APPENDIX 4-A. ANNUAL EFFICIENCY CALCULATION FOR CONDENSING BOILERS

TABLE OF CONTENTS

4-A.1 Introduction..2
4-A.2 Analysis..2

LIST OF TABLES

Table 4-A. 1 Operational data for calculation of seasonal thermal efficiency for condensing boiler (Boston climate) 4

LIST OF FIGURES

Figure 4-A. 1 Simplified Condensing Boiler Steady-State Thermal Efficiency as a Function of Return Water Temperature..3

4-A.1 Introduction

Appendix 4-A provides calculations used to estimate the seasonal energy performance of a condensing boiler when applied to a typical existing building. As discussed in chapter 4 of the TSD, the performance, couched in terms of operating thermal efficiency, of a condensing boiler is a function both of boiler design as well as boiler operation—the latter a function of the hydronic system design and controls. While this is to some extent true of all boilers, it is particularly true of condensing boilers. For high-efficiency condensing hot water boilers, where the rated efficiency depends on the return-water temperature, DOE developed a simplified model of the annual efficiency of a condensing boiler used to serve a typical hydronic coil supplying heat to a building heating, ventilation, and air-conditioning (HVAC) air distribution system. This type of distribution system is believed to be the most typical of that served by buildings using commercial packaged hot water boilers. The underlying assumption in this analysis is that a simple replacement of the existing boiler (or proposed boiler in a new construction) is what is being analyzed with no fundamental changes to the underlying system design other than programming of reset controls. While more optimum combinations of condensing boilers and modified hydronic systems (e.g. oversizing of hydronic coils in forced air systems, or utilizing radiant slab heating) potentially could provide additional energy savings when using condensing boilers, they would incur additional costs and would require additional speculation about what a purchaser may or may not do when confronted with a new standard for commercial boilers which effectively required the use of condensing equipment.

4-A.2 Analysis

The analysis shown here estimates the seasonal performance of a condensing boiler serving hydronic coils in a forced air delivery system. The analysis was carried out based on an example for condensing boiler calculations for a single climate (Boston, MA). The analysis is based on a slide presentation made to the Puget Sound chapter of ASHRAE by Jim Cooke of Mechanical Solutions NW in 2005[1].

Underlying assumptions for the simplified analysis were that:

1) The building heating load is proportional to the temperature difference between the outdoor air and a 50ºF assumed space-heating balance point[a].

2) That the building design heating load was at an outdoor temperature of 7ºF.

3) That the heating season for this climate consisted of the months from September through May

[a] The space-heating balance point is the outside air temperature above which no heating is required in the building. Generally a balance point is a statistical average based either on analysis of building heating use data or based on a mathematical model of building performance. A 50ºF is typical of many commercial buildings and reflects that these buildings have internal heat generation sources (lights, appliance and other plug loads) that offset building sensible heat losses through the envelope, infiltration, and ventilation down to the heating balance point temperature.

4) That the hydronic coils were sized such that the design heating load on the building was such that it could be met with 160ºF supply water temperature.

5) That the boiler thermal efficiency varied as shown in Figure 4-A.1. From a return water temperature of 180ºF to 133ºF, the thermal efficiency varied from 84% to 87% respectively. From a return water temperature of 133ºF to 60ºF, the boiler thermal efficiency varied from 87% to 96% respectively. This efficiency profile is a simplified version of the typical condensing boiler efficiency profile as a function of return water temperature.[1]

6) That condensing boiler efficiency at part load and under low fire conditions was not addressed explicitly, but was built in to the boiler performance curve in Figure 4-A.1. Because DOE's thermal efficiency rating is at full load, a DOE standard for condensing boiler would set only minimum full load efficiency, but would not address performance requirements under part load conditions.

7) The boiler operates on a reset supply water temperature, assuming 160ºF at or below the heating design ambient dry bulb temperature (7ºF), and 86ºF supply water temperature above 54 ºF design ambient dry bulb temperature. The reset water temperature is designed to meet the anticipated heat load in the space assuming continuous flow through the hydronic coils under all load conditions.

Based on these assumptions, Table 4-A.1 shows the following operational data for the boiler for each of 6 heating temperature bins: Hours in Bin, Average Ambient Temperature in Bin, fraction of peak heating load based on average temperature in bin, the fraction of the annual heating load based on the product of the average heating load in a bin and the number of hours in the bin, Supply Water Temperature, Return Water Temperature, whether the boiler is operating in condensing mode (i.e. Return Water less than 133 F), and the average boiler efficiency in the bin based on the simplified efficiency profile shown in Figure 4-A. 1 4-A.1.

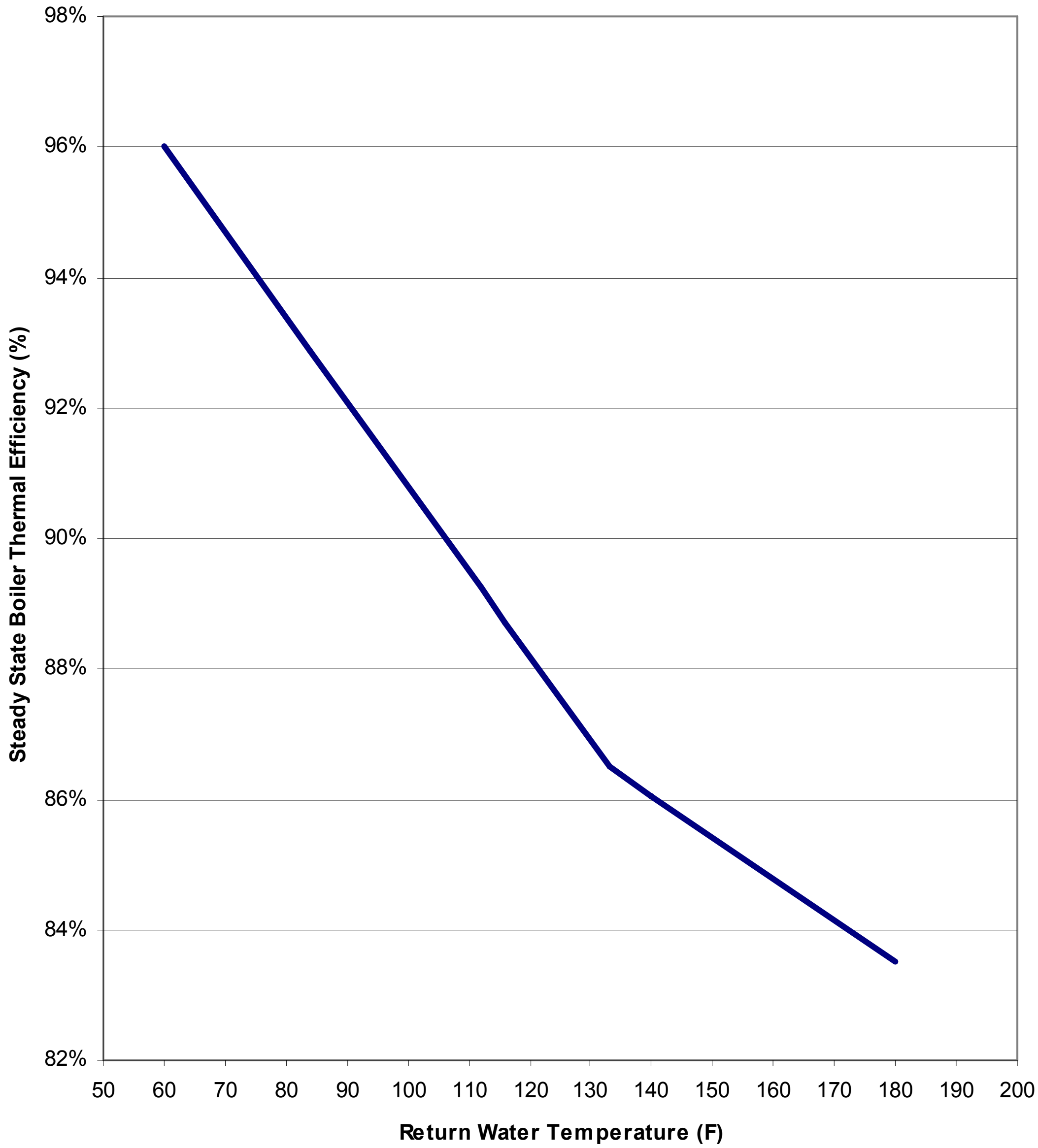

Figure 4-A. 1 Simplified Condensing Boiler Steady-State Thermal Efficiency as a Function of Return Water Temperature

Table 4-A. 1 Operational data for calculation of seasonal thermal efficiency for condensing boiler (Boston climate)

Temperature Bin	Hours in Bin	Avg. Ambient T in Bin	Fraction of Peak Heating Load	Fraction of Annual Heating Load	Supply Water T (F)	Return Water T (F)	Condensing Mode	Boiler Thermal Efficiency
54-68 F	1497	61	0%	0%	86	84	Yes	92.9%
41-54 F	1675	47.5	6%	7%	110	112	Yes	89.2%
28-41 F	2258	35	35%	55%	133	116	~50%	88.1%
14-28 F	627	21	67%	29%	147	129	No	86.8%
0-14 F	124	7.5	99%	8%	160	140	No	86.1%
(13)- 0 F	11	-7.5	134%	1%	160	140	No	86.1%
Average Boiler Thermal Efficiency								87.6%

Using this example DOE estimated that a representative seasonal thermal efficiency for a condensing hot water boiler would be approximately 88% when installed in this application. Again, DOE recognizes that other system designs and potentially other assumptions about the building load profile and the operation of the boiler under part load conditions could result in different estimates for the seasonal efficiency. In particular, for hydronic systems for which the existing or modified design could meet the load with average supply and thus return water temperature lower than shown in this example, DOE would expect higher seasonal thermal efficiency ratings.

REFERENCES

1 Cooke 2005. *"Condensing Boiler Technology"*. Presentation made by Jim Cooke of Mechanical Systems NorthWest to the Puget Sound ASHRAE Chapter in Nov 2005. Available at < www.pugetsoundashrae.org/PDF_files/AshraeCondensingtechnology.ppt>. Accessed November 22, 2009