NBSIR 85-3225

Laboratory Study of Gas-Fueled Condensing Furnaces

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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1. PURPOSE

This report is intended to serve as background information concerning revisions made to test procedure for condensing furnaces and published by the Department of Energy (DOE) as rules and regulations in the Federal Register on March 28, 1984 [1]*.

2. OBJECTIVE

The objective of this study was to determine if the direct measurement method of condensate collection that was developed during testing of a condensing boiler would be adequate for direct measurement of the condensate from forced warm air condensing furnaces.

Another objective of these tests was to quantify the effects of varying test room ambient temperatures and relative humidity on the rate of condensate collected with condensing furnaces.

3. BACKGROUND

The Department of Energy (DOE) test procedure for furnaces and vented heating equipment was issued as a final rule in the Federal Register (FR) on May 10, 1978 [2]. The procedure was based on the NBS Report [3] "Recommended Testing and Calculation Procedures for Determining the Seasonal Performance of Residential Central Furnaces and Boilers." Those procedures contained no provisions for testing furnaces that improve efficiency by recovering some of the latent heat by condensing the water vapor in the flue gas. Heating units that incorporate such energy savings means are known as condensing furnaces or boilers. In order to evaluate and advertise the advantages of condensing units, industry requested that provisions be made in the test procedure to accommodate such tests. In

* Numbers in brackets pertain to references listed on pages 35-36.

response, DOE published amendments to the test procedure on August 12, 1980 in the Federal Register (with correction notice on September 19, 1980) [4] to include special procedures for condensing furnaces and boilers. The FR amendments were based on the recommendations in the NBS Report, "Recommended Testing and Calculation Procedures for Estimating the Seasonal Performance of Residential Condensing Furnaces and Boilers." [5] The method consisted first of a mathematical analysis of the test results to assure that condensation would occur and then a calculation of the amount of condensation to be expected. The resultant heat recovery of the latent heat of vaporization of water formed was then used to reduce the heat losses and increase the seasonal efficiency rating of the unit tested. The method proposed by NBS in 1980 and adopted by DOE was based on analysis and evaluation by NBS of the only unit commercially available at the time and that was a condensing boiler [6]. The analytical method for determining the credit due to recovery of latent heat is described in the NBS Background report [3].

Following publication of the DOE test procedures [4] in 1980, a manufacturer of condensing boilers (Hydrotherm) petitioned DOE for waivers from those test procedures. The petition claimed that the prescribed method either understated the amount of condensate or indicated that there is no condensate when in fact a significant amount of condensate was collected during the test [7]. DOE allowed that manufacturer to instead use a method of direct condensate measurement for rating their equipment. From that time through 1983 DOE received seven similar requests. Subsequently, DOE allowed the use of a direct condensate measurement for all manufacturers on March 28, 1984 [1].

3.1 ISSUES CONCERNING NEW TEST PROCEDURES FOR CONDENSING FURNACES

3.1.1 Cyclic Testing for Measurement of Condensate Collection

A direct method which was published as Appendix C of NBSIR 80-2110 [5] called for measuring the amount of condensate produced during three test cycles of the furnace or boiler.

Prior to the March 1984 final rule, DOE published proposed rules in the Federal Register [7] which included test provisions for condensing furnaces and boilers. These proposed test methods were identical to the test method of Appendix C of [5] except that it specified a six cycle test instead of three cycles. The need for six cycles was determined based upon testing at NBS (see Section 5.1.2) which showed that with some types of condensing furnace, the amount of condensate collected per cycle was highly variable and the results of a three cycle test should be improved by doubling the number of test cycles.

Several commentors to these proposed procedures objected to the need for six test cycles in all cases and suggested that the test be reduced to three cycles if it could be shown that the condensate collection rate for the three cycles gave consistent results. The Gas Appliance Manufacturers Association (GAMA) suggested that if the standard deviation of condensate collected for three cycles did not exceed more than 20 percent of the mean value, the test should be stopped after three cycles. Another commentor suggested the standard deviation should not exceed 10% of the mean value in order to stop at three cycles. None of the commentors recommended a procedure if after six cycles the variation were still greater than 20% of the mean value. In an analysis of these comments [8], NBS recommended to DOE a procedure that allows a three cycle test and suggested alternatives to extended testing if this variability was exceeded. (See Appendix A.)

DOE published its final rules for furnaces and boilers in the Federal Register on March 28, 1984 [1]. These test procedures prescribed a three cycle test for a furnace or boiler having a "repeatable condensate collection rate" (i.e. standard deviation less than 20% of the mean over three cycles). "For those furnaces which do not demonstrate a repeatable condensate collection rate in the three cycles, an additional three cycles are required irrespective of variability." Sections of the DOE procedure [1] which apply to condensing furnace testing are included here as Appendix B.

3.1.2 Steady State Test for Condensate Collection

A petition for waiver from test procedures submitted by a furnace manufacturer (Amana Refrigeration, Inc.) asked that in addition to annual fuel utilization efficiency (AFUE) the steady state efficiency also be adjusted by direct measurement of the condensate collected during the steady state test. DOE granted that waiver and in the proposed test procedure [7] specified a 60 minute test period for determining the weight of condensate collected. After DOE proposed to include these provisions in the test procedure, three commentors asked that this test time be reduced to a thirty minute collection period. DOE accepted this adjustment to the testing period and published it in their final rules [1]. See Section 5.3 for discussion of test results on this subject.

3.2 AMBIENT TEST ROOM CONDITIONS OF TEMPERATURE AND RELATIVE HUMIDITY

These test room conditions were originally required to be within a range of $65^{O}F$ to $100^{O}F$. These test temperature tolerances were tightened in 1980 for condensing furnaces and boilers to a range of $65^{O}F$ to $80^{O}F$ [4]. The wider range remains in effect for non-condensing furnaces or boilers.

In 1982, ASHRAE published ANSI/ASHRAE Standard 103 [9] which specified a wider test room ambient temperature range for condensing units of 65°F to 85°F (the range called for in Appendix C of reference [4]). These ASHRAE specified room temperatures for condensing furnaces were also referenced by DOE with the latest published procedure [1].

Since no condensing hot air furnaces were commercially available at the time of publication of test procedures for condensing, boilers and furnaces (1980) specifications for testing of warm air furnaces were based upon information then available from industry. The effect of room air temperature for air supply to the heat exchanger had not been quantified until this study was begun.

Also the effects of relative humidity were not included in the 1980 test procedures published by DOE [4]. Room air conditions were monitored in the NBS study [6], however, the variations reported in that study were focused on the effects of boiler water temperatures only.

Although the proposed limits published by DOE [7] for room air temperatures of 65°F to 85°F and relative humidity of not more then 80% were prior to the results of this study, those proposed limits were not contested by industry and NBS did not believe it necessary to revise those proposed ambient room test conditions for the final rules. Test results found in laboratory tests are reported in Section 5.4.1 and 5.4.2.

4. TEST EQUIPMENT AND PROCEDURES

4.1 TEST FURNACES

Two gas fueled high efficiency condensing warm air furnaces were used in these tests. Both of these furnaces have annual fuel utilization efficienty (AFUE) ratings near 95%. Two warm air gas fueled furnaces with AFUE ratings in the mid 80% range were also tested. These furnaces were equipped with condensate drain lines but did qualify as condensing furnace under the existing DOE test procedures [3]. These were: The two high efficiency condensing furnaces are designated furnace "A" and "B" in this report and the borderline condensing furnaces are designated "C" and "D". Three of the furnaces can be seen in Fig. 1.

4.2 LABORATORY TEST EQUIPMENT

Figure 1 shows an overview of furnace testing in the Combustion Equipment Laboratory. Among the instruments shown in Fig. 1 are the non-dispersion type infra red analyzers used to measure carbon monoxide and carbon dioxide in combustion gases. Data collection equipment consisting of data logger, strip chart recorder, and computer tape recorder is in the left foreground.

Figure 2 shows two dew point meters being used in a test with furnace B. One of these meters is monitoring dew point of the combustion air supply and the other is sampling and measuring the flue gas dew point.

Other equipment not shown included scales for measuring condensate. A continuously recording calorimeter was used to measure gross heating value of the pipeline natural gas fuel supply.

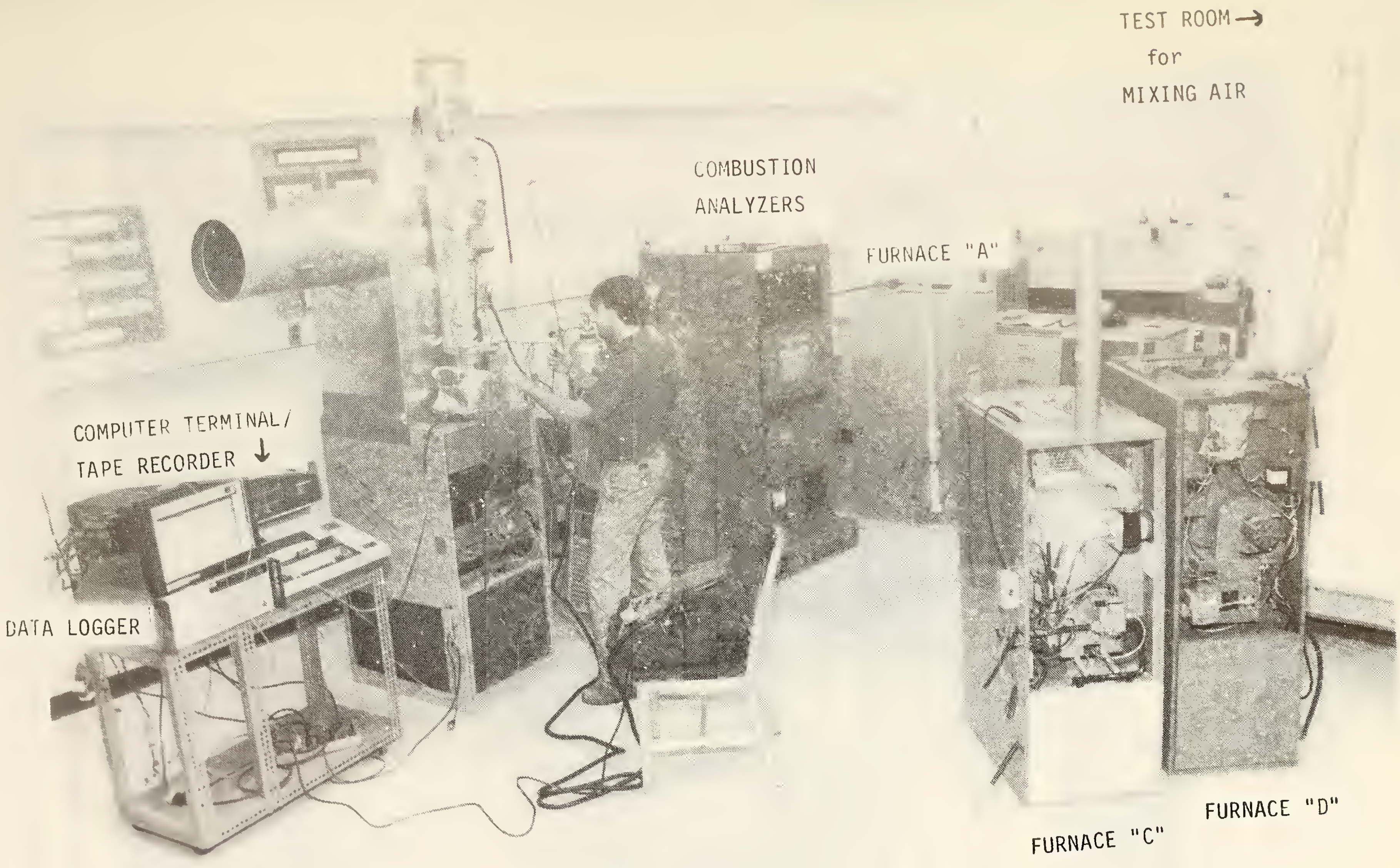


Figure 1. Overview of combustion equipment test laboratory showing test furnaces and test equipment

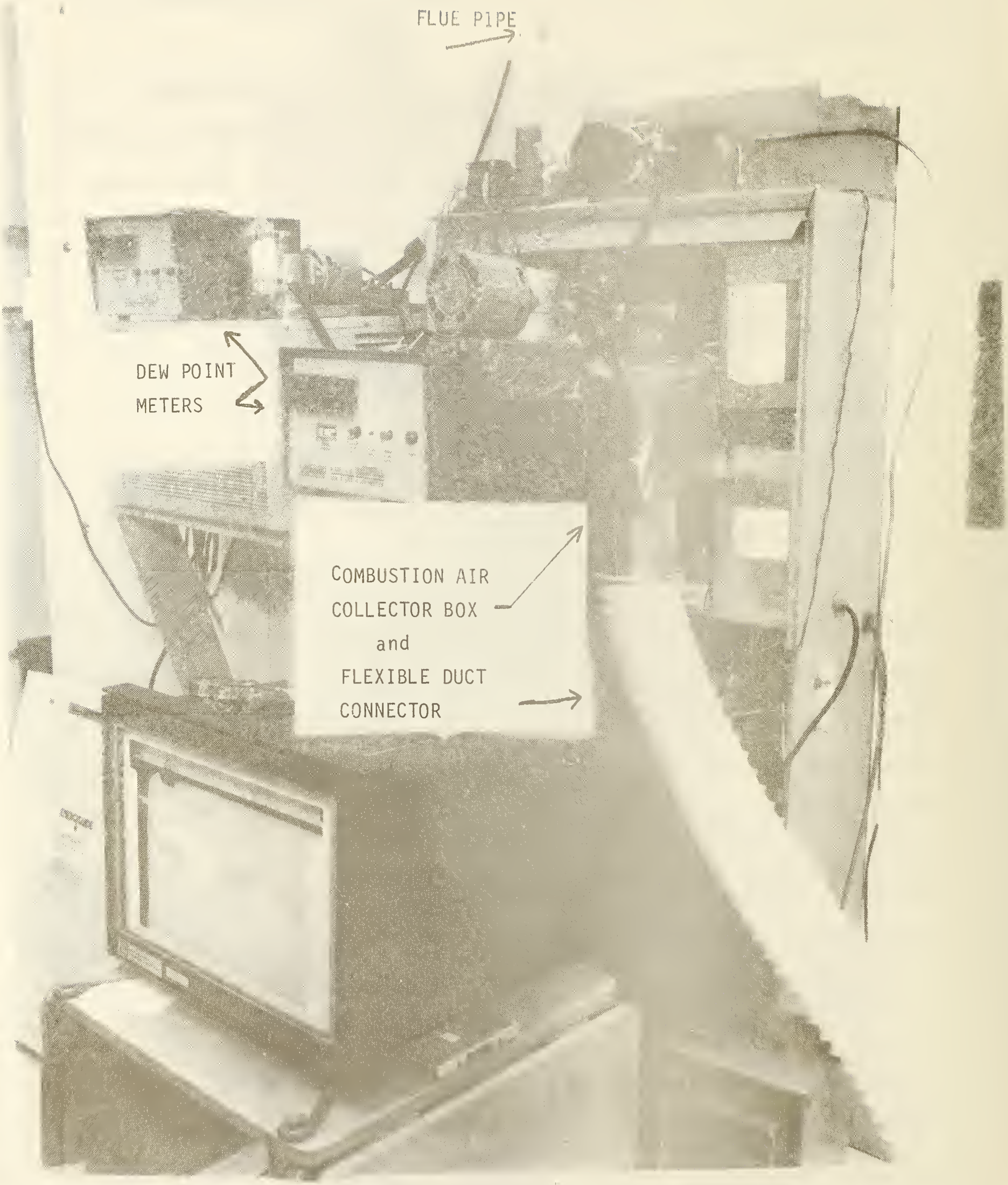


Figure 2. Test furnace "B" shown installed through wall of test room used for mixing warm air and showing equipment used to supply conditioned combustion air.

4.3 TEST PROCEDURES

4.3.1 Condensate Collection

The methods of test specified in Appendix C of NBSIR 80-2110 [5] were used in this study, (see Appendix A, Section 3.6, "Direct Measurement of Condensate"). The method for controlling combustion air temperature and humditity is described below.

4.3.2 Control of Combustion Air Temperature and Humidity

An environmental chamber was used to supply conditioned combustion air at various temperatures and relative humidities to the test furnaces. Test furnace A has its combustion air supplied via a direct connection to the furnace through an air intake pipe. The combustion air supply pipe of this furnace was directly connected to the environmental chamber as shown in Fig. 3.

Figure 3 shows a simplified overall schematic of the various flow paths involved in the test of furnace "A" including a cross sectional view through the furnace. Figure 4 shows a view of the test arrangement used to adjust the return air temperature to the furnace by blending ambient room air from outside the test room with partially recycled heated room air from the furnace. The purpose of study this test was to the effect of elevated return air temperature on condensate collection rate.

The furnace illustrated in Fig. 4 is shown in Fig. 2 installed through a side wall of the room with the combustion air, fuel inlet, controls section and flue pipe outside the room. The warm air discharge and return air inlet are inside the room. This test room acts as a mixing chamber of partially recycled heated room air with the ambient laboratory room air which was

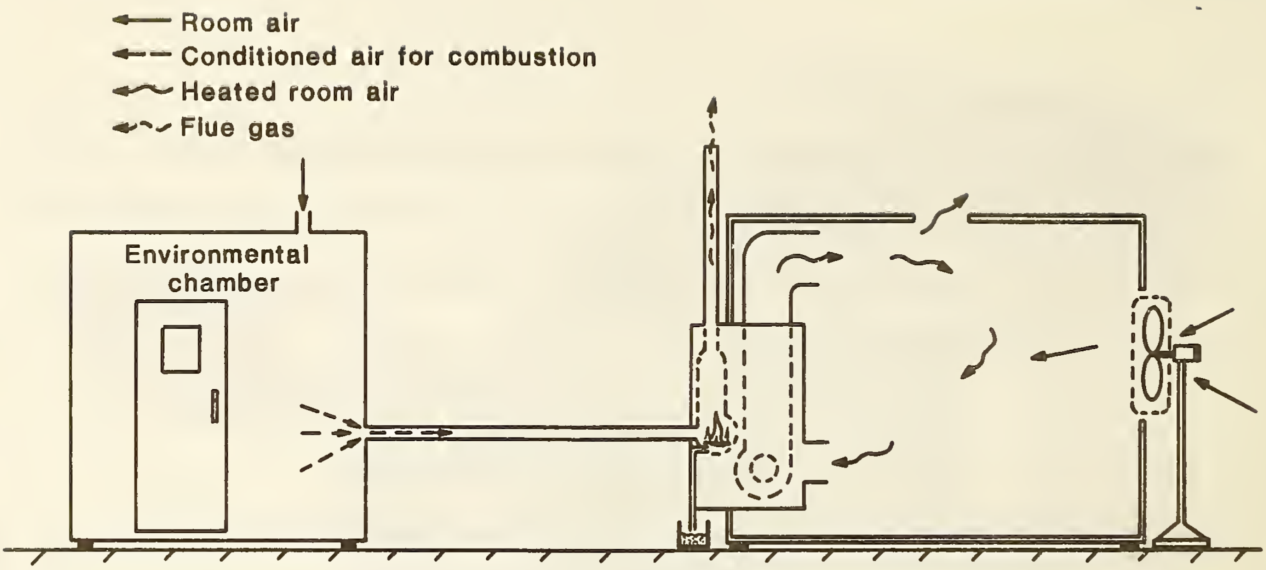


Figure 3. Overview of laboratory testing equipment showing flue gas and air flow paths used for conditioning combustion air and return air.

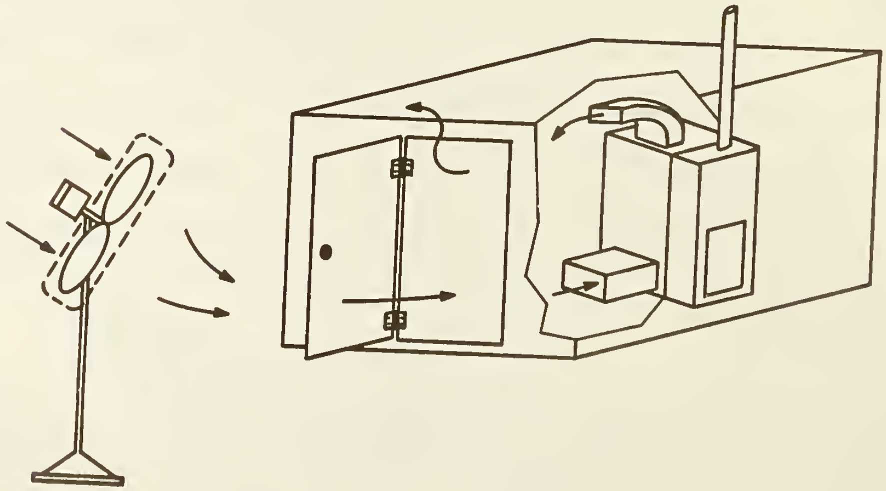


Figure 4. View of test room showing method used to mix warm air from furnace with ambient air for adjusting return air temperature.

approximately 68°F (20°C) to 75°F (24°C).

In Fig. 4, the return air and discharge warm air from the furnace are for reasons of clarity shown discharging to the left. However, in these tests, return air entered at floor level through a knockout opening in the base of the blower compartment and the furnace was mounted approximately 6 inches off the floor. Also, discharge air was directed toward the rear wall in this test.

Furnace B uses indoor room air for combustion. This air normally flows through holes in the jacket of the furnace to the combustion air fan. In order to supply conditioned combustion air to this furnace, the area where combustion air would be taken into the fan was surrounded by a box and a flexible hose was connected to the box (see Fig. 2). Combustion air was thereby supplied directly to the burner from the environmental chamber through this flexible hose.

5. TEST RESULTS

5.1 CYCLIC TESTING

The objective of these tests was to determine if three test cycles were sufficient in order to obtain repeatable test results of condensate collection rate.

5.1.1 High Efficiency Condensing Furnaces ("A" and "B")

Test results with furnace A showed very repeatable results. Table 1 shows these results for a series of 17 cycles. The standard deviation as a percentage of the mean value after three cycles was 1% or less for any three consecutive cycles. These data show that three cycles are sufficient with a high efficiency furnace. In these tests, the maximum theoretical amount of condensate possible with this furnaces fuel firing rate was 149.8 grams per cycle. Therefore, approximately 75% of the theoretical amount of water formed during combustion was condensed.* Similar repeatable results were also found with test furnace "B".

5.1.2 <u>Borderline Condensing Furnaces ("C" and "D")</u>

5.1.2.1 Variability of Condensate Collected

Table 2 (a) and 2 (b) shows the results found in testing furnace "C". These results show the high variability of condensate collection that is possible with a borderline condensing furnace (i.e., AFUE rating of less than 90%). In these cycles, the maximum condensation per cycle as a fraction of the maximum theoretically possible was 75%, the average was 13% and the minimum was 0.0%. These data show a periodic high flow of condensate every 3 to 4 cycles (i.e. No. 2, 5, 8 and 12). The reason for the periodic flow of condensate was apparently due to a build up of this condensed water in the heat exchanger. Additional test data were obtained with variable burner on-off times and showed similar results. Those data are discussed below in section 5.2.2.

5.1.2.2 Effect of the Number of Test Cycles

Table 2(b) shows data from a repeat test run of the cycling test reported in Table 2(a). Data collection began following the heat-up to steady state and cool-down tests. The first cycle began 12 minutes after the start of the cool-down test.

* Appendix C shows a calculation of the effect of condensate collection rate on part load efficiency.

Table 1. Condensate Collected during Cyclic Testing of Furnace "A" (3.3 minutes on, 13.3 min off)

Cycle No.	Fuel used, cubic feet	Condensate collected, grams	Mean Value last 3 cycles ($\bar{x}$)	Standard Deviation (Sx) last 3 cycles	Precent of Mean (Sx ÷ $\bar{x}$) 100
1	---	---	---		
2	---	---	---		
3	4.27	---	---		
4	4.27	48.1	---		
5	4.20	112.7	---		
6	4.18	113.4	---		
7	4.18	114.6	113.6	0.96	<1%
8	4.18	113.3	113.8	0.72	<1%
9-13	---	567.8 (113.5 Average)	113.5	----	
14	4.15	112.0	---	----	
15	4.16	114.4	---	----	
16	4.14	114.0	113.5	1.29	1%
17	4.11	112.4	113.6	1.06	1%

Table 2.-a CONDENSATE COLLECTION

WATER COLLECTED PER CYCLE

FURNACE "C"

CYCLING TEST - 3 MIN., 52 SEC. ON
15 MIN., 20 SEC. OFF

(1) CYCLE NUMBER	(2) MEASURED GRAMS	(3) MEAN ($\bar{x}$) last three cycles	(4) MEAN ($\bar{\bar{x}}$) last three cycles	(5) SAMPLE STANDARD DEVIATION (Sx) (Last Six cycles)	(6) PERCENT of MEAN 100 (Sx÷ $\bar{x}$)
Preheat (5 cycles)	54.1*				
1	0.2				
2	80.3				
3	1.0	27.2			
4	0.0	27.1			
5	58.3	19.8			
6	1.0	19.8	23.5	36.2	+154%
7	0.0	19.8	23.4	36.2	+155
8	38.3	13.1	16.4	25.5	+155
9	1.0	13.1	16.4	25.5	+155
10	1.2	13.5	16.6	25.5	+153
11	2.6	1.6	7.2	15.3	+212
12	97.8	33.9	23.3	39.4	+169
13	0.1	33.5	23.3	39.4	+169

Overall average per cycle 27.8 (excluding preheat)

* no condensate collected prior to the 5th cycle

Table 2. (b) Condensate Collected during Cycling Test

Repeat Test Furnace "C" Cycling @ 3 min 52 sec on; 15 min 20 sec off.
NOTE: Start of Test for calculating Averages begins with cycle (4)

(1) Cycle Number	(2) Measured Grams	(3) Average Last Three	(4) Average Last Four	(5) Average Last Five	(6) Average Last Six
1	0	----	----	----	----
2	0	----	----	----	----
3	0	----	----	----	----
4	65.3	----	----	----	----
5	0	----	----	----	----
6	6.0	23.8	----	----	----
7	58.5	21.5	30.9	----	----
8	0	21.5	16.1	24.7	----
9	0	19.5	16.1	10.7	21.6
10	0	0.0	14.6	10.7	10.7
11	64.4	21.5	16.1	24.6	21.5
12	0	21.5	16.1	12.9	20.5
13	0	21.5	16.1	12.9	10.7
14	0	0.0	16.1	12.9	10.7
15	67.2	22.4	16.8	26.3	21.9
16	0	22.4	16.8	13.4	21.9
17	0	22.4	16.8	13.4	11.2
18	0	0.0	16.8	13.4	11.2
19	63.7	21.2	15.9	26.1	22.4
overall $\bar{x}$ cycles (4)-(19)	20.3	17.1	17.3	16.8	15.8
S_x	30.4	9.3	4.1	6.4	5.6
$\bar{x}$ cycles (3)-(19)	19.1	16.3	17.3	17.4	16.3
$\bar{x}$ cycles (4)-(18)	17.4	15.6	17.4	15.9	15.1

The DOE procedure [1] calls for recording results of the first cycle for direct measurement of condensate when "flue gas temperature at end of a cycle is within 5°F (2.8°C) of each other for two consecutive cycles." Flue temperatures at the end of the first four cycles were as follows:

Cycle (1)	70.0°C	(3)	72.2°C
Cycle (2)	71.5	(4)	70.2

The above temperature data shows that the third cycle could have been used as the first cycle for these tests. However, the fourth cycle was used. Results would have been the same in either case over six cycles. The six cycles would have been required for these data since the first three cycles do not meet the DOE test for repeatability.

These data of Table 2(b) have been reduced to the average values calculated for between three and six cycles. This set of data also shows (see column 3) that averaging over three cycles could result in a zero average reading if for example the starting condition had been with cycles (8) (i.e. average of cycles 8, 9 and 10). The overall average for the 16 cycles (i.e. cycles (4) through (19)) was 20.3 grams with a standard deviation of 30.4. This is approximately 150% of the mean value.

This overall average over estimates the population average of these data because it begins and ends with a large collection of condensate. A more accurate reflection of the population mean would be found by either starting with cycle (3) or by dropping cycle (19) and would result in population average of 19.1 and 17.4 grams per cycle respectively. The true picture of the population average for this data set is seen in column (2) to include a series made up of one large collection and three small or zero collection rates. Taking the value of 17.4 as the population mean (using cycles 4 through 18) and comparing this to overall averages of the results shown at the bottom of columns (3) through (6) shows that four cycles was the most repeatable with a standard deviation of 4.1 which is within 24% of the mean value of 17.3 grams. If the first result (30.9) of this group (which is atypical of the entire data set because it includes two high readings in the set) is neglected, the standard deviation (0.61) is within 4% of the new group average of 16.1. The six cycle test that would be required (column 6) shows the averages fall into two groups spaced almost equally apart from the mean value of 15.1. These are the four low groups, averaging from 10.7 to 11.2, and the six high groups (averaging from 20.5 to 22.4). Using the overall mean value of 17.4 as the best estimate of the true population mean the largest error in the six cycle test is (17.4-10.7) or 6.7 grams per cycle low. This amounts to an error in part load efficiency of 0.4 percentage points, (see Appendix C for this calculation).

5.1.3 Discussion of Test Results

As a result of testing with furnace "C", the DOE proposed test procedure [7] specified that six test cycles be run for all condensing furnaces instead of the three cycles previously specified in NBSIR 80-2110 [5] which was the procedure to be used if test procedure waivers were granted. The use of six test cycles should offer at least some improvement to this highly variable rate of condensate collection. A first glance at the first few test cycles in Table 2(b) does not show much improvement with the initial six test cycles versus the first three. An explanation of the need for more than three cycles can be seen by analysis of the data in Tables 2(a) and 2(b). Condensate drained from this heat exchanger in spurts. Every fourth or fifth cycle resulted in a sudden flow (spurt) of condensate, followed by two or three very small collections of condensate. Apparently, there was either a reservoir of condensate being formed in the heat exchanger that overflowed every few cycles or there was condensate formed on the walls of the condensing heat exchanger section that became wetted to the point where it flowed off all at once. In any case, and for whatever reason the first cycle of condensate collected could be similar to any one of those amounts shown between cycles 1 and 13 in Table 2(a). Since the steady state, heat-up and cool-down tests may be run prior to this test, there could be any number of starting conditions with respect to the amount of condensate stored inside the heat exchanger. Therefore, cycles 9, 10 and 11 (in Table 2(a)) could possibly represent the 3 cycles used to measure condensate. This would give an average of 1.6 grams. If starting conditions were such that the first cycle was cycle 10, and cycles 10, 11 and 12 were used to rate the unit (which averaged 33.9 gms); this would have given an improvement in part load efficiency of 1.4 percentage points. The cycles 9, 10 and 11 would show less than 0.1 percent point increase in part load efficiency. The six cycle test would help but would not completely correct this discrepancy. Six cycles could possibly overestimate the condensate collection rate because it may include two longer collection cycles. However, it would not underestimate the improvement as three cycles could with these data.

After DOE proposed a six cycle test for all condensing furnaces, several manufacturers suggested that a three cycle test be allowed for units which gave repeatable results. This would reduce testing time and cost. Repeatable results were suggested as those resulting in a standard deviation for three cycles being with 20% of the mean value. Table 2 (a) shows those limits of variability could not be achievable for this unit in any of the six consecutive cycles. DOE agreed with the manufacturers and specified either a three cycle or six cycle test depending upon the results on variability as described above. DOE further specified a maximum of six cycles irrespective of the variability after six cycles. In the Analysis of Comments [8], an alternate approach was suggested if variability were greater than the 20% of the mean after six cycles. This approach is included in Appendix B.

5.2 EFFECT OF VARIABLE BURNER ON/OFF TIMES

The test procedure proposed by DOE for direct condensate measurement was based on an assigned average burner on period of 3.8 minutes, and off period of 13.3 minutes. These times were chosen in order to be consistent with the test procedure previously used for non-condensing furnaces. The previous test procedure for non-condensing furnaces was based on the finding that the efficiency calculated using one cycling rate and one heating load corresponding to the average outdoor temperature would approximate the weighted average for several on-off times representing several outdoor temperature ranges through the heating season (e.g., a Multi-Bin Analysis).

5.2.1 High Efficiency Condensing Furnace

This type of bin analysis was run using data obtained with furnace "A". Table 3 shows the results found.

Burner on/off times were calculated by first selecting outdoor air temperature. These were selected so that the total heating season hours between each temperature would be approximately the same number of hours for each bin. Data by month were obtained from reference [11] and were compiled in table format for the analysis in reference [12]. One of those tables of compiled data from [12] is included as Appendix D for the city used in this example (i.e. Charleston, West Virginia). This city was selected because it has close to the national average number of degree days used by the DOE procedure.

Table 3. Multi Bin Analysis: Furnace "A"

(1) Outdoor Temperature Toa	(2) Ton (min)	(3) Toff (min)	Load Fraction (%)	(4) Average gms/cycle	(5) gm per minute on time		(6) % on Time {Col(2) ÷ [Col(2)+ Col(3)]}·100		(7) Bin Hours/ Year	(8) Kgm Water Condensate/yr* [Col(5)·Col(6)· Col(7)·60÷100,000]
5^oF	7.3	5.1	100	206.3	28.2		59%			
						28.5		54.5%	94	87
14	6.0	6.0	50	172.2	28.7		50			
						28.7		40.5	1004	700
34	4.7	10.7	36	135.4	28.8		31			
						29.6		27	1228	588
42	3.8	13.3	23	113.7	29.4		23			
						29.7		16.5	1504	442
55	3.3	30.0	30	98.5	29.8		10			
						29.8		7.5	1049	140
							5			
									Total --	1958

*Basic Weather data for Charleston, W.VA. - 4938 Days from data in Reference 10 & 11. Degree Days here are based on seven months of the year (October Thru May) and is calculated from Total Degree hours (see Appendix D)

Estimated total condensed per year Based on one Bin:

@ 42^oF: (i.e. 3.9 min on & 13.3 min off) on time hours/yr = $\sum(6)\cdot(7)$ = 1116 hrs.
Condensate Kgm/yr = (1116) (29.4) (60) = 1968

Appendix D shows the cumulative degree-hours, degree-days and bin hours beginning at 65°F (summing upward from the bottom of the last three columns).

Equations used to calculate burner on/off times are presented in Appendix C-2. From Appendix D, note that the number of bin hours from 5°F to 9°F is 25 hours and from 10°F to 14°F is 69 hours. This totals 94 hours which is shown in column 7 of Table 3. The last column in Appendix D is the weighted average outdoor temperature between 64°F and the outdoor temperature (t_{oa}). This city with averge 42.2°F over the heating season is identical to the national average of 42°F used with DOE test procedure to calculate the on/off times of 3.8 minutes and 13.3 minutes. In both cases oversizing of 70% is assumed.

The bin analysis of Table 3 shows that a total of 1958 kg of condensate would be collected over the heating season. In order to compare this with the result from the DOE procedure for one bin (average on/off periods of 3.8 min and 13.3 min), the total hours per year is calculated as shown on Table 3 to be 1116 hours, and condensate collected is calculated to be 1968 Kg. This is within 0.5% of the multi-bin analysis result. The adequacy of the single bin approach is apparent from these results.

This calculation used a condensate collection rate obtained in the laboratory with ambient conditions of approximately 70-75°F and relative humidity of approximately 30-50%. If a more detailed analysis to represent field conditions were to be run, it would be necessary to consider the absolute humidity of the outdoor air for these various temperature bins. The effect of the variation of humidity on condensate collection is reported in section 5.4.2.

5.2.2 Borderline Condensing Furnace

Table 4 shows results of five cycling rates including for comparison those results reported in Tables 2(a) and 2(b) for the average on/off times specified by the DOE test procedure. Data in Table 4 shows that as the percentage of burner on time increased, there was a change in the pattern of condensate collection. The frequency of cycles were no condensate was collected fell off with increasing burner on periods.

The periodic changes that occur began to show a repeating pattern particularly with the maximum heating load factor (i.e. 100% equivalent to 7.32 minutes on/5.1 minutes off). Notice for test series no. 5 from cycles (20) through (26) the grams of sample collected was practically a repeat of cycles (7) through (13).

These results show very little effect of cycling rate on the rate of water condensed. (See column of overall averages per minute of burner on time.) A bin analysis using the Charleston, West Virginia data shown in Appendix D results in a weighted collection of 342 kg/year compared to 365 kg/year using the single bin collection rate data for 3.8 min. on/13.3 min. off). Again, the single bin gives a slightly higher value (7% higher). This is a much smaller effect in terms of part-load efficiency effect since only 10 to 15% of the total possible condensate was actually condensed in these tests. The total possible latent heat correction for complete condensation is 9.55 percentage points. Fifteen percent of the total possible condensed therefore amounts to 1.5 percentage points of efficiency. A seven percent variation in 1.5 points is only 0.1 point. These results confirm the adequacy of a single burner on/off period for the direct condensate measurement for both high efficiency and borderline types of condensing

Table 4 Effect of Burner cycling on collection (grams) - Test Furnace "C"

Test Series	Outdoor Air Temperature (Toa)	On Time (min)	Off Time (min)	Heating Load*	CYCLE (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	Overall Averages per cycle	Overall Average per minute of Burner on time	% Condensed of maximum possible
(1)	42°F	3.87	13.3	22%	0.2	80.3	1.0	0.0	58.3	1.0	0.0	38.7	1.0	1.2	2.6	97.8	0.1	21.7	5.6	13%
(2)		Repeat Test			65.3	0.0	6.0	58.5	0.0	0.0	0.0	64.4	0.0	0.0	0.0	67.2	0.0	20.3	5.3	12%
(3)	28°	4.7	10.7	36%	65.2	0.0	0.0	0.0	82.3	0.0	0.0	0.0	58.0	0.0	0.0	1.0	63.7	20.7	4.4	10
(4)	14°	6.0	6.0	50%	59.3	1.7	70.1	0.0	78.5	1.0	70.4	1.5	56.0	4.5	63.2	-cycles 12 thru 16- total 194.79		37.6	6.3	15
(5)	5°	7.32	5.1	100%	55.0	1.0	96.5	1.0	90.3	0.6	85.3	1.6	91.4	1.5	87.6	0.3	85.0 #	45.9(1-13)	6.3	15
					2.8(14)	91.1	0.7	74.5	54.5	6.3	86.3(20)	1.5	91.9	1.6	87.5	1.5	90.0(26)	45.4(14-26)	6.2	14
(6)	5° **	7.32	5.1	100%	41.0	5.1	87.8	41.5	0.3	71.0	67.1	49.3	0.2	87.4	0	71.5	53.4 #	42.5(1-18)	5.8	13
					50.4(14)	41.1	50.3	45.5	1.9(18)											

*Based on 70% oversize the heating load fraction is calculated from $\frac{65-Toa}{65-5} \cdot \frac{1}{(1+\alpha)}$ where $5^{o}F$ is design temperature and α is the fraction oversize

** Repeat test with a Condensate drain line obstruction removed.

Cycle number (14) continued next line

furnaces.

No tests were run with furnace "D" because that furnace, although equipped with a condensate drain, did not produce any condensate in either steady state or cyclic tests.

5.3 INVESTIGATION OF STEADY STATE TESTING

The objective of these tests was to determine the effect of condensate collection test period on rate of condensate collected. These data were obtained in order to respond to comments received from manufacturers requesting that the total test time be reduced to 30 minutes from the 60 minute test as proposed by DOE in [7]. A reduced test time would reduce testing costs.

Table 5 (a) shows the data obtained for three furnaces tested. Table 5 (b) shows these data in terms of condensate collection rate after steady state conditions were established (i.e. 30 minutes after start-up). The DOE procedure [1] specifies that steady state conditions be established before starting the collection of condensate. These data show that a 30 minute test gave results equivalent to the proposed sixty minute test. Condensate collected with furnace "C" was slightly less during the first 30 minutes compared to the proposed 60 minute test. However, the results after 30 minutes were obviously consistent with the extended test period of 90 minutes (i.e. average 4.9 g/min after 30 minutes and after 90 minutes for furnace "C").

DOE published rules for condensing furnaces on March 28, 1984 [1] which reduced the testing time period for this test to 30 minutes.

Table 5(a) -- Effect of Testing Time on Direct Measurement of Condensate for Steady State Test

Time interval (minutes)	Condensate Collected during time interval (grams)		
	Furnace A	Furnace B	Furnace C
0 - 10	229	298	0
10 - 20	224	301	0
20 - 30	216	298	88.7
30 - 40	211*	294*	38.8*
40 - 50	205	295	31.1
50 - 60	208	293	78.2
60 - 70	207	294	55.3
70 - 80	207	293	41.2
80 - 90	213	294	68.4
90 - 100	212	295	19.5
100 - 110	211	293	81.4
110 - 120	211	295	24.0

*Start of Steady State Conditions

Table 5(b) -- Condensation Collection Rate (gm/minute) vs. Length of Test Period After Start of Steady State

Test Period	Furnace A	Furnace B	Furnace C
30 minutes	20.8	29.4	4.9
60 minutes	20.8	29.4	5.2
90 minutes	20.9	29.4	4.9

Additional test data including the effect of test room air conditions on condensate collection rate at steady state conditions is included in Section 5.4.

5.4 EFFECTS OF AMBIENT TEST ROOM CONDITIONS

5.4.1 Effects of Room Air Temperature

This study involved variation in temperature of the return air supply. Combustion air was kept at approximately 70°F throughout these tests. In order to obtain data at above the normal room air temperature of the laboratory, the test room described in 3.3.2 was used in these tests.

Test results by linear regression analysis of data for room temperatures versus rate of condensate collected (gram/min) are shown in Fig. 5. These results are for furnace "A". Test results are shown for both cyclic and steady state tests. With the cyclic tests the blower input air temperatures used for Fig. 5 were obtained during the furnace fan on period. During burner off periods, test room air temperature became the ambient laboratory temperature of 70°F because the air supply fan remained on throughout the burner on/off periods. Therefore, return air temperature or "blower input air temperature" in Fig. 5 on start up was approximately 70°F for each test. However, this air temperature rose rapidly on start up of the burner, since this test room was small (362 cubic ft) compared to the warm air discharge rate of the furnace, (roughly 1000 cfm). As a result of this reduced room temperature starting condition of approximately 70°F, the effect of high ambient room air temperature reported here are conservative. If it had been possible to maintain a constant return air temperature during these cyclic tests, we could expect to see a greater drop off in condensate collection rate at the elevated temperature (i.e., a

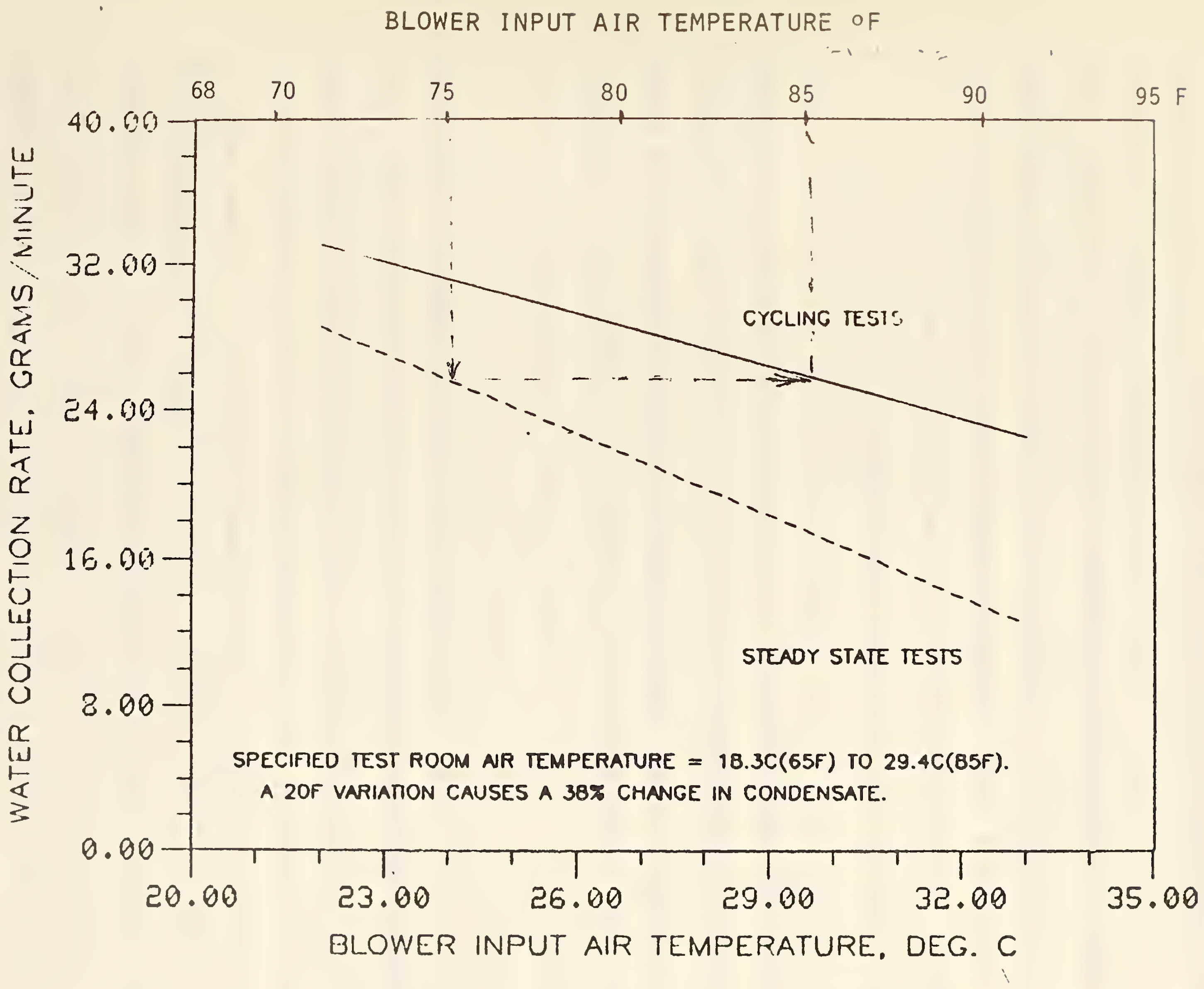


Figure 5. Effect of test room ambient temperature on rate of condensate collected using Test Furnace "A"

greater slope to the curve of cyclic tests). Alternatively, if the average room temperature were used in plotting the data of Fig. 5, the slope of the cyclic test line would have been greater because data points for a given ordinate value would have been shifted to the left.

This cyclic curve would be expected to be parallel to the steady state curve with the above adjustments to these test data on test conditions. The effects of a lower average air temperature on the air side of the heat exchanger is also the reason why the condensate collection rate for cyclic tests is greater than the steady state tests.

From the data shown in Fig. 5, it is seen that running a steady state test with room air temperature at 75°F would give the same result as a cyclic test run at 85°F (i.e., by following a line from 75°F down to the steady state line, to the right to the intersection at 85°F of the cyclic test line).

These test results show that effects of the test room temperature on direct condensate measurement and part load efficiency are significant. The difference in these tests on part load efficiency with each 10°F of room temperature amounted to 1.1 percentage points in part load efficiency and 1.6 percentage points in steady state efficiency. In other words, a maximum effect of part load efficiency with a return air temperature at the lower allowable limit of 65°F compared to 85°F at the upper limit could be 3.2 percentage points. These changes in part load efficiency are approximate and cannot be used to predict actual part load efficiency changes under rating conditions, because the temperature rise of the warm air in these tests was not readjusted with each change of inlet temperature to achieve the manufacturers rated maximum temperature rise as specified by the DOE procedures. Also in these tests the laboratory air temperature could not be adjusted below 70°F, therefore, these results were extrapolated from 70°F to 65°F.

However, these data may be used to predict what the maximum allowable variation in room air temperature could mean in terms of its relative effect on part load efficiency. The allowable variation in room air temperature could mean a change in reproducibility of 1.1 percentage points in part load efficiency with this test furnace.

5.4.2 <u>Test Room Humidity Effects</u>

Ambient conditions of humidity are of concern only for the combustion air supply. There were no controlled conditions of humidity for the return air side during these tests and there is no reason to expect any significant change of heat transfer through the heat exchanger due to humidity of the return air. Since one of the combustion products of fossil fuels which contain hydrogen is water, there is reason to believe that condensate collection would be effected by humidity in the air supplied for combustion. In these tests, conditioned air was supplied to the burner from an environmental chamber as described in 4.3.2. Test results are shown in Fig. 6 both for the cyclic tests and the steady state tests.

These results with cyclic tests show that a change from 10% to 90% relative humidity results in an increase of 7.6 g/min of water condensed. This is equivalent to 0.2 percentage points of part load efficiency for each 10 percent change in relative humidity. In these tests air supplied both for combustion and return air to the furnace fan was constant at 72°F (22°C) and at 92°F (33°C). The data for the steady state tests show approximately

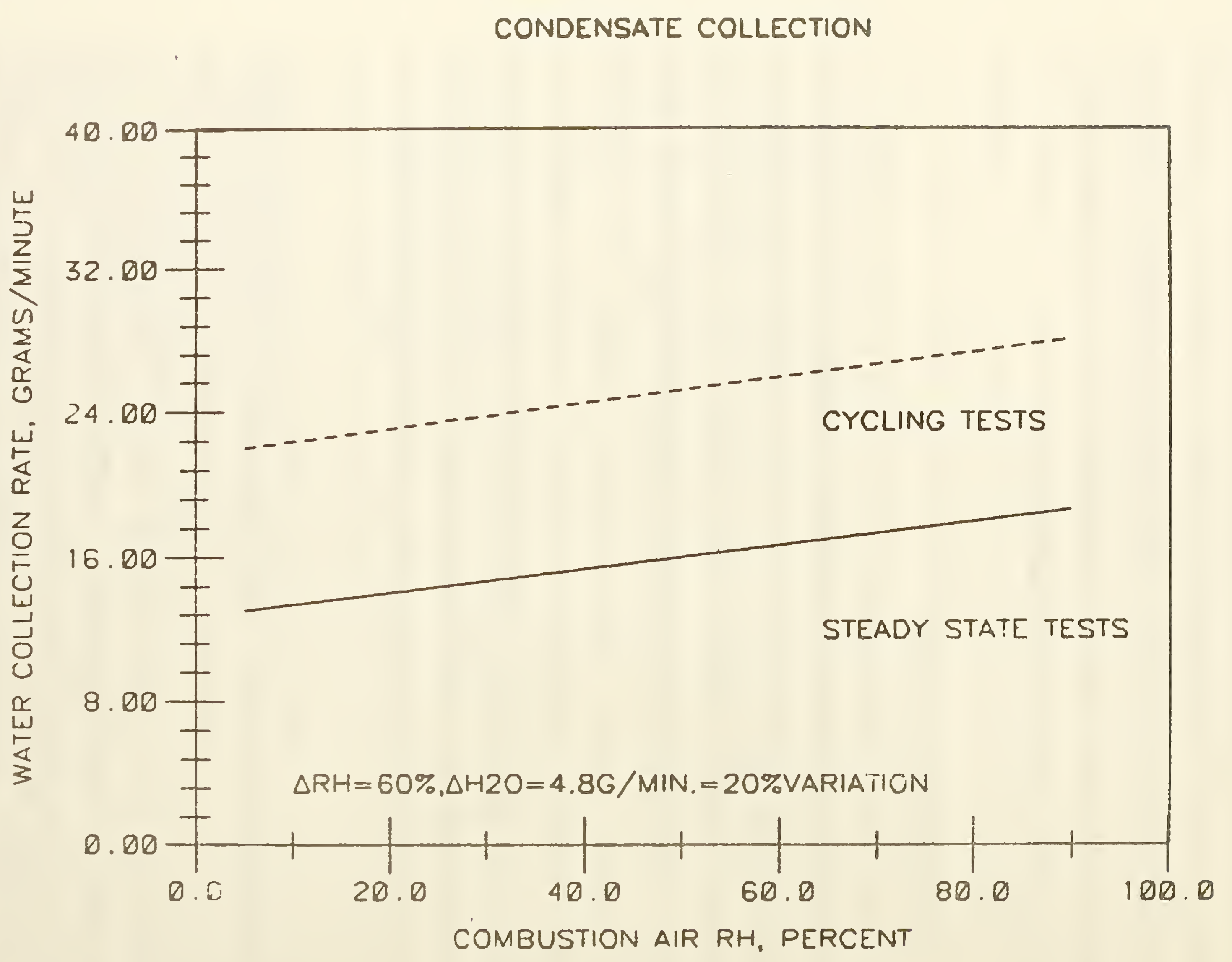


Figure 6. Effect of relative humidity of test room air at constant room temperature on rate of condensate collected - Using test furnace "A"

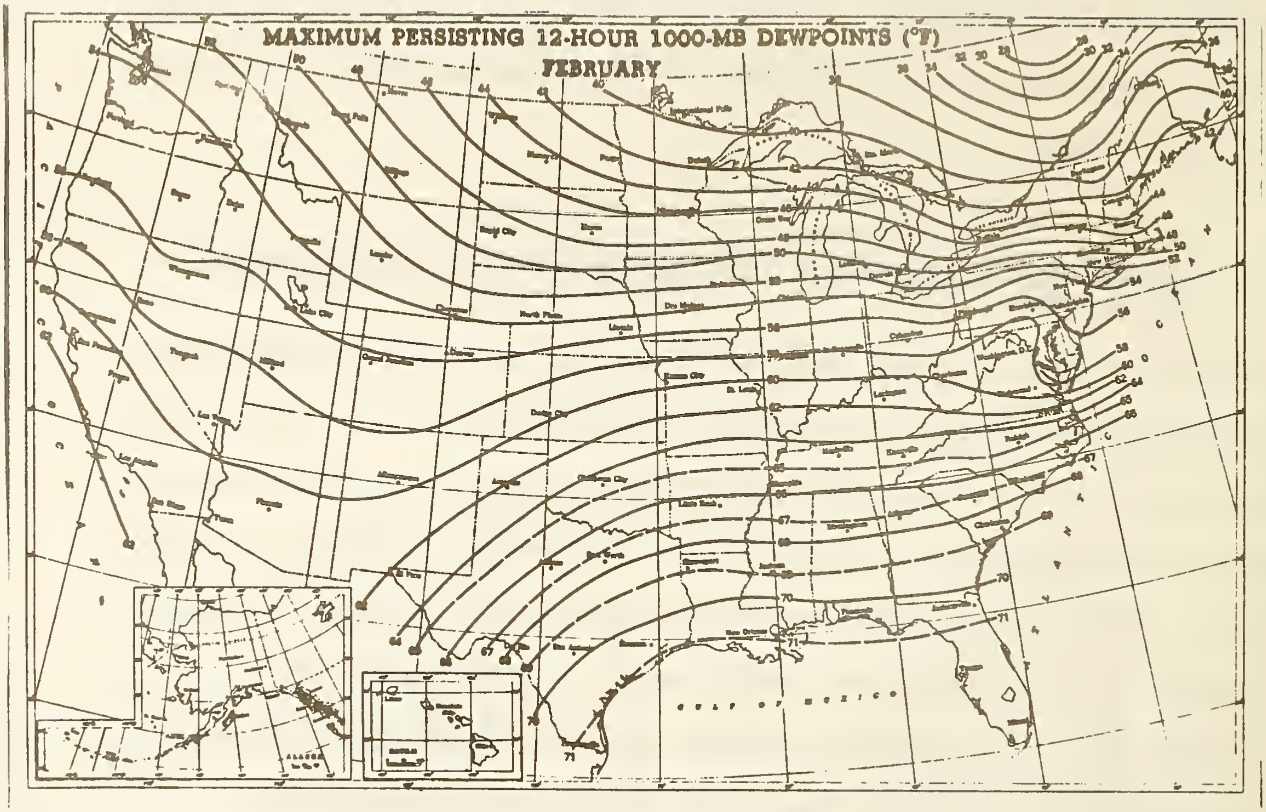
the same change in condensate collection rate (i.e., 1.0 percentage points increase in efficiency for an increase of 60 percentage points increase in relative humidity).

5.4.3 Disucssion of Test Results With Controlled Room Air Temperature and Humidity

In the calculation of steady state efficiency by the flue loss method, flue temperature is measured in terms of the temperature rise above room temperature. Similarly, the calculations of part load efficiency are related to temperature rise above room temperature. Therefore, a wide range of test room air temperatures have been allowed with non-condensing furnaces. With this direct measurement of condensate there is no correction for room temperature and the amount of condensate collected is used as measured in adjusting the credit for part-load efficiency.

A narrow ambient room temperature range of 65°F to 75°F was proposed in 1977 [13] for furnaces. Industry objected to that narrow range and cited the cost of expensive refrigeration equipment that would be needed in order to meet that proposed room temperature condition [14]. Several commentors suggested various temperature ranges of 65°F to 85°F or; 65°F to 95°F; or 65°F to 100°F. DOE published their procedure [2] specifying 65°F to 100°F for non-condensing furnaces. The proposed range of 65°F to 85°F for condensing furnaces would, therefore, be within a range originally recommended by the Industry that would not require the air conditioning of testing facilities.

The allowable 80% relative humidity in the range of 65°F to 85°F means the allowable dew point is between 61°F and 80°F. These extreme conditions are unlikely to exist, (see Fig. 7 for weather maps showing maximum dew point



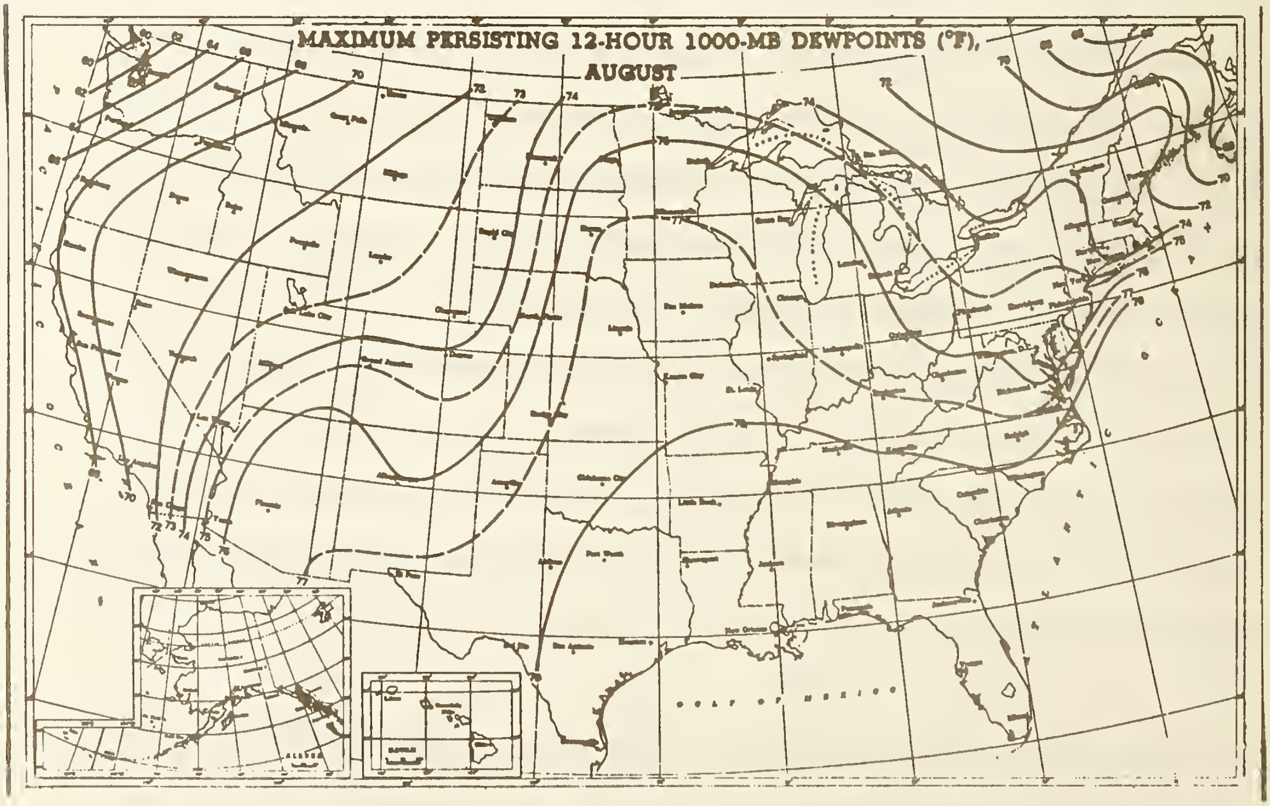


Figure 7. Weather maps showing two of the extreme months for maximum dewpoint readings in the United States (From ref. 15)

contour lines).

In view of the past objections to a tighter test room temperature specification and because there were no commentors objecting to the proposed procedures during the public comment period, NBS did not recommend changes to the proposed room temperature specification [14].

It should be understood, that test parameter effects such as room air temperature and humidity are a concern regarding the ability to reproduce test results in the laboratory, either within the same laboratory (i.e., repeatability of results) or between laboratories (i.e., reproducibility of results). These test parameters do not pertain to the differences between laboratory and field conditions. Several designs of condensing furnaces use outdoor air which is piped to the furnace through an outside wall and through roughly 25 feet of 1.5 inch diameter plastic pipe. Therefore, actual temperature and humidity conditions of the combustion air will depend upon the outdoor temperature and the degree of heat transfer to room air that results before combustion air enters the furnace. With respect to return air temperature in the home during the heating season, that will depend upon the users thermostat setting and overall heating system design with respect to the return air duct work location, surface area and insulation. Specifying a return air temperature that would reflect in use conditions is beyond the scope of this study.

6.0 SUMMARY

It is shown that a single cycling rate representing the heating season average typical burner on/off times (as currently used in the DOE test procedures) would also be adequate for use in the direct condensate measurement test under cyclic conditions.

Under this cyclic test for direct condensate measurement, it is also shown that a three cycle test would be adequate for the high efficiency condensing furnace because that type of furnace resulted in a highly repeatable rate of condensate formation and collection. With borderline condensing furnaces, it is shown that the amount of condensate collected would be so variable that a test for repeatability would be difficult or impossible under the guidelines suggested by several commenters to the proposed procedures.

In the direct condensate measurement test under steady state conditions, it is shown that a thirty minute collection period provides sufficient information regarding the condensation rate and can replace the originally proposed sixty minute test period.

The effect of ambient room return air temperature over the allowable range is found to be significant in terms of its effect on condensate collected. For of part-load efficiency the effect can be up to three percentage points over the range of allowable room temperatures. Effects of humidity are considerably less than the effect of return air temperature, being only 0.2 percentage points per 10% change in relative humidity.

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APPENDIX A, B, C, D

A. DOE Test Procedure for Direct Measurement of Condensate

B. Alternative Method of Rating Condensate Collection Rate for Borderline Condensing Furnace

C. Sample Calculations

    1. Part Load Efficiency Effect With Condenste Collection Rate

    2. Calculation of Burner On/Off Time

D. Weather Data Used for Bin Analysis of Condensate Collection

APPENDIX A

boiler shall be started simultaneously with the main burner(s). The water flow rate shall be the same as that maintained during the steady-state test described in section 9.1 of ANSI/ASHRAE 103–82. During the heat-up test for oil fired boilers maintain the draft in the flue pipe within ± 0.01 inch of water column of the manufacturer's recommended on-period draft. Record the measured temperatures.

3.6 *Direct measurement of condensate.* For condensing furnaces and boilers, the condensate heat loss shall be determined either by the method specified in section 11.2.33 of ANSI/ASHRAE 103–82 or by the following test procedures:

Control devices shall be installed to allow cyclical operation of the unit and return water or air flows as described in sections 9.2 and 9.3 of ANSI/ASHRAE 103–82 and sections 3.2, 3.3, 3.4 and 3.5 of this appendix. The test unit shall be leveled prior to test. Operating times and beginning and end of condensate collection shall be determined by a clock or timer with a minimum resolution of one second. Humidity of the room air shall, at no time, exceed 80 percent.

Control of on or off operation actions shall be within ± 6 seconds of the scheduled time. Condensate drain lines shall be attached to the unit as specified in the manufacturer's installation instructions. A continuous downward slope of drain lines from the unit shall be maintained. Additional precautions shall be taken to facilitate uninterrupted flow of condensate during the test.

The flue pipe installation must not allow condensate formed in the flue pipe to flow back into the unit. An initial downward slope from the unit's exit, an offset with a drip leg, annular collection rings, or drain holes must be included in the flue pipe installation without disturbing normal flue gas flow, as specified in section 7.2.2 of ANSI/ASHRAE 103–82. Flue gases should not flow out of the drain with the condensate.

Collection-containers must be glass or polished stainless steel, so removal of interior deposits can be easily made. The collection-container shall have a vent opening to the atmosphere.

The scale for measuring the containers and sample condensate mass shall be calibrated with an error no larger than ± 0.5 percent over the range of interest.

The condensing furnace or boiler shall be tested by the flue loss method in accordance with the provisions for condensing units, as specified in section 9 of ASNI/ASHRAE 103–82 and section 3 of this appendix. The condensate collection-containers shall be dried prior to each use and shall be at room ambient temperature prior to a sample collection. Tare weight of the collection-container must be measured and recorded prior to each sample collection.

The unit should be operated in a cyclical manner until flue gas temperatures at the end of each on-cycle are within 5° F (2.8° C) of each other for two consecutive cycles. On-cycle and off-cycle times are listed in Table 2 of this appendix. Begin three test cycles. Return air temperature for furnaces shall be as specified in section 9 of ANSI/ASHRAE 103–82 and section 3 of this appendix. Return water temperature for boilers shall be as specified in section 2.3 of this appendix. Operation of the furnace blower or boiler pump shall conform to the time delay requirements specified in sections 9.2 and 9.3 of ANSI/ASHRAE 103–82 and sections 3.2, 3.3, 3.4, and 3.5 of this appendix for cool down and heat up tests. Operation of the boiler pump shall conform to the time delay requirements specified in section 3.3 of this appendix.

Begin condensate collection at one minute before the on-cycle period of the first test cycle. The container shall be removed one minute before the end of each off-cycle period of the sixth test cycle. Condensate mass shall be measured for each test cycle.

Fuel input shall be recorded during the entire test period starting at the beginning of the on-time period of the first cycle to the beginning of the on-time period of the second cycle, etc., for each of the test cycles. Fuel higher heating value (HHV), temperature and pressures necessary for determining fuel energy input (Q_c) shall be recorded. The fuel quantity and HHV shall be measured with errors no greater than one percent. Determine the mass of condensate for each cycle (m_c) in pounds. If at the end of three cycles, the sample standard deviation is within 20% of the mean value for 3 cycles use total condensate collected in the three cycles as m_c, if not, continue collection for an additional three cycles and use the total condensate collected for the six cycles as m_c. Determine the fuel energy input during the three or six test cycles (Q_c) expressed in Btu.

Begin a steady-state condensate collection after steady-state conditions have been achieved as specified in section 8 of ANSI/ASHRAE 103–82 and section 2 of this appendix. The steady-state collection period shall be 30 minutes. Condensate mass shall be measured immediately at the end of the collection period to prevent evaporation loss from the sample. Fuel input shall be recorded for the one hour steady-state test period. Fuel Higher Heating Value (HHV), temperature and pressures necessary for determining fuel energy input $Q_{c,ss}$ will be observed and recorded in Btu's. The fuel quantity and HHV shall be measured with errors no greater than one percent. Determine the mass of condensate for the steady-state test, $m_{c,ss}$, in pounds by subtracting the tare container weight from the total container and condensate weight measured at the end of the 30 minutes test period.

3.7 *Direct measurement of off-cycle losses testing method.* Reserved.

3.8 *Direct measurement of the S/F factors for oil furnaces and boilers.* For oil furnaces and boilers that are marketed and sold with attached barometric dampers, the S/F factor shall be determined either by using assigned factors in Table 2 of ANSI/ASHRAE 103–82 or by the following test procedure:

To directly measure the S/F factor, seal the barometric damper plate in the closed position. Operate the furnace or boiler until steady-state temperatures are attained. Adjust the draft in the flue within one foot of the heat exchanger exit to be between 0.075 and 0.085 inch water column. A mechanical draft inducer or a natural draft developed by adjusting the height of the test stack may be used. Remove the seal from the barometric damper and adjust the damper gate to achieve proper draft, as specified by the manufacturer. If the draft over the fire is specified as a range, adjust the draft to the mid-point of that range.

After steady-state conditions are again achieved with the draft adjusted as specified, measure CO_2 before and after dilution at points marked A and B in Figure 2 of this appendix. To ensure that the sample is well mixed after dilution obtain a representative sample of stack gas by sampling from several points on a horizontal plane through the cross section of the stack. The test setup shown in Figure 2 enhances the mixing of dilution air and flue gases. Alternatively, a straight length of stack or other flue piping arrangement may be used with stack samples taken sufficiently downstream after dilution in order to obtain a well-mixed sample.

3.9 *Furnaces and boilers that includes small air passages in the flue.* For furnaces and boilers that includes small air passages in the flue where such passage serves a utility other than for draft relief, the air passage shall be open during all tests and the test data shall be reduced as specified in section 4 of this appendix.

These units shall be considered as direct exhaust systems, for the purposes of this test procedure. These provisions shall not apply to systems which allow for air flow through the air passage in excess of 10 percent of maximum steady state total flue flow; in these cases, such passages are to be considered as draft diverters or draft hoods.

4.0 *Calculations.* Calculations shall be as specified in section 11 of ANSI/ASHRAE 103–82 with the exception of section 11.2.6, and the inclusion of the following additional calculations:

4.1 *Annual fuel utilization efficiency for electric furnaces and boilers.* The annual fuel utilization efficiency for electric furnaces and boilers (AFUE) is equal to the heating seasonal efficiency for electric furnaces and boilers ($Effy_{hs,e}$) as defined in section 11.1 of ANSI/ASHRAE 103–82.

4.2. *Average ratio of stack gas mass flow rate to flue gas mass flow rate at steady-state operation.* The following paragraphs are in place of the requirements specified in section 11.2.8 of ANSI/ASHRAE 103–82:

For gas furnaces and boilers with integral draft diverters, calculate the average ratio of stack gas mass flow rate to flue gas mass flow rate at steady-state operation (S/F) defined as:

$$S/F = 1.3\ R_{T,s}/R_{T,F}$$

where:

$R_{T,s}$ = as defined in 11.2.3 of ANSI/ASHRAE 103–82

$R_{T,F}$ = as defined in 11.2.2 of ANSI/ASHRAE 103–82

For gas furnaces and boilers equipped with draft hoods determine the S/F by the method set out above or use the assigned value of 2.4. This alternative method may be used until 24 months from the effective date of the amendment. After that date, the assigned value may not be used and only the method set out above may be used.

For oil furnaces and boilers, S/F shall be 1.40 for units not shipped with barometric

Appendix A (continued)

dampers or for units shipped with barometric dampers, S/F shall be either 1.40 or determined by:

$S/F = R_{T.S}/R_{T.F}$

where:

$R_{T.S}$ = as defined in 11.2.3 of ANSI/ASHRAE 103–82 in which the value of CO_2 measured in the stack in 3.8 of this appendix is used

$R_{T.F}$ = as defined in 11.2.2 of ANSI/ASHRAE 103–82 in which the value of CO_2 measured in the flue in 3.8 of this appendix is used

4.3 *Optional direct condensate measurement method.* For condensing furnaces and boilers for which the direct measurement of condensate is used, as specified in section 3.6 of this appendix, calculate the part-load efficiency (η_u) and the steady-state efficiency (η_{SS}) expressed as a percent and defined as:

$\eta_u = Effy_{hs} + L_G - L_C$

$\eta_{SS} = Effy_{SS} + L_{G.SS} - L_{C.SS}$

where:

$Effy_{hs}$ = heating seasonal efficiency for non-condensing furnaces and boilers, as defined in 11.2.34 of ANSI/ASHRAE 103–82

L_G = latent heat gain under part-load conditions, as defined in 4.3.1 of this appendix

L_C = part-load heat loss due to the condensate going down the drain and corrected for the fact that the condensate did not go up the flue as heated vapor, as was assumed in determining $L_{S.SS.A}$, as defined in 4.3.2 of this appendix

$Effy_{SS}$ = steady-state efficiency for non-condensing furnaces and boilers, as defined in 11.2.5 of ANSI/ASHRAE 103–82

$L_{G.SS}$ = latent heat gain under steady-state conditions, as defined in 4.3.3 of this appendix

$L_{C.SS}$ = steady-state heat loss due to the condensate going down the drain and corrected for the fact that the condensate did not go up the flue as heated vapor, as was assumed in determining $L_{S.SS.A}$, as defined in 4.3.4 of this appendix

4.3.1 *Latent heat gain under part-load conditions.* Calculate the latent heat gain under part-load conditions (L_G) expressed as a percent and defined as:

$L_G = 100(1053.3)\, m_c/Q_c$

where:

100 = conversion factor to express a decimal as a percent

1053.3 = latent heat vaporization of water, Btu per pound

m_c = as defined in 3.6 of this appendix

Q_c = as defined in 3.6 of this appendix

4.3.2 *Part-load heat loss due to the condensate.* Calculate the part-load heat loss due to the condensate going down the drain and corrected for the fact that the condensate did not go up the flue as heated vapor, as was assumed in determining $L_{S.SS.A}$ (L_C) expressed as a percent and defined as:

$L_C = L_G[1.0(T_{F.SS} - 70) - 0.45(T_{F.SS} - 42)]/1053.3$

where:

L_G = as defined in 4.3.1 of this appendix

1.0 = specific heat of water (liquid), Btu per pound − °F

$T_{F.SS}$ = as defined in 11.2.4 of ANSI/ASHRAE 103–82

70 = assumed average indoor air temperature, °F

0.45 = specific heat of water vapor, Btu per pound − °F

42 = average outdoor temperature corresponding to 5,200 degree day location, °F

1053.3 – Latent heat of vaporization of water, Btu per pound

4.3.3 *Latent heat gain under steady-state conditions.* Calculate the latent heat gain under steady-state conditions ($L_{G.SS}$) expressed as a percent and defined as:

$L_{G.SS} = 100(1053.3) m_{C.SS}/Q_{C.SS}$

where:

100 = conversion factor to express a decimal as a percent

1053.3 = latent heat of vaporization of water, Btu per pound

$m_{C.SS}$ = as defined in 3.6 of this appendix, pound

$Q_{C.SS}$ = as defined in 3.6 of this appendix, Btu

4.3.4 *Steady-state heat loss due to the condensate.* Calculate the steady-state heat loss due to the condensate going down the drain ($L_{C.SS}$) expressed as a percent and defined as:

$L_{C.SS} = L_{G.SS}[1.0(T_{F.SS} - 70) - 0.45(T_{F.SS} - 42)]/1053.3$

where:

$L_{G.SS}$ = as defined in 4.3.3 of this appendix

1.0 = specific heat of water (liquid), Btu per pound − ° F

$T_{F.SS}$ = as defined in 11.2.4 of ANSI/ASHRAE 103–82

70 = assumed average indoor air temperature, ° F

0.45 = specific heat of water vapor, Btu per pound − ° F

42 = average outdoor temperature corresponding to 5200 degree day location, ° F

1053.3 = latent heat of vaporization of water, Btu per pound

4.4 *Direct determination of off-cycle losses for furnaces and boilers equipped with stack dampers.* Reserved

4.5 *Modulating controls.*

4.5.1 *Weighted-average part-load utilization efficiency.* For furnaces and boilers equipped with two stage thermostats, calculate the weighted-average part-load utilization efficiency at each design heating requirement ($\eta_{U.WT}$) expressed as a percent and defined as:

$\eta_{U.WT} = X_1 \eta_{U.RED} + X_2 \eta_{U.MAX}$

where:

X_1 = fraction of heating load at reduced operating mode, as defined in 4.5.2 of this appendix

$\eta_{U.RED}$ = the part-load efficiency at the reduced fuel input rate and is defined as the heating seasonal efficiency ($Effy_{hs}$) in 11.2.34 of ANSI/ASHRAE 103–82, measured at the reduced fuel input rate and calculated by using the appropriate on and off times as specified from Table 2 of this appendix

X_2 = fraction of heating load at maximum operating mode, as defined in 4.5.3 of this appendix

$\eta_{U.MAX}$ = the part-load efficiency at the maximum fuel input rate and is defined as the heating seasonal efficiency ($Effy_{hs}$) in 11.2.34 of ANSI/ASHRAE 103–82, measured at the maximum fuel input rate and calculated by using the appropriate on and off times as specified from Table 2 of this appendix

For furnaces and boilers equipped with step-modulating thermostats, calculate $\eta_{U.WT}$ expressed as a percent and defined as:

$\eta_{U.WT} = X_1\, \eta_{U.RED} + X_2\, \eta_{U.MOD}$

where:

X_1 = as defined in 4.5.2 of this appendix

$\eta_{U.RED}$ = as defined in 4.5.1 of this appendix

X_2 = as defined in 4.5.3 of this appendix

$\eta_{U.MOD}$ = average part-load efficiency for the modulating mode, as defined in 4.5.8 of this appendix

4.5.2 *Fraction of heating load at reduced operating mode.* Determine the fraction of heating load at the reduced operating mode (X_1) expressed as a decimal and listed in either Figure 4 or Table 3 of this appendix for appropriate values of the balance point temperature (T_C). T_C is defined in section 4.5.4 of this appendix.

4.5.3 *Fraction of heating load at maximum operating mode.* Determine the fraction of heating load at the maximum operating mode (X_2) expressed as a decimal and listed in either Figure 4 or Table 3 of this appendix for appropriate values of the balance point temperature (T_C).

4.5.4 *Balance point temperature.* Calculate the balance point temperature (T_C) which represents a temperature used to apportion the annual heating load between the reduced input cycling mode and either the modulation mode or maximum input cycling mode. T_C is defined as:

$T_C = 65 - [\Delta T_D(1 + \alpha_{DHR})\,[Q_{OUT.RED}/Q_{OUT.MAX}]]$

where:

65 = average outdoor temperature at which a furnace or boiler starts operating, °F

ΔT_D = the difference between the outdoor air temperature where heating is typically required and the outdoor design temperature, the national average temperature difference is 65° F − 5° F or 60° F

5 = outdoor design temperature

α_{DHR} = oversize factor at each design heating requirement, as defined in 4.5.5 of this appendix

$Q_{OUT.RED}$ = heat output rate at the reduced fuel input rate, as defined in 4.5.6 of this appendix

$Q_{OUT.MAX}$ = heat output rate at the maximum fuel input rate, as defined in 4.5.7 of this appendix

4.5.5 *Oversize factor at each design heating requirement.* Calculate the oversize factor at each design heating requirement (α_{DHR}) expressed as a decimal and defined as:

$\alpha_{DHR} = [Q_{OUT.MAX}/DHR] - 1$

where:

$Q_{OUT.MAX}$ = as defined in 4.5.7 of this appendix

DHR = typical design heating requirements, as listed in Table 1 of this appendix

APPENDIX B

Cyclic Testing (the following discussion is from reference 8)

A three cycle test would be sufficient for the very high efficiency condensing furnace. This can be defined in the terms recommended by the commentors. If the sample standard deviation after a series of three cycles is completed were not greater than 20% of the mean value for those three cycles, the testing may be terminated after three cycles. This test procedure will require weighing the condensate collected after each cycle (which is not now required). If these guidelines were not met, three additional cycles would be run and the mean and variability results calculated based on six cycles.

If after six cycles, the test results were not within the specified limits of varibility additional testing would be required. This additional testing presents a potential problem of extended testing that would be considered excessively costly for certification. The extreme variability of the furnace data shown in Table 2 shows that it would be impossible to meet these guidelines of variability even after 18 cycles. In order to reduce the possibility of extended testing time by independent laboratory certifiction of the unit, the following options would be involved:

(1) The manufacturer should be permitted to submit a rated mean value for the unit that would apply for that basic model. If after the three additional test cycles were run (for a total of six), the sample mean value for six cycles were within ±30% of the manufacturers rated mean value, testing would be terminated. The rated value would then be either of:

    the manufacturers rated mean value; or the
    measured value whichever were the lowest.

DOE may wish to expand on this to consider alternatively allowing the manufacturers claimed rating to apply (since it would be based on a larger number of cycles). This variance of ±30% from the mean is not very significant in terms of the overall efficienty for the furnace described here in Table 2(a). An increase of 30% in condensate collected amounted to only 0.3% increase in steady state efficiency for this furnace.

(2) If after six cycles, the sample mean were outside these limits specified above, then additional testing would be necessary. For example, it may be that a small amount of condensate does form during each cycle but does not drain from the furnace during any of the first six cycles but then drains out in a later cycle. The option of running three or more additional cycles for certification testing beyond six should then be permitted. The rating would then be based on the total number of cycles using the guideline of being within ±30% of the manufacturers rated mean value. In the example given here (Table 2(a)), the sample mean was within the ±30% of the population mean value after the seventh cycle and remained within that range thereafter.

APPENDIX C-1

Sample Calculation of Part Load Efficiency Effect of Condensate Collection Rate

Example: Furnace C. With 6.7 grams per cycle difference in condensate, collected or (6.7 ÷ 3.8 minute) = 1.76 gram per minute.

- Input rate of furnace is 57.5 cubic feet per hour. Using methane as typical composition for stoichiometric calculation (this natrual gas is 96% methane)

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

- One cubic foot (ft^3) of fuel forms two ft^3 of water vapor. This water is equivalent to 0.1 lb or 45.4 grams

$$(2\ ft^3 \div 360\ ft^3/lb\ mol) \times 18\ lg/lb\ mol = 0.1\ lb.$$

- This furnace consumes 57.5 cubic feet of natural gas per hour or 0.96 cubic feet per minute and forms 43.6 grams/minute of water vapor. Of this total vapor formed 1.76 grams/minute is condensed.

- The total latent heat of vaporization of water in combustion of natural gas is assigned 9.55% as the part load latent loss.

- The equivalent in latent heat recovery percentage points for 1.76 grams/minute of condensate is (1.76 ÷ 43.6) x 9.55 = 0.39 percentage points in efficiency.

Example of calculation for buner on and off times presented in Table 3

$$\text{Ton} = \frac{60x}{4Nx(1-x)} = \frac{60}{4N(1-x)} \text{ and } \text{Toff} = \frac{60}{(4)(N)(x)(1-x)} - \text{Ton} = \frac{60(1-x)}{4Nx(1-x)} = \frac{60}{4Nx}$$

Where x is the load factor fraction N is the furnace number of cycles at half loads set equal to 5 for furnaces and 2 for boilers.

The calculation of load factor x is from the equation:

$$x = \frac{65-\text{Toa}}{65-5} \cdot \left(\frac{1}{1+\alpha}\right)$$

Where: α is the oversize fraction and 5°F is the Average design temperature.

The calculation of Ton and Toff is from reference (12)

Example: Outdoor Temperature of 42°F and an oversize fraction of 70% ($\alpha = .7$)

$$x = \frac{65-42}{60} \cdot \left(\frac{1}{1.7}\right) = 0.225$$

$$\text{Ton} = \frac{60(0.225)}{4(5)(0.225)(0.775)} = 3.87 \text{ min}$$

$$\text{Toff} = \frac{60}{4(5)(0.225)(0.775)} - 3.87 = 13.33 \text{ min}$$

Appendix D

Outdoor temperature data of ' total hours in temperature ranges of 5 degrees during heating season for Charleston W Va. (from reference 12)

outdoor temperature range f deg.	tc midpoint	total hours	heating degrees	deg. hours	deg. days	cumulative deg. hours	cumu-lative hours	toa
-5.--1.	-3.0	.0	68.	0.	4938.4	118522.	5189.	42.2
0.- 4.	2.0	.0	63.	0.	4938.4	118522.	5189.	42.2
5.- 9.	7.0	25.0	58.	1450.	4938.4	118522.	5189.	42.2
10.-14.	12.0	69.0	53.	3657.	4878.0	117072.	5164.	42.3
15.-19.	17.0	114.0	48.	5472.	4725.6	113415.	5095.	42.7
20.-24.	22.0	216.0	43.	9288.	4497.6	107943.	4981.	43.3
25.-29.	27.0	360.0	38.	13680.	4110.6	98655.	4765.	44.3
30.-34.	32.0	624.0	33.	20592.	3540.6	84975.	4405.	45.7
35.-39.	37.0	921.0	28.	25788.	2682.6	64383.	3781.	48.0
40.-44.	42.0	614.0	23.	14122.	1608.1	38595.	2860.	51.5
45.-49.	47.0	601.0	18.	10818.	1019.7	24473.	2246.	54.1
50.-54.	52.0	596.0	13.	7748.	569.0	13655.	1645.	56.7
55.-59.	57.0	552.0	8.	4416.	246.1	5907.	1049.	59.4
60.-64.	62.0	497.0	3.	1491.	62.1	1491.	497.	62.0

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The objective of this study was to determine if the direct measurement method of condensate collection that was developed during prior testing of a condensing boiler would be adequate for direct measurement of the condensate from gas fueled forced warm air condensing furnaces. Results of these tests were for purposes of supporting a test procedure proposed by the Department of Energy and responding to questions raised in comments to the proposed procedures. Another objective of these tests was to quantify the effects of varying test room ambient temperatures and relative humidity in the rate of condensate collected with condensing furnaces. These test results with a high rate of condensate collected with condensing warm air furnace show that:

- each 10°F decrease of room temperature amounted to an increase of 1.1 points in part load efficiency and 1.6 points in steady state efficiency.
- an increase of 0.2 percentage points in cyclic operating efficiency was found for each 10% rise in relative humidity (with constant room temperature).

Results that were used by the Department of Energy in resolving questions raised by commenters included:

- A thirty minute period was found to be acceptable in place of a one hour test under Steady State test conditions.
- Three test cycles were found to be sufficient for high efficiency furnaces having repeatable condensate collection rate.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Annual Efficiency; Condensing Furnace; Cyclic Efficiency; Part load efficiency; Test Procedures; Gas Fueled.

13. AVAILABILITY

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