoor temperature the supply and return water temperatures decrease and efficiency increases.

2. OBJECTIVE

The objective of the work described in this report is the evaluation of the performance of a condensing boiler refit to an existing "baseboard" heating system with integrated domestic hot water, using a control strategy (outdoor reset) to achieve condensation during some fraction of the heating season. The focus has been more on the effectiveness of the control strategy than on the performance of the specific boiler and fuel tested. The project. was planned to provide information which can aid in assessing the potential for achieving energy savings achievable through the refit of condensing boilers to existing hydronic-heat homes.

3. EXPERIMENTAL

In this project a condensing oil-fired boiler was tested first in the **BNL** and then installed at the field site along side the existing boiler. This unit (Monitor Model FCX) is a steel boiler designed with a primary (non-condensing) and secondary (condensing) heat exchanger section. This general arrangement is used in many condensing boiler designs and allows the use of lower cost materials in the primary section. Return water from the heating zones passes first through the secondary section and then through a crossover to .the primary heat exchanger. In the operation of boilers of this type it is desirable to have crossover water temperatures above the saturation temperature of water vapor in the flue gas to avoid high corrosion rates in the primary heat exchanger. This needs to be considered in the control system design and operation of the boiler.

All lab tests were conducted at BNL and the boiler was installed with a small, closed-loop cooling circuit including a plate heat exchanger. Cold supply water flowed through the secondary side of this heat exchanger, picked up the heat fiom the circulating boiler water, and then was discharged to the drain. **A** flow meter was used in combination with temperature measurements before and after the heat exchanger, on the secondary ("city water") side to accurately measure energy output from the boiler. Fuel flow, for energy input, was measured using a coriolis flow meter. During these steady state tests the rate of collection of condensate in steady state and the chemistry of the condensate were studied as a function of return water temperature in steady state.

All field tests were conducted in a 2000 ft^2 ranch-style home with a finished basement and a baseboard hydronic heating system. The heating system has **4** zones as follows:

Zone **1** – heats most of the main floor with a total length of fin-tube baseboard radiation of **54** feet.
Zone **2** – heats the finished basement with a total baseboard length of **24** feet.
Zone **3** – heats an added den with a total baseboard length of 19 feet.
Zone **4** – heats the master bedroom with a total baseboard length of **18** feet.

The system provides domestic hot water using an indirect, **40** gallon tank with an internal heat exchanger. This tank is treated as a priority zone from the heating boiler. The baseline boiler installed in the house is a conventional, non-condensing steel boiler, fired with oil. This unit is configured as a cold-start boiler which is a bit unusual for oil firing. The boiler (Thermodynamics Model LM **75)** has a conventional chimney vent without a barometric damper and uses a modern retention-head, yellow flame oil burner (Beckett Model **AFII)** with an effective firing rate of **0.65** gallons per hour. The nominal AFUE rating for the boiler is **85.2%.**

The condensing boiler tested has two hydronic supply output connections. One is directly from the primary heat exchanger and provides water at the highest temperature for high output to the domestic hot water tank. The second supply output circuit has an internal pump and mixing valve which combines cooler return water with high temperature water from the primary heat exchanger. This results in a lower temperature mixed supply to the space heating zones. **As** normally supplied includes a mixing valve with a manually-set, fixed heating zone supply water temperature. This design enables the boiler to easily be used with heating systems requiring any circulating water temperature. This basic arrangement for the boiler is shown in Figure **4.**

For the purposes of this field test the manually set, fixed mix temperature valve was replaced by a valve operator which provides an outdoor reset function. The valve is not commonly used in the **U.S.** and was made available to this project by the manufacturer for test purposes **(ESBE** Model **VSE-1).** Figure 5 includes photos of the manual mixing valve and the outdoor reset mixing valve. The outdoor reset valve includes a **24VAC** power input, an outdoor temperature sensor, and a supply water (mixing valve outlet) . sensor. This valve provides a “reset curve” which is field adjustable. The reset curve chart is included in Figure **6.** The selection of the operating curve is typically done by trial and error in a specific home with Curve **4** in Figure **6** as the suggested initial condition. The control enables operation between the curves (i.e. the control can be set to 3.5 or **3.75** as desired).

In the field test the piping was arranged so that either boiler could be used to meet the domestic hot water or heating loads. The boilers could be switched back and forth rapidly to enable performance comparisons during similar weather conditions. Figure **7** shows the basic hydronic piping arrangement for just the heating part of the system and Figure **8** shows the arrangement for just the domestic hot water **part** of the system.

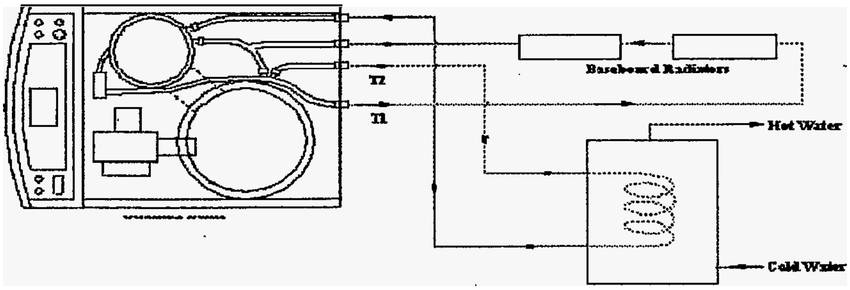

Figure 4 Basic arrangement of condensing boiler

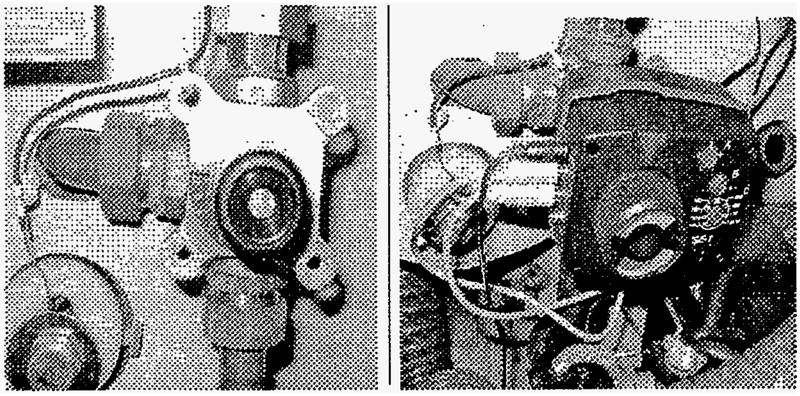

Figure 5 Photos of conventional (fixed temperature) mixing valve and mixing valve with outdoor reset function

Instrumentation installed at the site includes BTU meters on the heating and domestic hot water circuits as shown in Figures 7 and **8.** These meters **(ISTEC** Model 5202) have pulse count outputs for both accumulated Btu's and gallons of water flow. These pulses were logged using a (Hobe H21-02 logger from Onset Computer Corp.). Fuel flow for direct measurement of heat input was measured using a positive displacement fuel flow meter (ISTEC Model V20 **4** USG N-RE) This unit also has a pulse output recorded with the same logger, Temperatures in the system were measured using installed type K thermocouples, logged using an Omega Model OM-CP_OCTTEMP thermocouple logger.

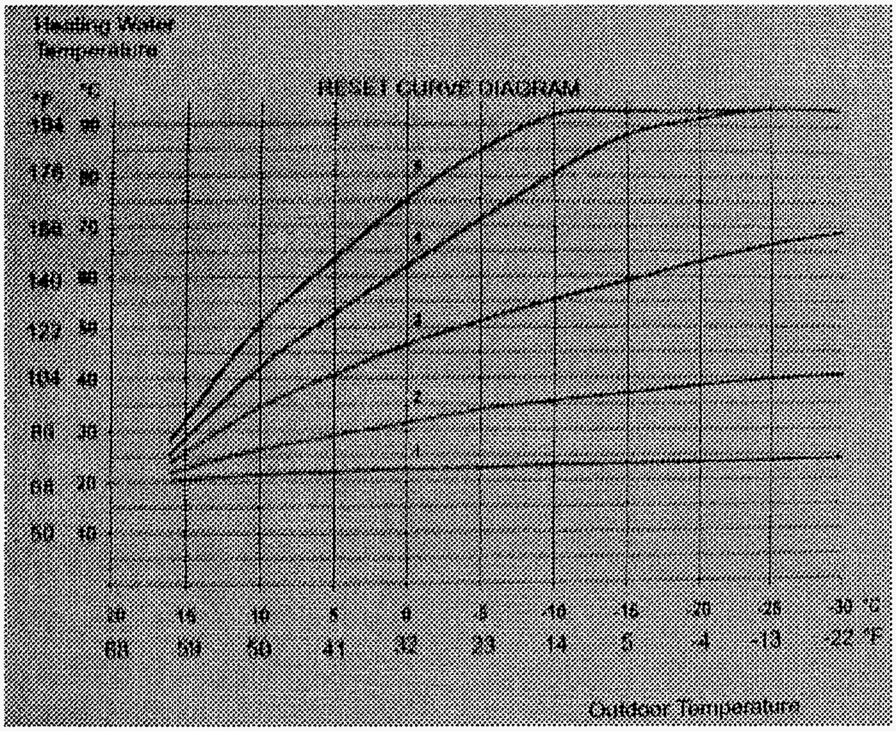

Figure 6 Automatic mixing valve response chart

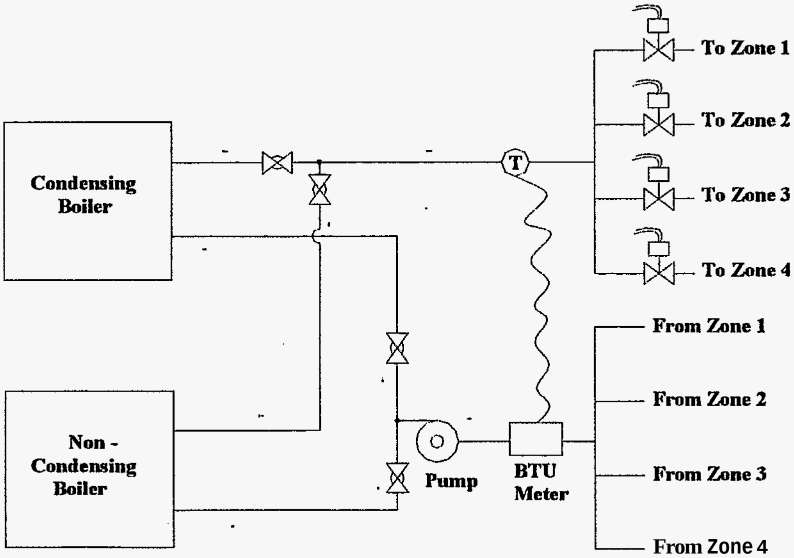

Figure 7.Illustration of the hydronic arrangement at the field site – heating mode

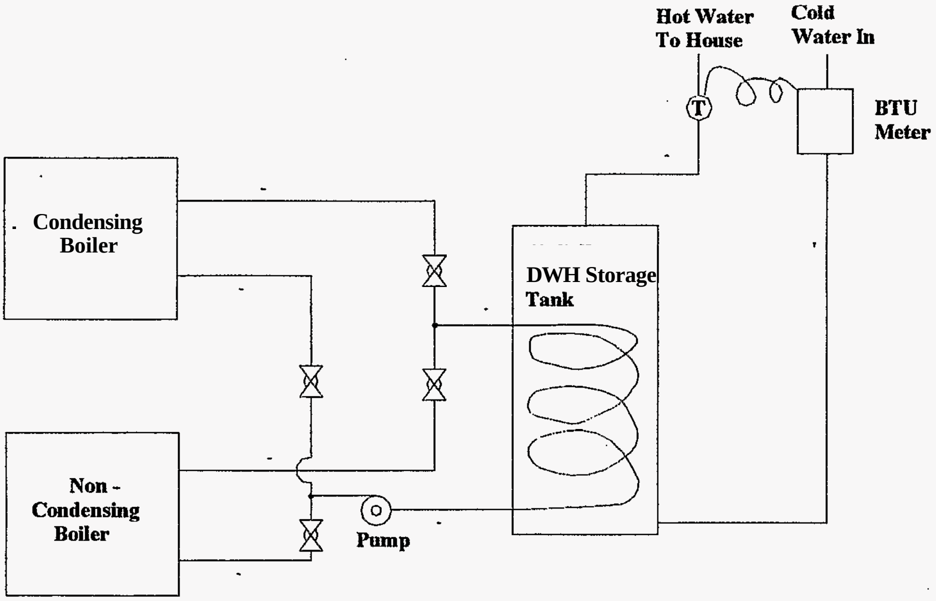

Figure 8 Illustration of the hydronic arrangement at the field site – domestic hot water mode

For efficiency determinations a basic input/output approach was used. For some measurement periods the only load was space heating and efficiency in these cases was based only on fuel consumption and Btu's to the space heating zones. These were generally special, relatively short term tests, often conducted with constant attendance to give provide data at high load conditions. More commonly there was a significant domestic hot water component to the load over a test period. In the summer test period domestic hot water was the only load. During these times test periods for efficiency determination were started and ended just after the domestic hot water tank was "satisfied". This was done to ensure that there was, in all cases, the same amount of energy stored in the domestic tank.

4. RESULTS OF LABORATORY TESTS OF THE CONDENSING BOILER

For the condensing boiler tested in the BNL lab Figure 9 shows the measured thermal efficiency as a function of return water temperature. Figure 10 shows the rate of condensate collection, again as a function of return water temperature. These basically serve to show that this boiler needs a return water temperature below about **115** F to begin condensing and this is about **8** degrees below the saturation temperature. If gas were used instead of oil the return water temperature at which condensation started to occur would be considerably higher.

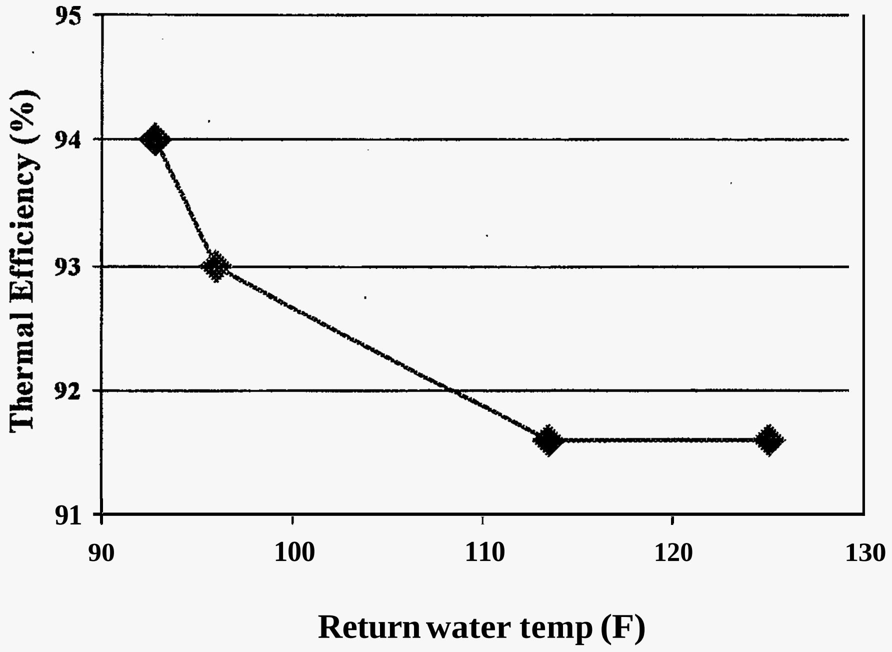

Figure 9 Thermal efficiency of the oil-fired, condensing boiler as a function of return water temperature. Measured in the BNL lab.

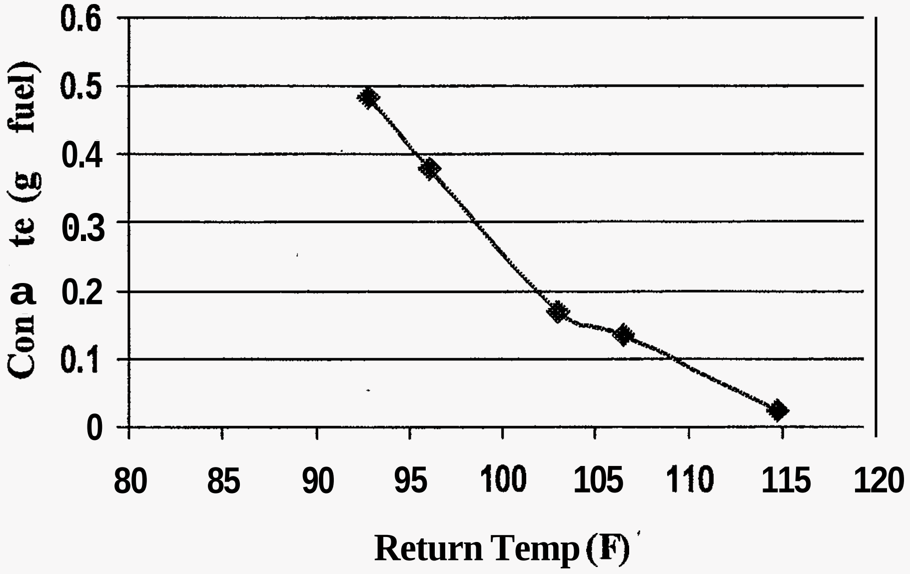

Figure 10 Rate of condensate collection as a function of return water temperature. Oil-fired condensing boiler tested in the BNL lab.

5. RESULTS OF FIELD TEST

5.1 Tests of the Baseline (Non-Condensing) Boiler in the Combined Heating and Domestic Hot Water (Winter) Mode

The primary objective of this project was the evaluation of the hydronic distribution system with low circulating water temperature to determine potential for condensing. However, a limited amount of testing was also done of the baseline boiler during typical winter operation. Here the boiler is configured in a cold-start mode. When there is a call for heat the boiler operates with a fixed temperature limit set at 190 F. During typical heat calls the circulating water flow through the baseboards varies from 3 to 4.9 gallons per minute, depending upon the number of zones calling. Return water temperature varies from 145 to 165, again depending upon the number of zones calling. During a typical response to a thermostat call, the burner fires two or three times over a 24-37 minute time period until the demand is satisfied, indicating that the capacity of the burner exceeds the capacity of the baseboard system to deliver heat to the home. In one test the home was allowed to go cold overnight and the system performance was carefully monitored during the recovery period. Here all 4 zones were calling for heat for a two hour period. The rate of delivery of heat from the boiler to the baseboards over this time period averaged 54,000 Btu/hr. For comparison purposes, the nominal output of the 115 feet of baseboard in the home at 180 F and 550 Btu/hr/ft would be 63,250 Btu/hr. Considering the supply and return water temperatures the actual measured output seems quite reasonable. **This** boiler is fired with an input rate of 88,200 Btu/hr. Assuming an average efficiency of 80%, the maximum output would be 70,560 Btu/hr. The burner input is then oversized by **3**1% relative to the maximum baseboard delivery.

Performance tests with the baseline system were done over three winter time periods and results are shown in Figure 11 as input plotted vs. output. This will be compared with other systems in later sections. These points are converted to an efficiency vs. output plot in Figure 12.

5.2 Tests of the Condensing Boiler in the Combined Heating and Domestic Hot Water (Winter) Mode

One of the objectives in testing this specific arrangement for the condensing boiler was to determine what was the minimum setting of the controller on the outdoor reset mixing valve would provide adequate comfort for the test home. Referring to Figure 6 it was generally observed that a curve 3 met the home demand although under prolonged cold periods one zone (basement) was found to be marginal. Setting the control to follow curve 4 in this same figure clearly provided adequate heat. Based on all considerations a curve between 3 and 4, but closer to 3, is seen as correct for this specific home. This is really a subjective observation, based on occupant comments. Measurements of room temperature on the main floor of the home show that curve **3** is clearly adequate. In the application of a system of this type to any home there would ideally be an adjustment period where the occupants find the correct setting of the outdoor reset control and this is discussed in the manufacturer's product instruction sheets.

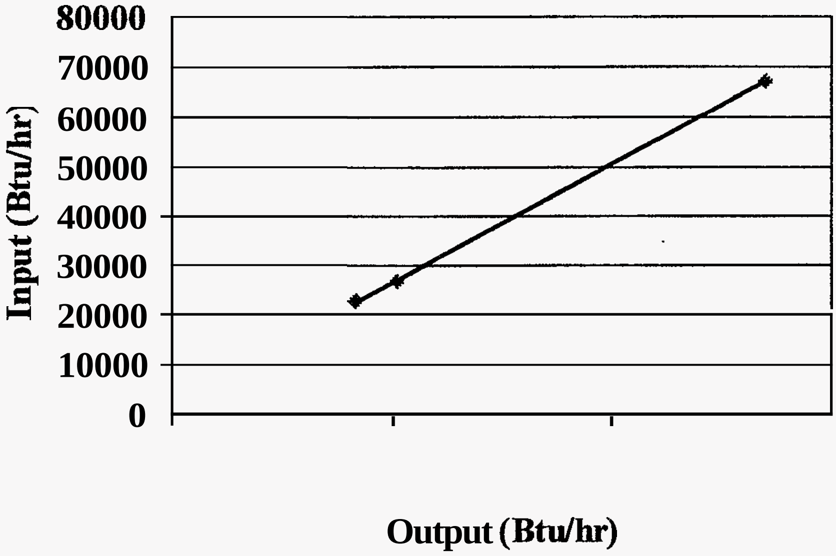

Figure 11 Results of field tests, non-condensing boiler, winter mode, input vs. output

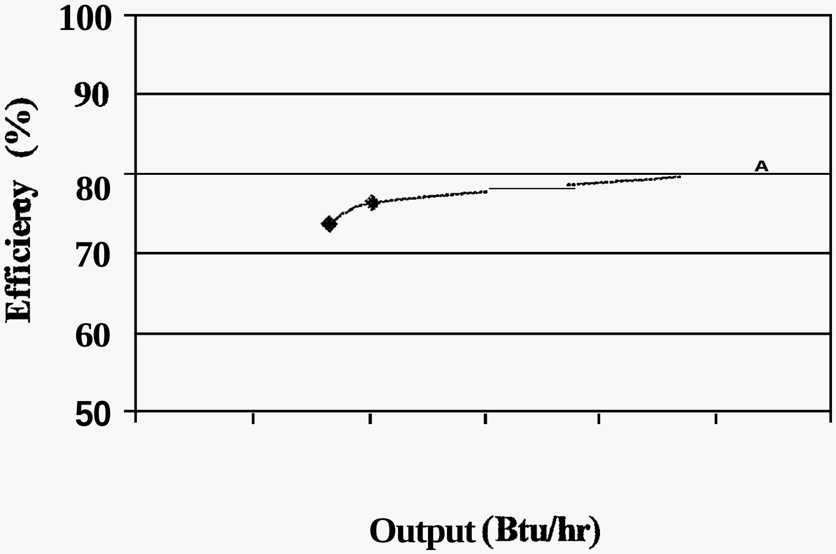

Figure 12 Results of field tests, non-condensing boiler, winter mode, efficiency vs. output

In addition to the setting of the outdoor reset control mixing valve, the circulation flow rate has an important impact on the return water temperature, condensation, and uniformity of temperature in the heated space. For nearly all tests with the condensing boiler this was adjusted to 2.7 gallons per minute when all zone valves were open, providing a supply / return temperature difference of 10-40 degrees (supply temperature dependent, see Figure 23). When less than 4 zone valves were open the flow typically decreased to 2.3 gpm.

Performance testing with this system was done primarily over a one month period and system data was recorded daily over this time. However, selected specific time periods, where the load was particularly well defined were used for detailed performance analysis.

Figure 13 provides an example of the way that the system operates with this control strategy and illustrates some of the data which was collected and used to analyze performance. This data was collected over an early morning time period in April, starting at about 3 am. The outdoor temperature during this period was steady at 41 F. In this figure, Temperature 1 is the water being sent to the baseboards for space heating and 2 is the return. The home "called" for heat constantly during this period. Temperature 3 is the boiler water. Point 4 is the hot water from the DHW storage tank measured roughly 12 inches from the tank and useful as an indicator of when hot water draws are being taken and also used for calculation of the domestic hot water energy flow. Temperature 5 is the gas temperature leaving the boiler primary heat exchanger and entering the secondary (condensing) section. This temperature is useful only as an indicator of when the burner is firing. Temperature 6 is the temperature of the water flowing from the boiler to the heat exchanger in the domestic hot water tank. This point provides a good indicator of when a domestic hot water tank "call" is in progress. In Figure 13 the first event shown is a tank call and this is labeled as time period A. After this time period the boiler only provides space heating and the burner fires with a regular period during this time. At points B and C illustrated in the figure there is a draw of domestic hot water from the tank, indicated by a sharp, sudden increase in temperature 4. During normal space heating load the boiler is maintained at a high, normal temperature but the mixing valve/control arrangement provides very low water temperature to the hydronic distribution system.

The behavior of the system when the tank call starts is interesting. As shown in Figure 13 there is a sudden, sharp drop in the boiler water temperature as there is a sudden flow of relatively cold return water from the tank heat exchanger piping. The control valve, which has a strongly damped response, reacts by opening. As the water temperature increases with the burner firing the supply to the baseboard distribution system overreacts, reaching higher than normal levels for a brief period.

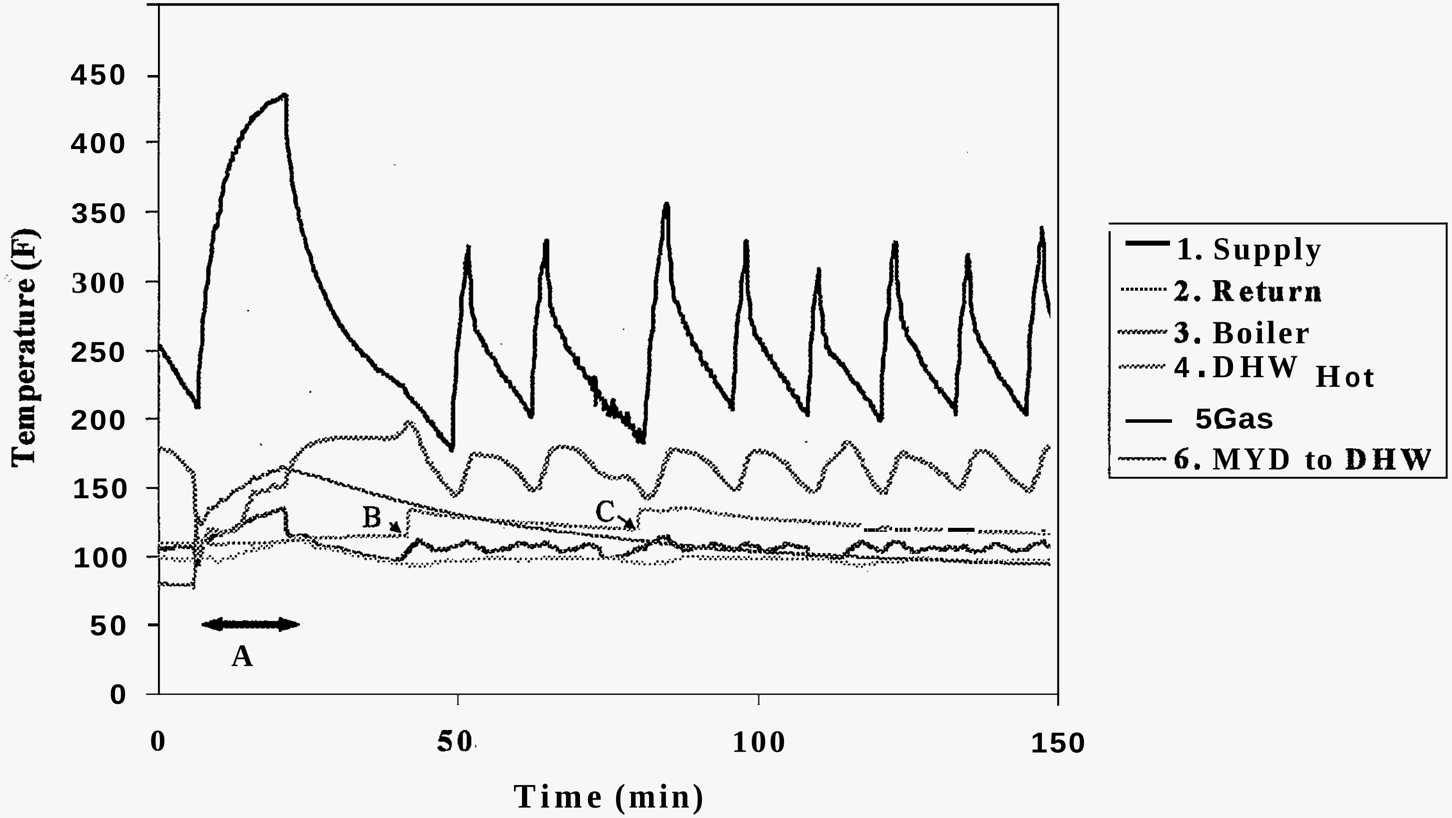

Figure 13 Condensing boiler, heating mode, example of operation (see text for explanation of temperature measurement points)

For the condensing system tested in the winter mode analysis of input and output energy and efficiency can be done in two' ways. First, for time periods where there was no domestic hot water tank call, fuel energy input can be determined from burner run times and output can be determined from hydronic loop flow rates (from logged flow meter pulse data) and the supply and return water temperatures. Here energy flows to the domestic hot water system are simply ignored because they just come out of the storage tank. The boiler, for these time periods, is in a heat only mode. Typically periods up to **8** hours can be found in the data where a tank call did not occur, often at night. In the second approach time periods are selected for analysis which include both heating and domestic hot water. Here the time period must be selected so that the amount of energy stored in the tank is the same at the start and end.of the period. To do this the analysis of fuel energy input, hydronic heating output, and domestic hot water energy output was integrated over a time period starting and ending just at the end of a hot water storage tank call.

Figure **14** shows input / output results for both of these cases. In Figure **15** the linear regression lines from Figure **14** have been converted into efficiency vs. output. Clearly the system is more efficient in a heating only mode.

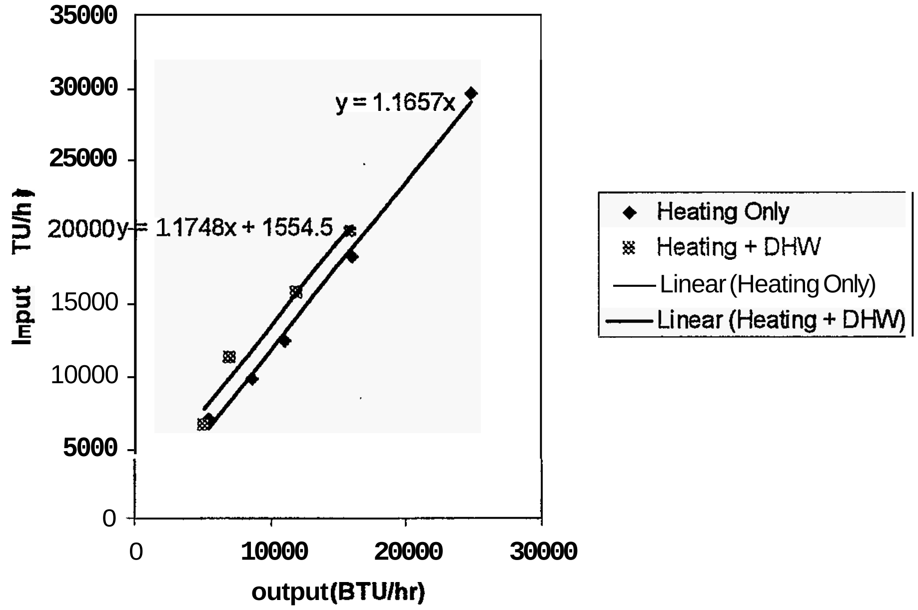

Figure 14 Condensing boiler, winter mode, input vs output heating and combined heating DHW loads

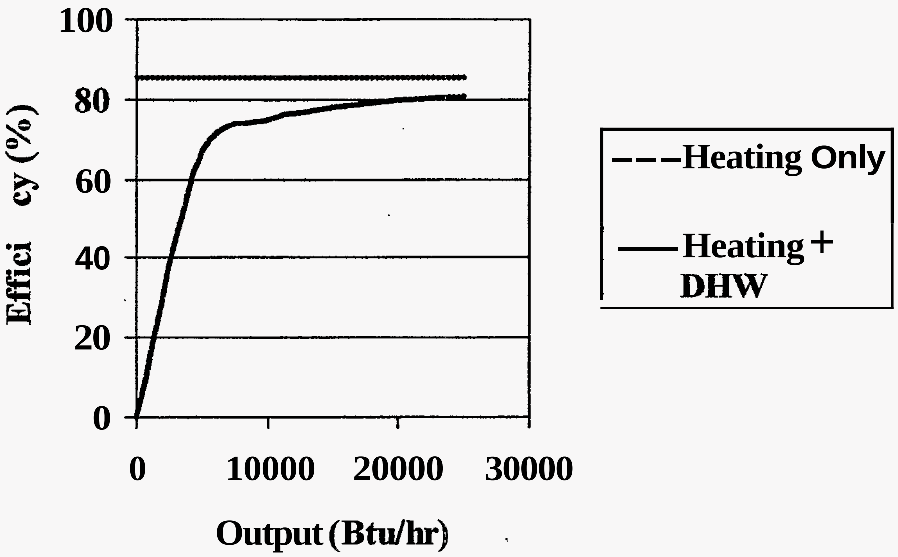

Figure 15 Condensing boiler, winter made, efficiency vs outout, heating only and combined heating DHW modes

5.3. Non-Condensing Boiler. Domestic Hot Water (Summer) Mode

For this case Figure 16 shows the trends in temperatures of the supply and return water to the indirect tank and the flue gas for a typical tank call. This specific data set was recorded during the night, when there was no domestic hot water draw. The time required for the system to go from cold boiler start to tank satisfied was 13 minutes. The supply water temperature reached a maximum of 178 F and the return to the boiler reached a maximum of 111.5 F. The return water temperature is below the flue gas saturation temperature and it is likely that this system is condensing locally in the boiler during these calls, even though the boiler is not designed for this.

Figure 17 shows the input vs. output relation for this boiler / storage tank system operating in the domestic hot water (summer) mode. The input at idle (zero output) is estimated based on fuel use and cycle period during times when there is no domestic hot water draw. Typically in this case the burner fires every 10-12 hours only to keep the tank at the setpoint temperature. Over the range shown the relationship between input and output is linear and the regression equation is y = 1.9249*x+1208.2 where x is output and y is input. The input / output curve of Figure 17 has been converted to an efficiency vs. output curve in Figure 18.

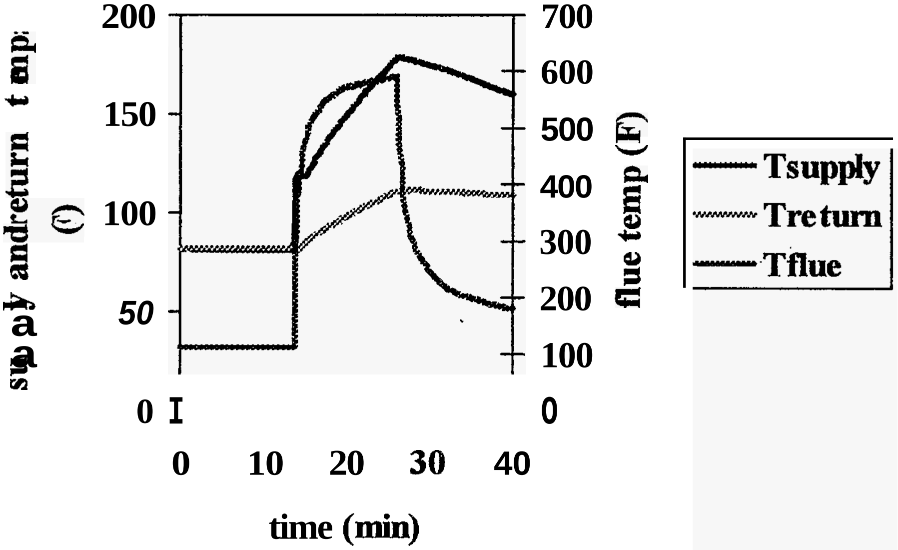

Figure 16 Non-condensing boiler, summer mode. Behavior during a typical storage tank heat call

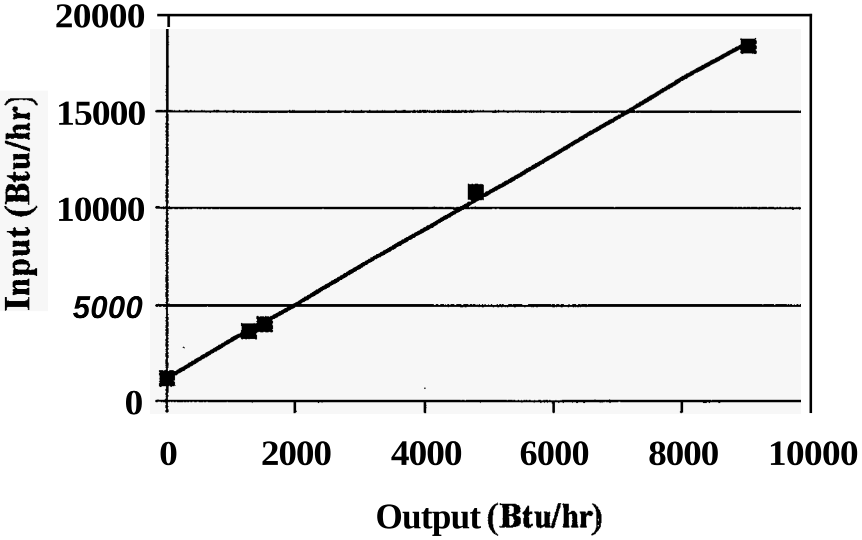

Figure 17 Non-condensing boiler, summer mode. Input vs. output

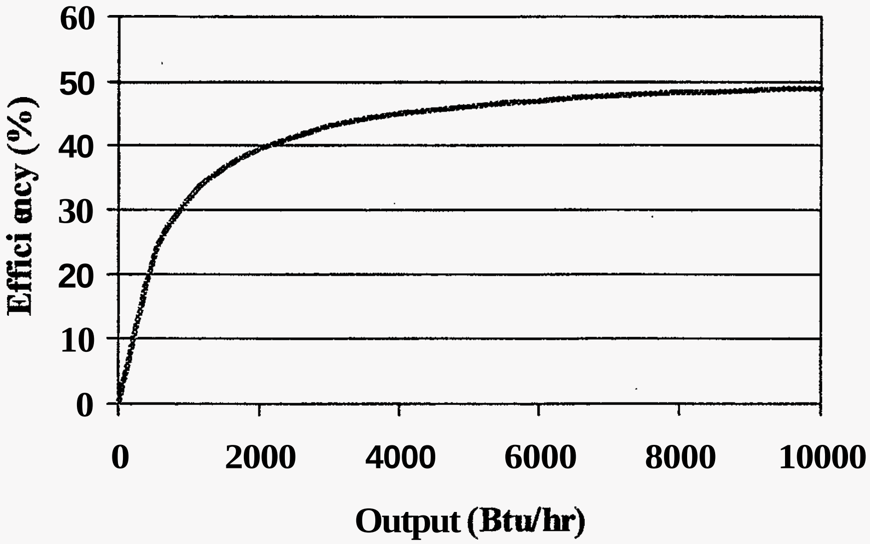

Figure 18 Non-condensing boiler, summer mode. Efficiency vs. output

5.4. Condensing Boiler, Domestic Hot Water (Summer) Mode

For this case Figure 19 shows the supply and return water temperatures between the boiler and the indirect tank for a'typical tank call. Here the boiler maximum temperature control was set to provide a limit of **150** F. The burner cycles twice during a typical call and the time to satisfy the tank **is 18** minutes. The maximum return water temperature during the tank call is 101 **F,** well below the flue gas saturation temperature and the boiler can operate in a condensing mode during the entire period of the tank call.

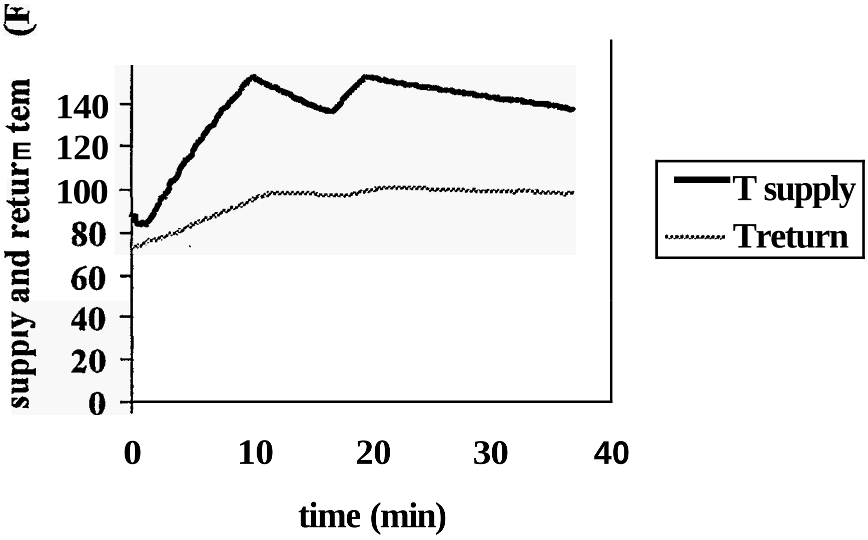

Figure 19 Condensing boiler, summer mode, Suppy and return water temperatures during a typical response to a tank heat call. note- boiler set for 150 F max

Data collected on energy input and output during this time period is shown in Figure20. The line shown in this figure is a linear regression and has the equation y=1.4466x+982.1 where x is the output and y is the input (both in Btu/hr). In all cases the data represents averages over time periods ranging from 1.5 hours to 21 hours. Cumulative data on input and output are always recorded at moments when the domestic hot water storage tank is just "satisfied". The very high output data point on this chart represent a 1.5 hour time period with a laundry load.

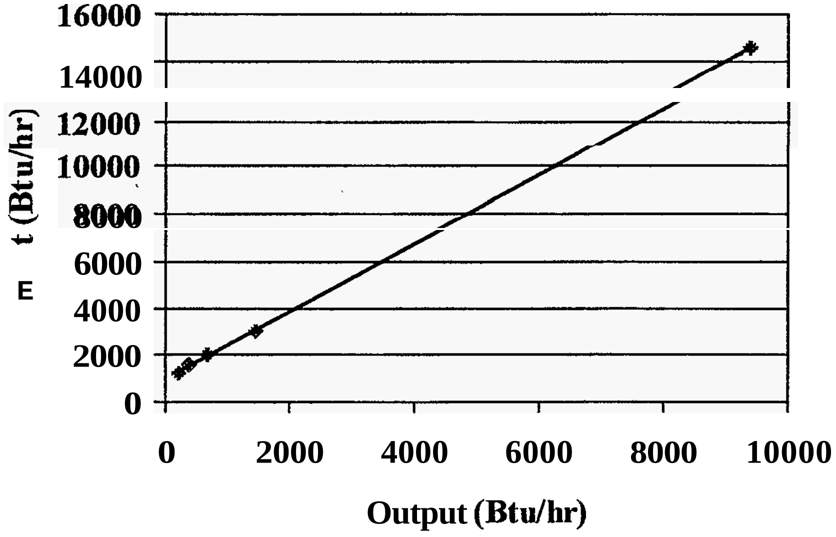

Figure 20 Condensing boiler, summer mode. Input vs. output

The linear input/output curve from Figure 20 can be converted to an efficiency / output curve based on the linear regression. This is shown in Figure 21.

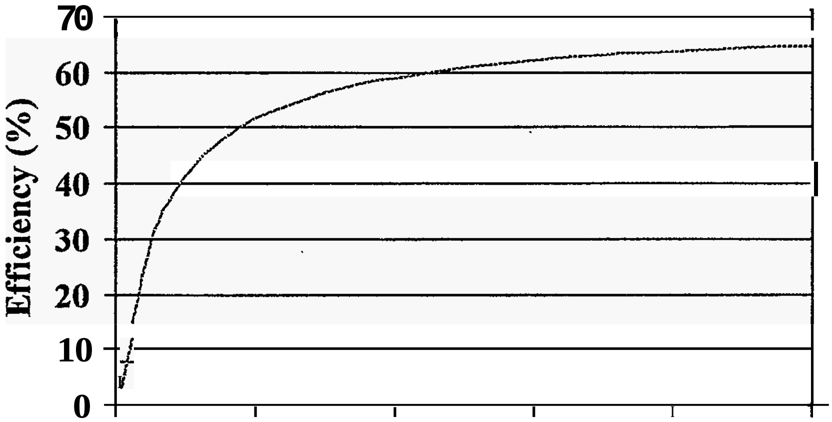

Figure 21 Condensing boiler, summer mode. Efficiency vs. output

6. ANALYSIS AND DISCUSSION

As discussed in Section 2, the primary objective of this work was to evaluate the potential use of condensing boilers in homes with conventional baseboards with an outdoor reset strategy. The primary question them is what is the minimum hydronic system return temperature consistent with comfort for a given outdoor temperature? Figure 22 shows the estimated maximum baseboard heat delivery rate as a function of internal water temperature. For mean system temperatures above 140 **F,** manufacturer's nominal rating has been used. For lower temperatures, where manufacturer's rating data is not available, it has been assumed that output is proportional to the difference between water temperature and room temperature. Figure **23** shows the calculated return water temperature, based on an assumed hydronic loop flow of 2.6 gpm. Using these the whole system output can be calculated for any point on the outdoor reset curves from Figure *6***.** This has been done for three cases: curve **3,** curve **4** and curve **"3.5"** - taken as a simple average of curves **3** and **4.** To complete this evaluation, the heat demanded for space heating is needed as a function of outdoor temperature and this has been developed from Btu delivered data averaged mostly over night-time periods to eliminate solar gain effects. Figure **24** combines the load vs. outdoor temperature with the heat delivered vs. outdoor temperature results. The load data points show considerable scatter due to wind and other factors. **A** linear regression line is provided. The results show that reset curve **3** would be adequate for most of the season but fails to provide adequate heat under the very coldest outdoor conditions. Curve 3.5 does meet the heat demand of the home.

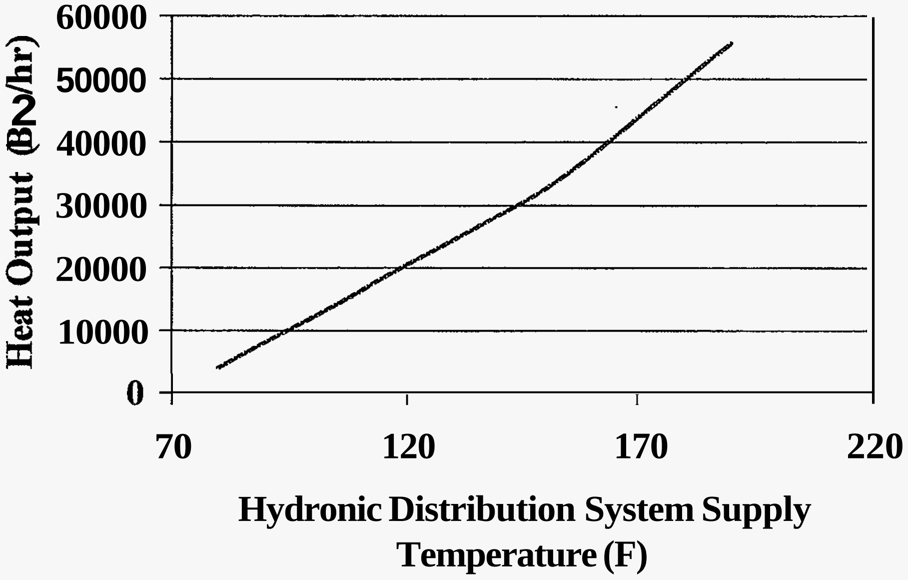

Figure 22 Total baseboard heat output as a function of supply temperature based on assumed flow of 2.6 gpm

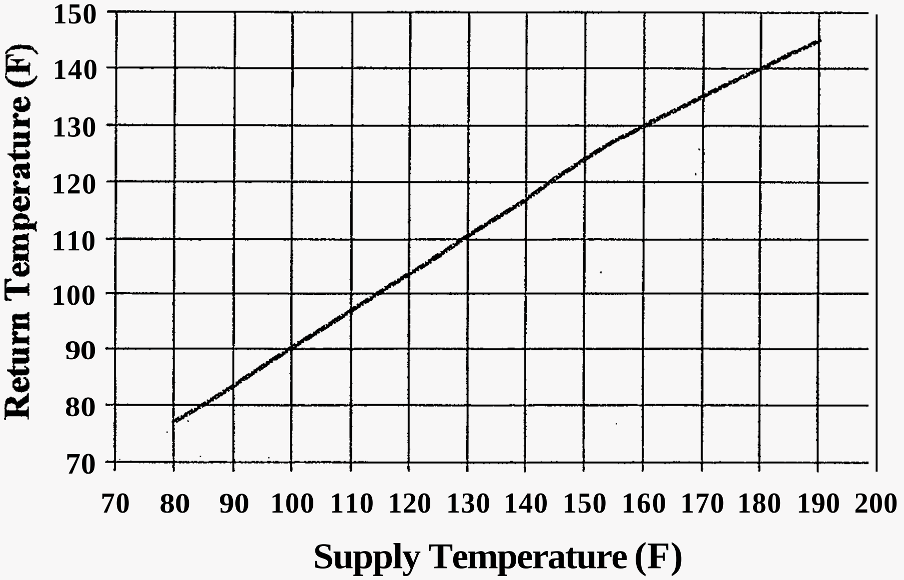

Figure 23 Baseboard system return water temperature as a function of supply temperature based on assumed flow of 2.6 gpm

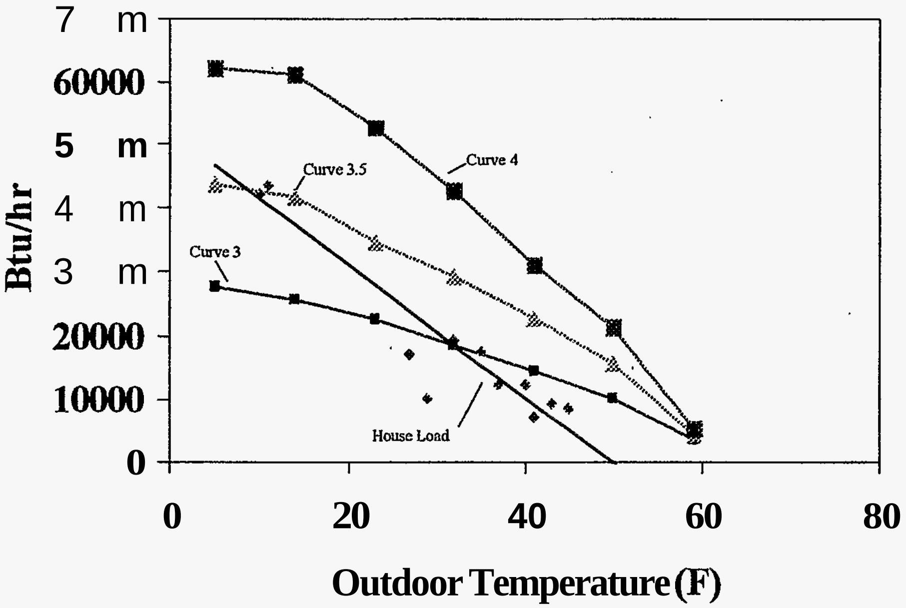

Figure 24 House heat load vs. outdoor temperature and condensing boiler supply vs outdoor temperature for different settings of the reset controller.

With the conclusion that the heat load of the home can be met using curve **3.5** on the reset controller, the needed supply temperature can be found from Figure 6, and the corresponding return water temperature at the assumed flow rate can be found from Figure **23.** Assuming that condensation starts at a return water temperature 7 degrees below the saturation temperature, the outdoor temperature range over which condensation occurs can be found for a give fuel and burner excess air level. This can be combined with a local outdoor temperature data to determine the fraction of the heating season over which condensation can be expected. For the region where this test was done (Long Island, **N.Y.)**Figure *25* shows the average heating season temperature distribution, based on load.

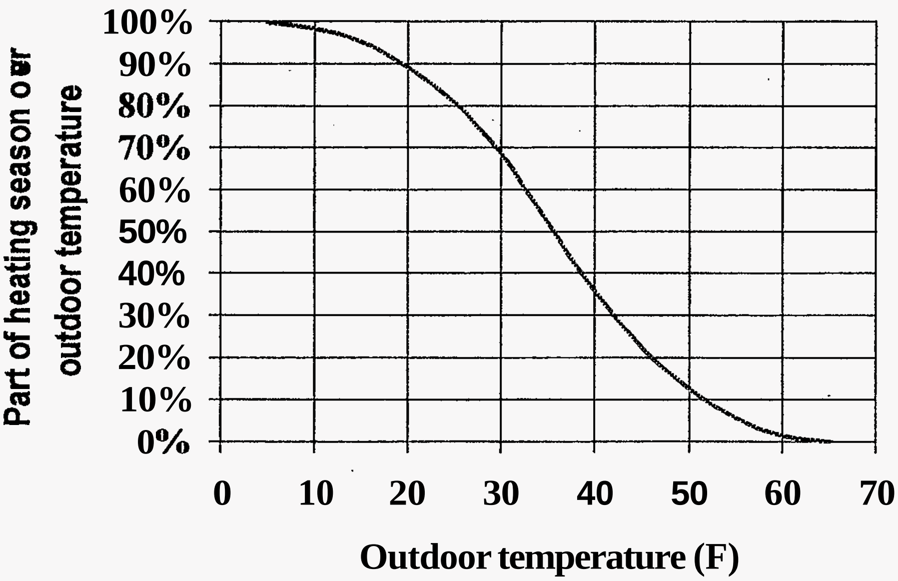

Figure 25 Distribution of heating load as a function of outdoor temperature for Long Island, N.Y. region where the test site was located.

To illustrate, Figure *25* shows that *50%* of the heating season occurs with an outdoor temperature over **37 F.** This means that 50% of the heating degree hours (or heating load) occur at temperatures over **37** F

For an assumed burner excess air level of 20%, Table *2* shows the results of the analysis and specifically the percentage of the heating season over which condensation could be expected for the three fuels considered. The conclusion is clear that a significant part of the heating load could be met with a boiler operating in a condensing mode for all of the fuels.

Table 2. Results of Analysis – Condensation Potential for Gas, Propane, and Oil

Fuel	Flue gas saturation temperature (F)[1]	Return water temperature at which condensation begins (F)[2]	Corresponding Supply water temperature (F)[3]	Outdoor temperature at this condition (F)[4]	% of heating season based on load in condensing range[5]
Gas	135.8	127.8	156	14.0	96
Propane	129.6	122.6	146	19.4	90
Oil	122.2	115.0	137	24.8	80

While the primary emphasis in this work has been on evaluation of the potential for use of condensing boilers with conventional baseboard heating systems the data collected during the project provides some basis for comparing actual in-field efficiency of the two systems included in the test. For the winter mode, where there is both heating and domestic hot water load, Figure 26 .provides an efficiency, output comparison. Figure 27, provides the'same comparison in the summer, domestic hot water only mode.

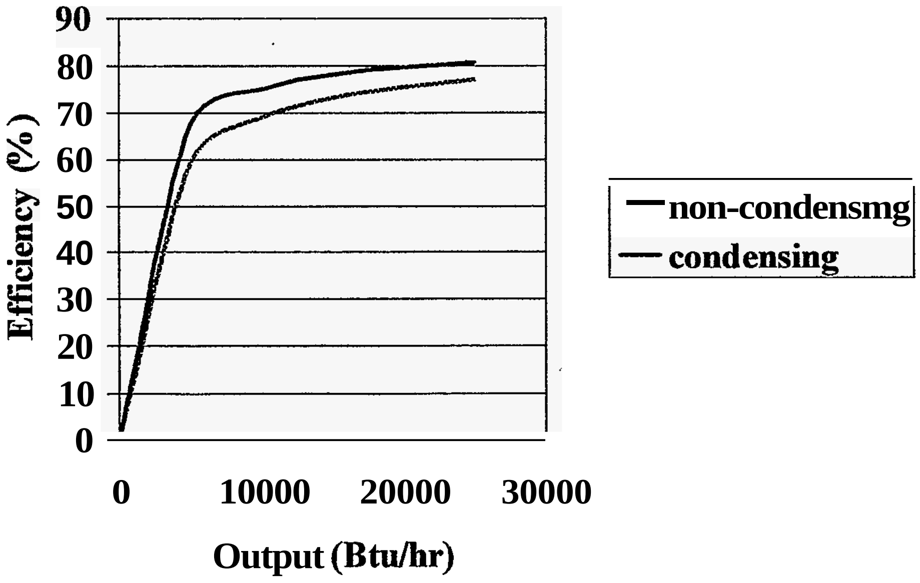

Figure 26 Comparison of the efficiency of the baseline system and the condensing boiler with the outdoor reset control during winter mode.

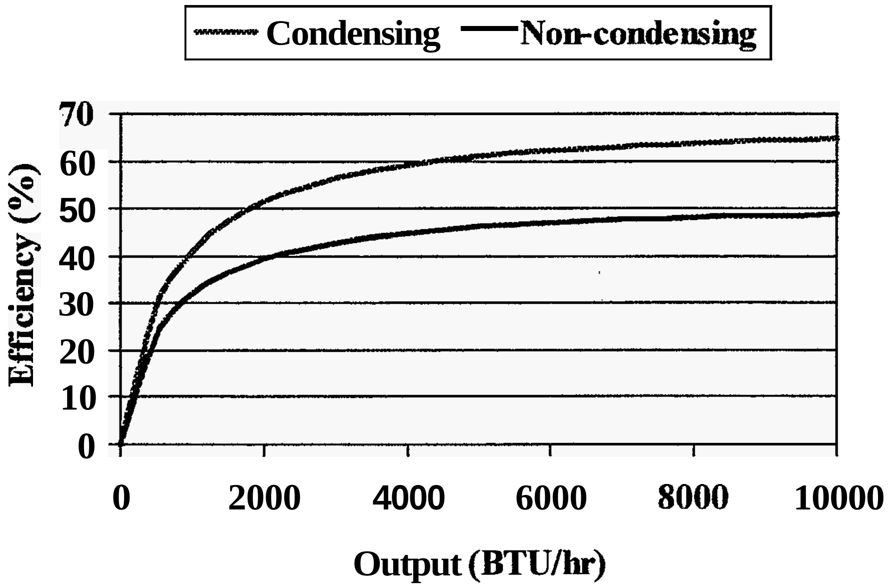

Figure 27 Comparison of efficiency of the baseline system and the condensing boiler with the outdoor reset control in the summer mode.

The results included in Figure 26 and 27 show that the condensing boiler yields higher efficiency than the non-condensing boiler in actual use. However, the increase in efficiency achieved with the condening boiler during the heating season is smaller than might have been expected. Several factors may have contributed to this result:

1. The non-condensing boiler operates with a cold start control. The condensing boiler during the heating season does not operate with this control mode but instead stays at a fixed boiler temperature even during periods of no load. During the summer months both boilers were operated in a cold start mode.
2. The condensing boiler is a direct vent unit with an outdoor air intake surrounding the exhaust. The terminal was located 24 inches above the exhaust connector on the boiler and this may have led to a sensible and latent (from reevaporation of condensate on the heat exchanger) loss from the boiler during the off cycle.
3. Both boilers used the same flow meters and temperature sensors for measurement of heat output. However, the condensing boiler was connected to this instrumentation by about 15 feet of piping. The conventional boiler was connected to this instrumentation by 2-3 feet of piping. While the piping was well insulated this may have led to cyclic losses not accounted for.

7. CONCLUSIONS

The primary conclusion of this work is that condensing boilers can achieve energy efficiency benefits even when used in homes with common baseboard radiators by incorporating a reset control which modulates the water temperature supplied to the baseboards with outdoor temperature. With oil firing, in the test home, 80% of the heating season load can be met with the boiler operating in a condensing mode. With propane firing 90% of the load can be met with condensing operation and with natural gas firing, **96%.** This of course depends upon the oversizing of the baseboard convectors relative to the design load of the home and the excess air level on the burner.

8. REFERENCES

1. Method of Testing **for** Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers. ASHRAE Standard 103-1993. American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. Atlanta, Ga. (1993).
2. R. Krajewski and Andrews, J., Hydronic Distribution Systems for use with Condensing Boilers, BNL 51731 (October 1983)