ADVANTICA

March 2002

FURTHER ANALYSIS OF THE 1991 NATIONAL COMBUSTION PERFORMANCE SURVEY RESULTS

Advantica report designation: R5095

Prepared for:

Mike Thompson, Centrica, Farnborough, GU14 0JW.

Allyn Jones, HSE, Bootle, Merseyside, L20 3QZ.

Prepared by:

Bryan Cheyney & John Cotton

Advantica Ltd
Ashby Road
Loughborough
Leicestershire
LE11 3GR
United Kingdom
Tel: +44 (0) 1509 282000
Fax: +44 (0) 1509 283131
E-mail: info.uk@advantica.biz
Website: www.advantica.biz

ADVANTICA

Further Analysis of the 1991 National Combustion Performance Survey Results

Executive Summary

An earlier report included a partial analysis of combustion measurements made during a survey performed in 1991, and one of the main recommendations was the need to examine more CO and CO/CO_2 ratio emissions data. New work has now been undertaken, to re-examine all the data from the National Combustion Performance Survey available from the archives. These data comprise sets of CO, CO_2 and CO/CO_2 ratio measurements, made with Telegan performance testers on some 3000 district appliances.

For the "as-found" data, adoption of a critical CO concentration designed to identify all cases that would not meet the <0.004 ratio criterion (a "catch-all" value) would in most cases slightly more than double the number of failures, ie. numbers of appliances to be fully serviced. Similar analysis of the "as-left" data was less successful, because the CO criteria derived in this way are not sufficiently robust for absolute appliance safety. In order to investigate the possibility that different CO concentration criteria might apply where there could be shown to be differences in the method of sampling, it was decided to separate appliances by flue type, ie. open, natural draught/balanced or powered, as appropriate. This has been undertaken for boilers, combis, air heaters, instantaneous water heaters, circulators, fires and wall convectors.

It is concluded that an absolute CO "trigger" is possible for servicing those appliances currently subject to the "as-found" CO/CO_2 ratio 0.004 criterion, if some extra service load is acceptable. CO criteria have been deduced, based on selecting all appliances failing an agreed CO/CO_2 ratio criterion, proposed to be 0.006. The possibility of adopting a servicing "trigger", either CO/CO_2 ratio or absolute CO, exists for fires and cooker grills, but the high service loads would probably be prohibitive for these appliances. The use of an absolute CO "as-left" safety criterion is not recommended, although possible values can be found in this report for some types of appliance.

Additional statistical analysis work is suggested. For any statistical consideration, there should be as few deletions of data from the original survey sample as possible. It is also proposed, if an absolute CO "as-left" criterion is required, to consider whether the intermediate sets of readings taken during the survey throughout appliance servicing, which until now have been excluded from both stages of the current work, could yet be of any value.

ADVANTICA

Further Analysis of the 1991 National Combustion Performance Survey Results

Contents

ADVANTICA

Further Analysis of the 1991 National Combustion Performance Survey Results

1 INTRODUCTION

An earlier report (Reference 1) included a partial analysis of combustion measurements made with Telegan performance tester instruments during a survey performed in 1991, and one of the main recommendations was the need to examine more CO and CO/CO_2 ratio emissions data. The prime objective of such an exercise would be to improve the statistical validity in deriving suitable servicing trigger levels for domestic gas appliances, particularly appliances other than central heating boilers.

New work has therefore now been undertaken, to re-examine all the data from the National Combustion Performance Survey available from the archives. These data comprise sets of CO, CO_2 and CO/CO_2 ratio measurements, made mostly with Telegan performance testers on some 3000 district appliances. Note that only those data sets that can be classified either “as-found” or “as-left” (the latter called “final” data in Reference 1) have been utilised, ie. no interim measurement stages have been included.

The objectives may be stated as follows:-

1) To provide support for the proposal for an absolute CO “trigger” for servicing boilers and combis (as is used in the UK by some European firms), and to set (a) suitable CO value(s).

2) To examine the use of servicing “triggers” for other appliances generally.

3) To consider the absolute CO method for determining whether an appliance is safe to leave.

2 DATA MANIPULATION

The method of preparing the 1991 Combustion Survey data that had been employed previously, where data from only two of the then British Gas Regions (about 30% of the total) had been analysed, has now been applied to all the remaining data. These data were then copied to a new worksheet file, redistributed in such a way that each sheet of the file contained all the data for any one type of appliance. The data carried their original reference numbers so that the source could always be traced. Ten appliance types were identified, using the first two digits of the GC Number, as below,

11 and 13	cooker grills
31 and 32	independent gas fires
35	flued convectors
37	fires associated with back boilers
41	free-standing and wall-mounted central heating boilers
42 and 43	warm air heaters
44	back boilers
47	combination boilers ("combis")
51 and 52	instantaneous water heaters
53	circulators and back circulators

This classification list omits a very small number of less common appliances, such as fixed unflued heaters, combined cooker/circulators, etc. These could be brought in later if desired, by associating them with other groups. The full sequence of data manipulation was as follows:

a) Where no GC number had been entered on the survey forms, deduce the appliance type from information supplied, and record this as the appropriate first two digits. Ensure all BBU boilers were coded with the digits 44, not 41, where information was available to check this. Ensure all BBU fires carried the digits 37, even though for some the boiler GC number only had been entered and for others the correct code had been 32, not 37. Any fires known to be decorative or live fuel inset types, but for which no GC number had been entered were given the first two digits 30, to distinguish them from other fires (31 and 32). Unfortunately, this does not identify separately a small number of decorative or inset types that carry GC numbers with first two digits 32.

b) Reject all readings that did not refer to the "as-found" condition and were not the last set recorded, ie. the "as-left" readings. For more than 40% of appliances there were only "as-found" readings. Collect together all "as-left" readings (equivalent to "final" readings in Reference 1).

c) Reject all data obtained by Draeger tubes, or where the analyser type had not been entered. Where neither "as-found" nor "as-left" data remained, the appliance reference was deleted.

d) Examine each set of three readings for order of magnitude errors in reading, recording or entering, by comparing the quotient of CO and CO_2 values with the entered ratio value. This could usually be corrected but, if not, the data were rejected. Smaller discrepancies were accepted.

e) Sort all Regional data by appliance type, as indicated by the first two GC number digits. Within each appliance type, re-sort the data in order of Regional reference number. This ensured that data for any specific appliance could be quickly traced through all versions of the database.

It should be noted that the effects of c) and d) above are to make the distribution of appliance combustion results less representative, in that some with high CO and high ratios were eliminated because the Draeger tube method was used.

3 BASIC RESULTS

From the new database, it has been possible to plot the CO concentration against the CO/CO_2 ratio for each appliance type, as in the previous exercise. Because of the larger numbers of data it was found best to do this as two graphs, one for "as-found" and one for "as-left" data (see Figures 1 to 22). Any major outlier on any of these plots was then checked, to ensure that no order of magnitude error had been carried through the database. One or two such errors were found, and these have been dealt with in the same way as before (see Reference 1). Where there was insufficient information to be able to correct the error, the point has been retained on the plot, but it has not been used in deducing the critical CO value (as detailed below).

On each of the graphs, the lowest value of CO concentration corresponding to a CO/CO_2 ratio of 0.004 (for "as-found" data) or 0.008 (for "as-left" data) could usually be seen by enlarging that part of the plot. This was then confirmed by reference to the columns of figures in the database. For the "as-found" data, adoption of a critical CO concentration (a "catch-all" value) designed to identify all appliances that would not meet the <0.004 servicing "trigger" ratio criterion (Reference 2) would in most cases more than double the number of failures, ie. appliances to be fully serviced. The values obtained are not tabulated separately, but may be taken as the open flue figures given in Table 1. These matters are reconsidered below in terms of separate flue types, and in terms of possibly changing the basic CO/CO_2 ratio criteria.

Similar analysis of the "as-left" data was not always successful because, in many cases, there are not enough data in the vicinity of the safety limit ratio 0.008 (Reference 2) to define a cut-off value of CO concentration. In the earlier analysis of the data for two Regions only, "as-left" CO concentration criteria were derived from the "as-found" data, where values in the vicinity of the ratio 0.008 were more numerous. This has again been done, but even the CO criteria derived in this way are not sufficiently robust to make firm recommendations on the use of a CO criterion for absolute appliance safety.

4 DETAILED ANALYSIS

4.1 Appliance Classification by Flue Type

Experimentally, in order to investigate the possibility that different CO concentration criteria might apply to different methods of sampling, the data on balanced flue gas fires, which would have been sampled from the terminal, were separated from that on other fires (all assumed to be open flued). This was facilitated by there being only one manufacturer of balanced flue fires prior to 1991, so the appropriate GC numbers were easily looked up. Figures 1 and 2 are plots of CO concentration against CO/CO_2 ratio for the "as found" condition, with balanced and open flue fires shown separately. They clearly indicate that the former are much less scattered and

that a much higher CO criterion applies (229 ppm, compared with the general figure of 56 ppm). To derive this latter figure, the two points (0.0040, 25) and (0.0062, 25) are assumed to be in error, because their three entries in the database are not compatible. Following from this result, it was decided to attempt to separate other appliances by flue type, ie open, natural draught balanced or powered, where appropriate. This has been undertaken for boilers, combination boilers, air heaters, instantaneous water heaters, circulators and wall convectors, as shown in the appropriate Figures.

In order to check out the flueing arrangements for each appliance, as identified by its GC number, two main data sources have been consulted (References 3 and 4). Inevitably, a few appliance flue types remained unidentified, mainly for post-1974 water heaters and circulators. Most of these were eventually traced through contact with British Gas Services, who were able to access their own database. A very small number still remain unaccounted for, mostly where there appears to be a typing error in the GC number, or the number is incomplete. In principle, it should be possible to revisit the original questionnaire sheets to search for more information, as part of a planned extension of the project.

The values for absolute CO, designed to select all appliances failing 0.004 ("as found") and 0.008 ("as left") CO/CO_2 ratio criteria, respectively, for each appliance and flue type, are summarised in Table 1. Difficulties have arisen where there were no "as left" measurements greater than or in the vicinity of 0.008. In these cases CO criteria have been derived from the "as found" data and plots, where usually the ratio 0.008 is bracketed by other data.

Problems arising from incomplete identification of flueing arrangements have been handled for boilers and combination boilers by plotting the data for the "unknowns" separately. Figures 11 to 14 show that these particular appliances do not affect the selection of CO criteria, especially for combis, where one or two unusual powered flue results seem to dominate. Air heaters are assumed to be all open flued, and all water heaters to be either unflued (GC No. 51/…) or balanced/powered flued (GC No. 52/…). Any water heater known to have a powered flue is indicated separately.

4.2 Effects of Changing the "As-Found" Criterion

As stated in Section 3, the use of an absolute CO criterion as a servicing trigger, designed to include all appliances failing a basic 0.004 ratio, would increase the numbers to be serviced by 2 to 3 times (in some cases more). This can be seen in columns 3, 4 and 5 of Table 2a.

There would appear to be scope for raising the basic ratio value to reduce this excess, and so this approach has been investigated. New values of the ratio were selected and, using the plots, "catch-all" CO values were read off, then checked with the columns of figures in the database. Numbers of passes and fails were obtained by first sorting the data into ascending order, then counting the numbers of lines. The results are set out in Tables 2a and 2b. These show that, even if the basic CO/CO_2 ratio were set higher, the numbers of appliances identified for servicing by a new "catch all" CO criterion would still exceed those identified by the basic 0.004 ratio. This is particularly so for fires, back boilers and cooker grills; and the reason may be

that it is difficult to avoid taking dilute samples, resulting in misleadingly low CO indications.

4.3 Gas Fires

Though not necessary in pursuit of the main objective, the opportunity has been taken to examine the spread of "as-found" readings for gas fires (balanced flue excluded). Gas fires are particularly interesting because of the wide spread of CO_2 values recorded. Plots have been made of the numbers in CO/CO_2 ratio ranges incremented by 0.001 to 0.04 (Figure 7) and of numbers in CO concentration ranges incremented by 50 ppm to 1000 ppm (Figure 8) using a histogram presentation. As expected, the two plots have similar shapes.

Originally, 21 DFE or ILFE type fires (so described in the database) had been given the unique first two digits of 30 for the GC number. However, after rejecting non-Telegan data, the number of these appliances remaining (six) was too small for analysis as a separate category. Many had been rejected because CO_2 readings were too low. Later enquiries revealed the possibility that some more recent designs of these types of fire, possibly meeting the requirements of BS 5258 Part 12 or Part 16 (References 5 & 6) might have been allocated GC numbers with the first two digits 32. A significant number in the general fires sample might have introduced a bias. However, a quick check (not exhaustive) showed that out of 594 fires, 516 are definitely not of this type and only one is. The number in the remaining 77 is therefore likely to be very small, possibly zero.

4.4 Omitted Data

At the start of the current analysis, a decision was made that only *bona fide* Telegan performance tester readings should be involved, because that instrument was similar to those used currently. However, there is clearly a possibility that, by rejecting many Draeger measurements that had probably replaced "off scale" Telegan readings, a significant bias will have been introduced. This bias was most likely to affect the numbers of passes and failures, and so affect the disadvantages of employing certain absolute CO criteria.

All rejected data were re-examined. Most had been rejected because either the method of analysis had not been entered or Draeger tubes had been used. All sets of readings in both categories were assumed to be otherwise valid, except where no CO_2 value had been recorded, or where all three figures had been entered but were not numerically compatible. The total number of such sets of "as-found" readings, for all appliance types that had been selected for analysis, is 150. These have been checked individually to see whether any would, when added to the sample of readings used to determine the new CO/CO_2 ratio and absolute CO criteria in Tables 1 and 2, actually cause any of the criteria to be changed. In fact, the only appliance categories where the restored data were not compatible with the proposed new criteria were fires, BBU fires and cooker grills. This sheds further doubt on the possibility of applying any particular criteria, whether CO/CO_2 ratio or absolute CO, for servicing fires or cooker grills.

5 DISCUSSION

A number of possibilities have been explored for setting values of absolute CO as criteria for servicing, all of them based on CO/CO_2 ratio as the definitive criterion. Where appropriate, for each appliance type, a sub-classification has been made according to the type of flue. All the figures are presented in Tables 2a and 2b, and these show that the absolute CO method is not likely to be acceptable for fires or cooker grills, and probably not for back boilers. The reason is that, even if the definitive CO/CO_2 ratio criterion were raised to 0.008, there would still be considerably more appliances identified for servicing than there would have been using the present boiler servicing criterion, ie. a ratio of 0.004.

If one single absolute CO criterion were to be accepted for boilers (not including back boilers) and combis, this would have to be the one shown in Tables 1 and 2 for open flue types. This would result in larger numbers of balanced and powered flue types identified for servicing than shown in the Tables. However, if different CO criteria were used, according to flue type, the numbers would be those shown, making the CO criterion derived for (say) ratio 0.006 look possible. Back boilers could not be included, unless a separate CO criterion were selected, which would have to be lower than that for other open flue boilers. It looks as though instantaneous water heaters, balanced flue convectors and balanced flue fires could be included with boilers.

Assuming a separate absolute CO criterion were set for back boilers, it would apparently be possible to use this criterion for air heaters as well. The likely reason that these two classes of appliance behave similarly is that they both usually operate on shared flues. Circulators have not been included because the data on flue type were not complete, and the sample was small.

All the above findings stop short of actually recommending the absolute CO method of assessment for servicing. This is because, unless some sort of CO_2 measurement (however crude) is made simultaneously, there is no safeguard against obtaining a very dilute sample on a high ratio appliance, even accidentally, which could reduce the CO level below the criterion. This makes the method a fail-to-danger type. Apart from the fail-to-danger aspect, the absolute CO method is not likely to be acceptable for open flue gas fires, because it would include large numbers of low ratio fires for servicing, even if the CO criterion of 100 ppm were used (based on a ratio of 0.008). This applies to independent and BBU fires, but does not in this investigation include DFE or ILFE fires, because there were too few data. This lack of data arises because, for many such fires in the survey, the sample for analysis was too dilute for the Telegan performance tester to be used. The CO/CO_2 ratio could be used directly as a “trigger” for servicing.

The figures supporting the point about the servicing load for non-BBU gas fires, based on Tables 2a and 2b, are as follows,

Ratio	To Service	CO ppm	To Service
0.004	22%	56	51%
0.006	16%	80	41%
0.008	13%	100	34%

There is at the moment no agreed "trigger" value of the CO/CO_2 ratio for gas fires, and there may in fact be no justification for a value lower than 0.008.

In the combustion survey, cooker grills were the only cooker burners tested, so it was never going to be possible to present here a comprehensive conclusion on cookers. For grills, however, using the highest possible absolute CO criterion of 100 ppm (based on ratio 0.008) the numbers of satisfactory grills included for servicing would probably be too many, but a simple CO/CO_2 ratio could be used as a "trigger". There would be a major problem with hotplates, in standardising the test.

The figures supporting the above points concerning cooker grills, based on Tables 2a and 2b, are as follows,

Ratio	To Service	CO ppm	To Service
0.004	17%	40	57%
0.006	11%	70	38%
0.008	9%	100	27%

It must be noted that the numbers would be higher in practice, since there were a significant number of cooker grill data rejected because they had not been obtained with the Telegan performance tester. Some of these would have been combustion "failures".

The conclusion on setting a final "as-left" safety criterion in terms of absolute CO for any of the appliance types is that, for such a critical purpose, the data available in this report are not sufficiently comprehensive. It is suggested here (as in Reference 1) that, for the final combustion performance test of whether an appliance is safe to leave, CO/CO_2 ratio alone is the correct criterion. This calls into question any use of an absolute CO "trigger", which uses a cheaper instrument, if the more expensive CO/CO_2 instrument is needed on completion of servicing anyway.

6. CONCLUSIONS

1. An absolute CO "trigger" for servicing those appliances currently subject to the "as-found" CO/CO_2 ratio 0.004 criterion is possible, if some extra service load is accepted. The CO criterion would be based on selecting all appliances failing an agreed CO/CO_2 ratio criterion, suggested to be 0.006. On this basis the absolute CO "triggers" would be,

   a) Balanced flue convectors and balanced flue fires: 500 ppm CO

   b) Boilers, combis, water heaters:

open flue	180 ppm CO
balanced flue	210 ppm CO
powered flue	500 ppm CO

   c) Back boilers, air heaters: 80 ppm CO

2. The possibility of adopting a servicing "trigger", either CO/CO_2 ratio or absolute CO, exists for fires and cooker grills, but the high service loads would probably be prohibitive. This poses special problems for fires that are part of back boilers or back circulator units.

3. Although values can be found in this report for some types of appliance, the use of an absolute CO "as-left" safety criterion is not recommended. The reasons are,

   a) Values derived from the data in this report are not sufficiently robust, and

   b) For a safety criterion there must be no possibility of fail-to-danger (eg. a dilute sample, which would give rise to a misleadingly low CO indication).

7. RECOMMENDATIONS

1. In order to make all CO "trigger" conclusions more robust, explore further possible statistical approaches, eg. determine the chance of missing say one appliance with unsatisfactory combustion performance of a given type by setting a specific CO concentration. For any statistical consideration, there should be as few deletions of data from the original survey sample as possible, so readings not taken with the Telegan tester should be restored.

2. If an "as-left" absolute CO criterion is required (despite Conclusion 3, above, which recommends against it) the intermediate sets of readings taken during the survey throughout appliance servicing, which have been excluded from both stages of the current work, could yet be of some value. They represent tests made on "borderline" appliances, for which there are currently too few data, but there are several sets of readings for each appliance, and it has up to now been argued that to include them would bias the conclusions.

3. If Conclusion 3 is accepted, then the database (restored, as in Recommendation 1, above) could be used to assess the feasibility of servicing appliances to meet specific "as-left" CO/CO_2 ratio safety criteria, not necessarily 0.008.

References

1. Initial evaluation of proposed procedures for the measurement of gas appliance CO emissions (using combustion performance survey data). Advantica Technologies report R4271 by J A Cotton, March 2001.
2. Servicing – right first time. IGE Communication 1397 by J Newcombe, M D Price and A D Sussex, 1989.
3. 1994 British Gas Service List for Domestic Central Heating Appliances.
4. 1974 British Gas Manual of Appliance Identification.
5. BS 5258-12:1990. Safety of domestic gas appliances. Specification for decorative fuel effect gas appliances (2nd and 3rd family gases) - Withdrawn.
6. BS 5258-16:1991. Safety of domestic gas appliances. Specification for live fuel effect gas fires (2nd and 3rd family gases).

Table 1. Absolute CO Combustion Criteria

(Servicing-Trigger and Ultimate-Safety)

Appliance Type	No. with known flue "As Found"	Flue Type Identified	"Catch All" CO Criterion					
			Ratio <0.004 "As Found"			Ratio <0.008 "As Left"		
			ppm CO	Fig. No.	Source	ppm CO	Fig. No.	Source
BF Fire + Convector	116	100%	200	1, 2 & 5	AF (BF Fires)	600	3, 4 & 6	AL (BF Fires)
Conventional Fire	567	100%	56	1 & 2	As Found	220	3 & 4	As Left
BBU Fire	190	100%	50	7	As Found	150	8	As Left
Back Boiler	249	100%	80	9	As Found	120	10	As Found
Other OF Boiler	185	)	100	)	As Found	180	)	As Found
ND BF Boiler	336	) 98%	130	) 11	As Found	400	)11 & 12	As Found
PF Boiler	111	)	250	)	As Found	600	)	As Found
OF Combi	12	)	140	)	As Found	180	)	AF (Boilers)
ND BF Combi	21	) 96%	175	) 13	As Found	400	)11 & 14	AF (Boilers)
PF Combi	41	)	130	)	As Found	600	)	AF (Boilers)
Air Heater	59	87%	60	15	As Found	100*	15 & 16	AF and AL*
Circulator - all types	30	>80%	80*	-	As Found*	90*	-	As Found*
UF Water Heater	14	) 89%	250*	) 17	As Found*	400*	)17 & 18	As Found*
BF/PF Water Heater	87	)	400*	)	As Found*	500*	)	As Found*
Cooker Grill	665	100%	40	19 & 20	As Found	140	21 & 22	As Left

* Denotes that interpolation, extrapolation and/or engineering judgement have been used, due to a lack of data in the critical region.

Table 2a. Comparison of CO/CO_2 Ratio and Absolute CO Criteria

(Based on "As-Found" Measurements)

		CO/CO_2 Ratio 0.004			CO/CO_2 Ratio 0.005		
Appliance Type	No. with known flue "As Found"	No. Failing CO/CO_2 Ratio 0.004	Derived CO Criterion ppm	No. Failing Derived CO Criterion	No. Failing CO/CO_2 Ratio 0.005	Derived CO Criterion ppm	No. Failing Derived CO Criterion
BF Fire + Convector	116	6	200	13	4	400	4
Conventional Fire	567	123	56	288	112	75	235
BBU Fire	190	27	50	115	20	148	49
Back Boiler	249	30	80	55	29	80	55
Other OF Boiler	185	14	100	29	12	140	19
ND BF Boiler	336	31	130	58	22	200	42
PF Boiler	111	2	250	2	1	400	1
OF Combi	12	1	140	1	0	140	0
ND BF Combi	21	0	175	0	0	200	0
PF Combi	41	1	130	3	0	400	0
Air Heater	59	5	60	10	2	100	5
UF Water Heater	14	2	250	2	2	300	2
BF/PF Water Heater	87	2	400	2	2	400	2
Cooker Grill	665	114	40	376	87	51	327

NOTES:
1. For CO/CO2 ratio criteria of 0.005 and over, the boiler criteria have been used for combis.
2. Circulators have not been included because of uncertainty of some of the flue types.

Table 2b. Continued Comparison of CO/CO_2 Ratio and Absolute CO Criteria

(Based on "As-Found" Measurements)

Appliance Type	No. with known flue "As Found"	CO/CO_2 Ratio 0.006			CO/CO_2 Ratio 0.008		
		No. Failing CO/CO_2 Ratio 0.006	Derived CO Criterion ppm	No. Failing Derived CO Criterion	No. Failing CO/CO_2 Ratio 0.008	Derived CO Criterion ppm	No. Failing Derived CO Criterion
BF Fire + Convector	116	4	500	4	4	600	4
Conventional Fire	567	91	80	230	72	100	191
BBU Fire	190	14	148	49	9	148	49
Back Boiler	249	25	80	55	17	120	41
Other OF Boiler	185	8	180	16	6	180	16
ND BF Boiler	336	19	210	42	11	400	21
PF Boiler	111	1	500	1	1	600	1
OF Combi	12	0	180	0	0	180	0
ND BF Combi	21	0	210	0	0	400	0
PF Combi	41	0	500	0	0	600	0
Air Heater	59	2	100	5	1	110	1
UF Water Heater	14	2	400	2	2	400	2
BF/PF Water Heater	87	2	400	2	1	500	2
Cooker Grill	665	73	70	254	58	100	179

NOTES:
1. For CO/CO_2 ratio criteria of 0.005 and over, the boiler criteria have been used for combis.
2. Circulators have not been included because of uncertainty of some of the flue types.

Figure 1. Fires "As-Found"

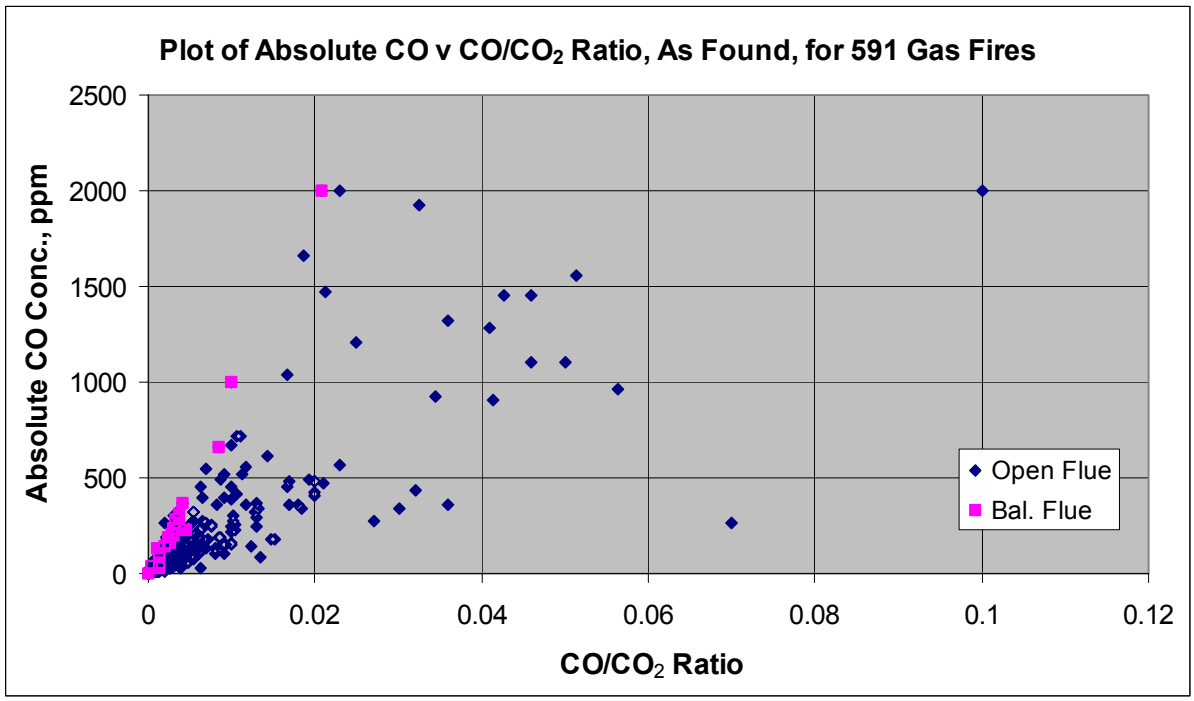

Figure 2. Fires "As-Found" - expanded

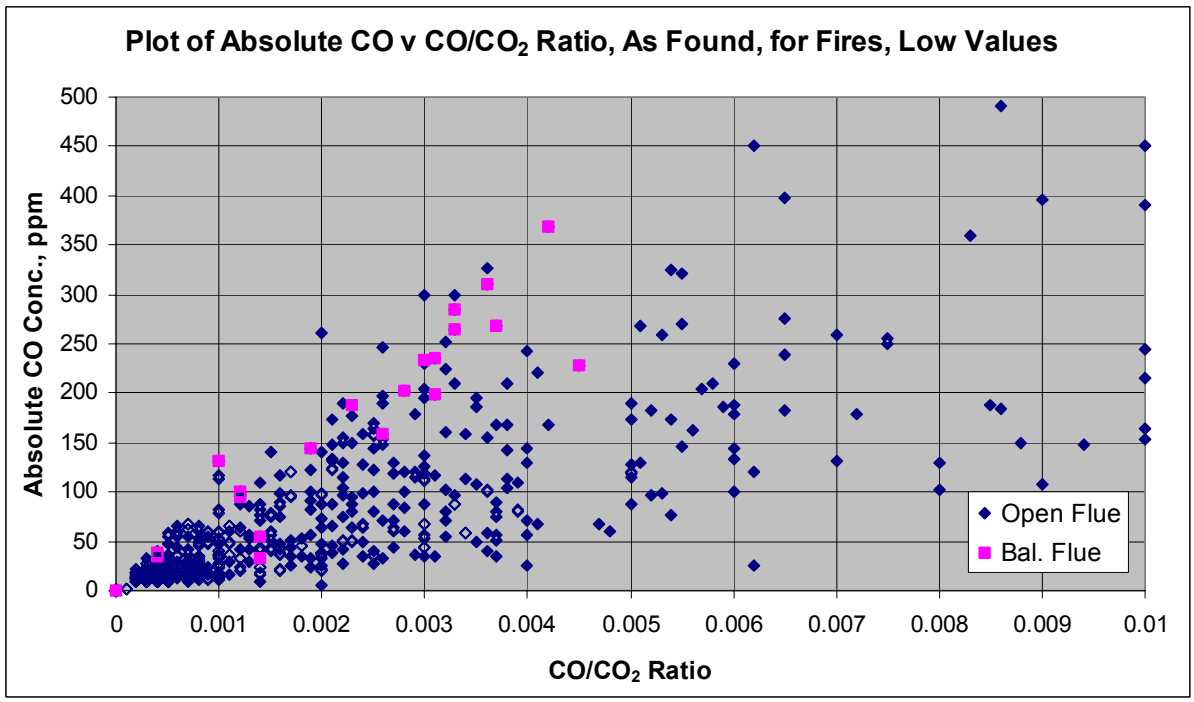

Figure 3. Fires "As-Left"

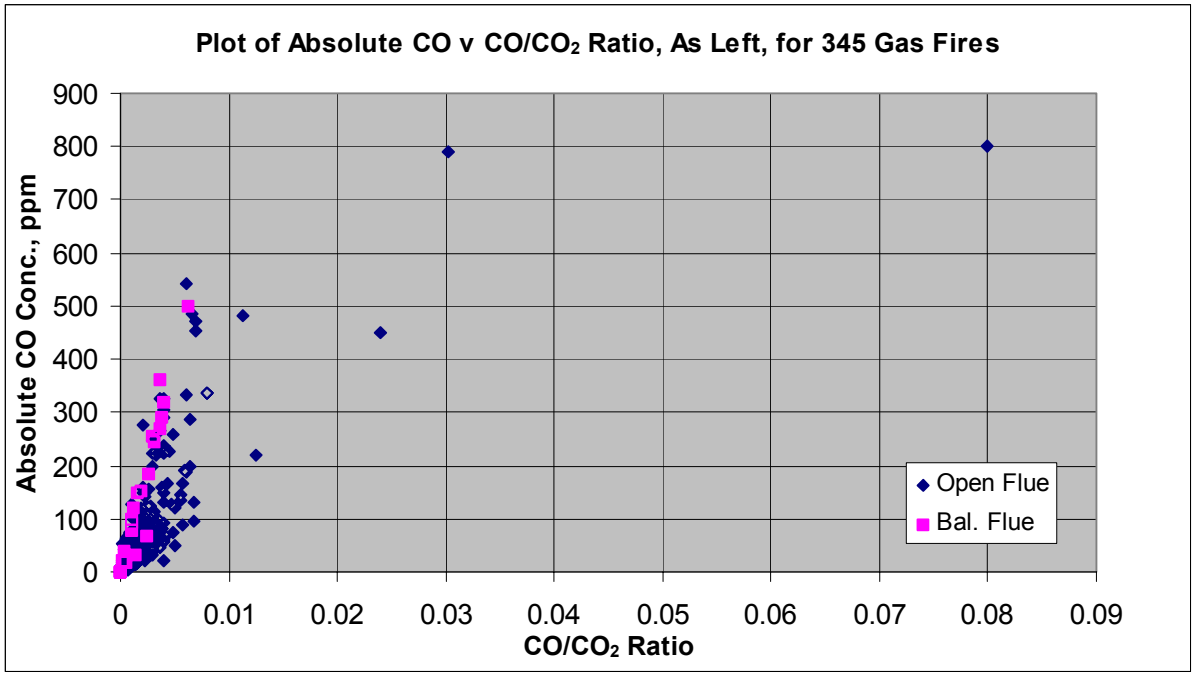

Figure 4. Fires "As-Left" - expanded

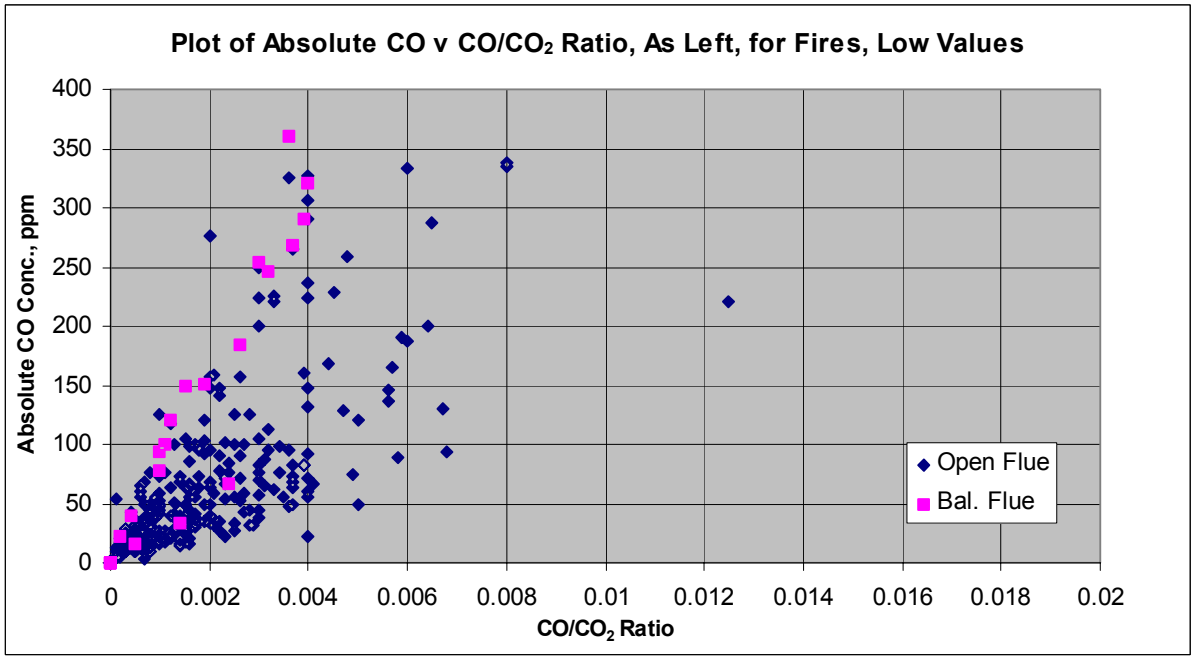

Figure 5. Convector Units "As-Found"

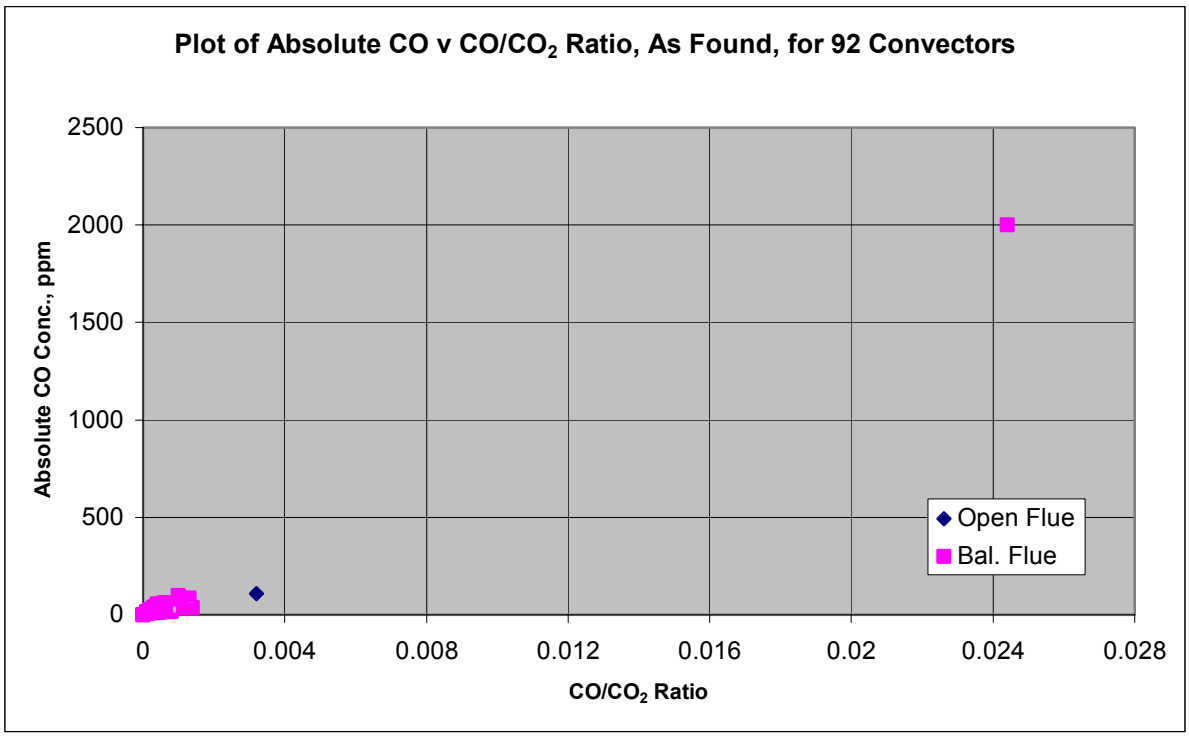

Figure 6. Convector Units "As-Left"

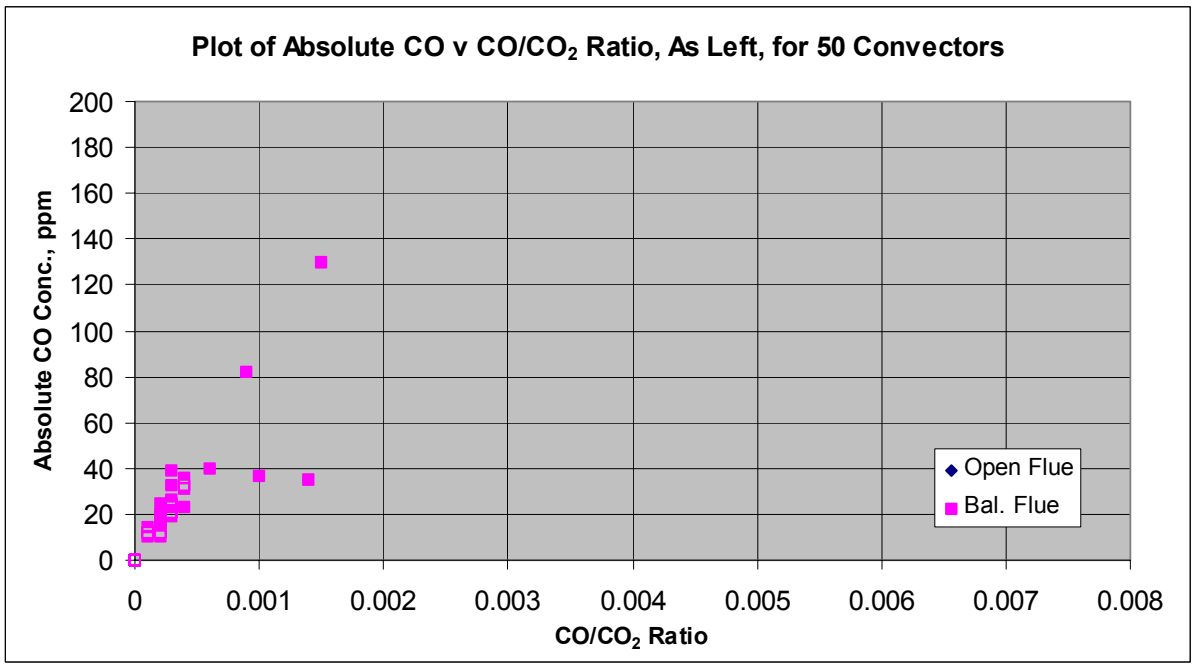

Figure 7. Back Boiler Fires "As-Found"

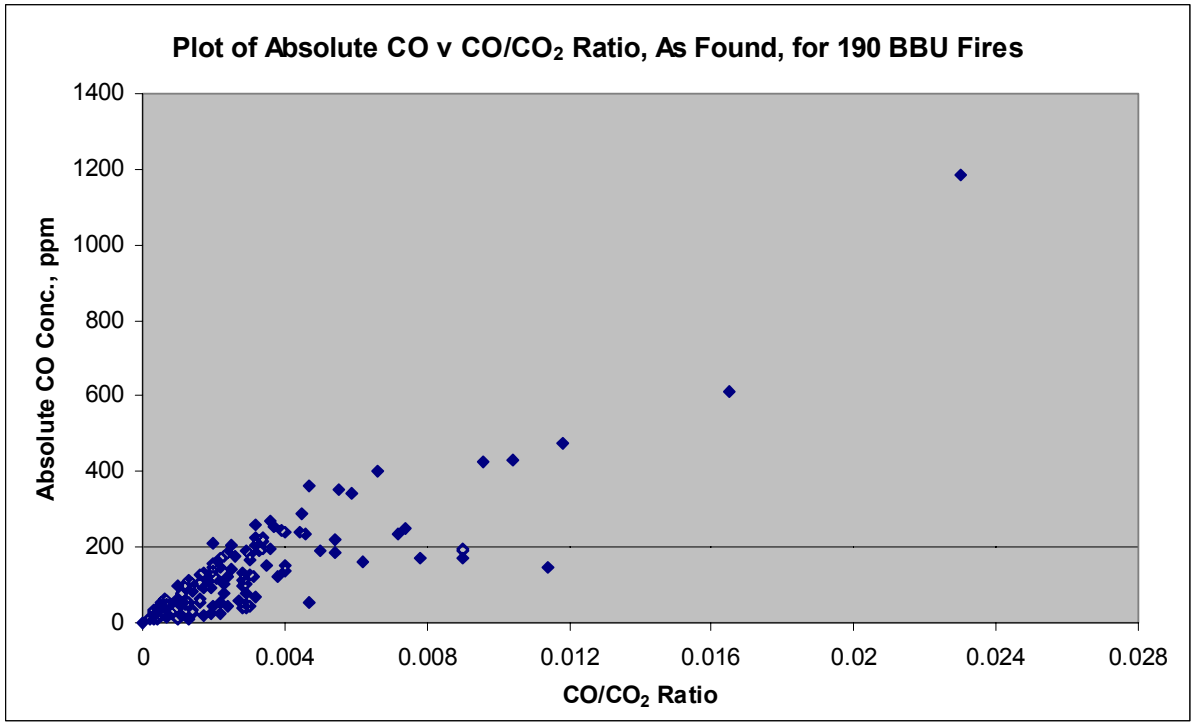

Figure 8. Back Boiler Fires "As-Left"

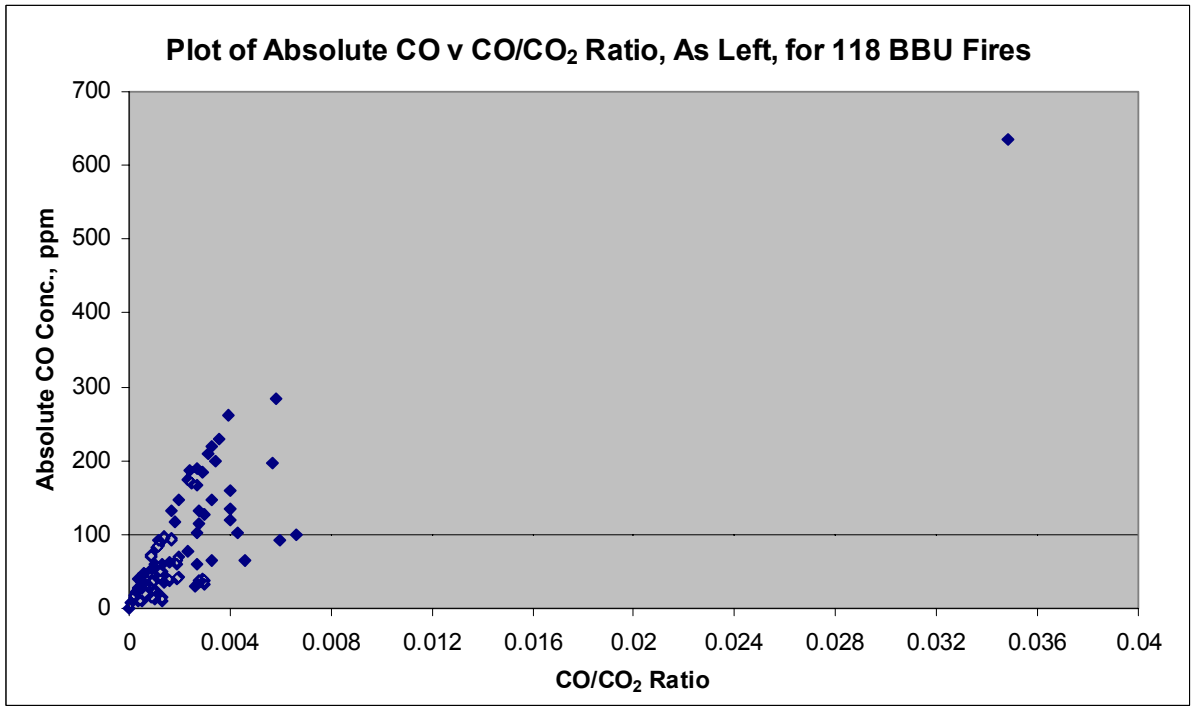

Figure 9. Back Boilers "As-Found"

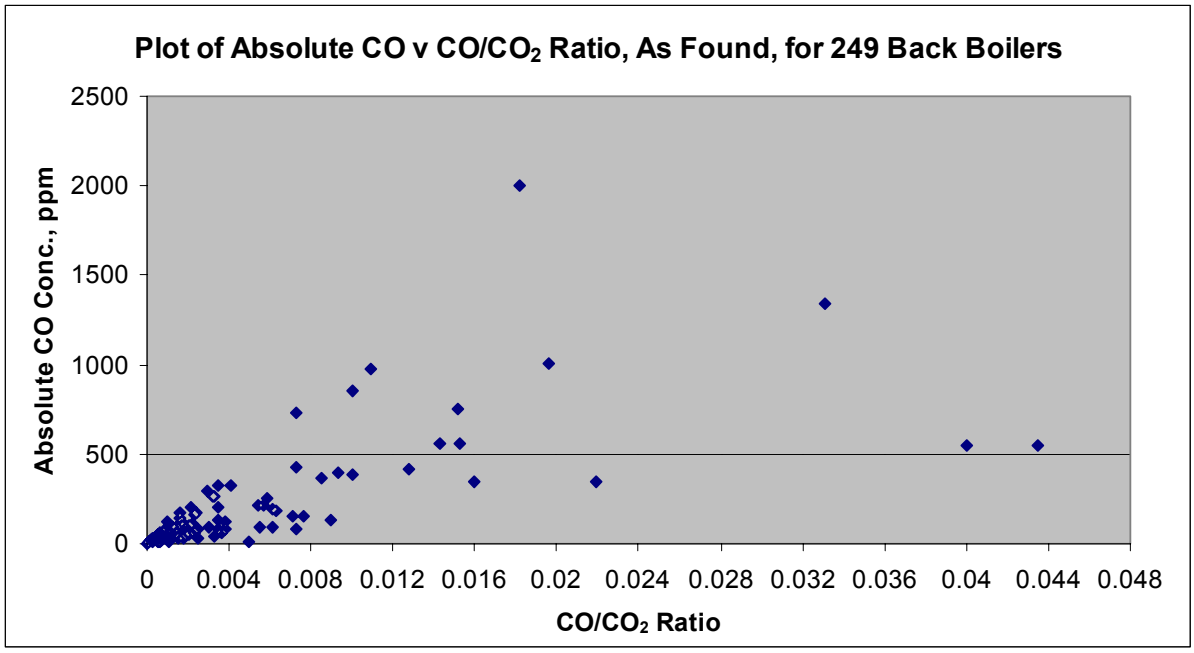

Figure 10. Back Boilers "As-Left"

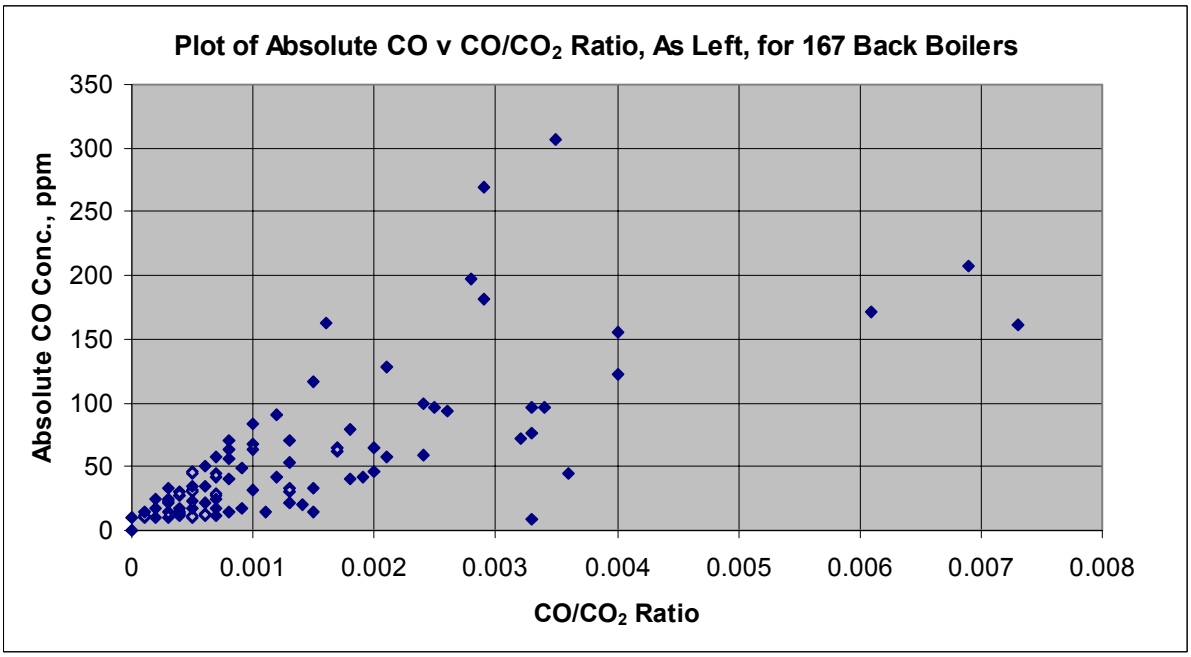

Figure 11. Central Heating Boilers "As-Found"

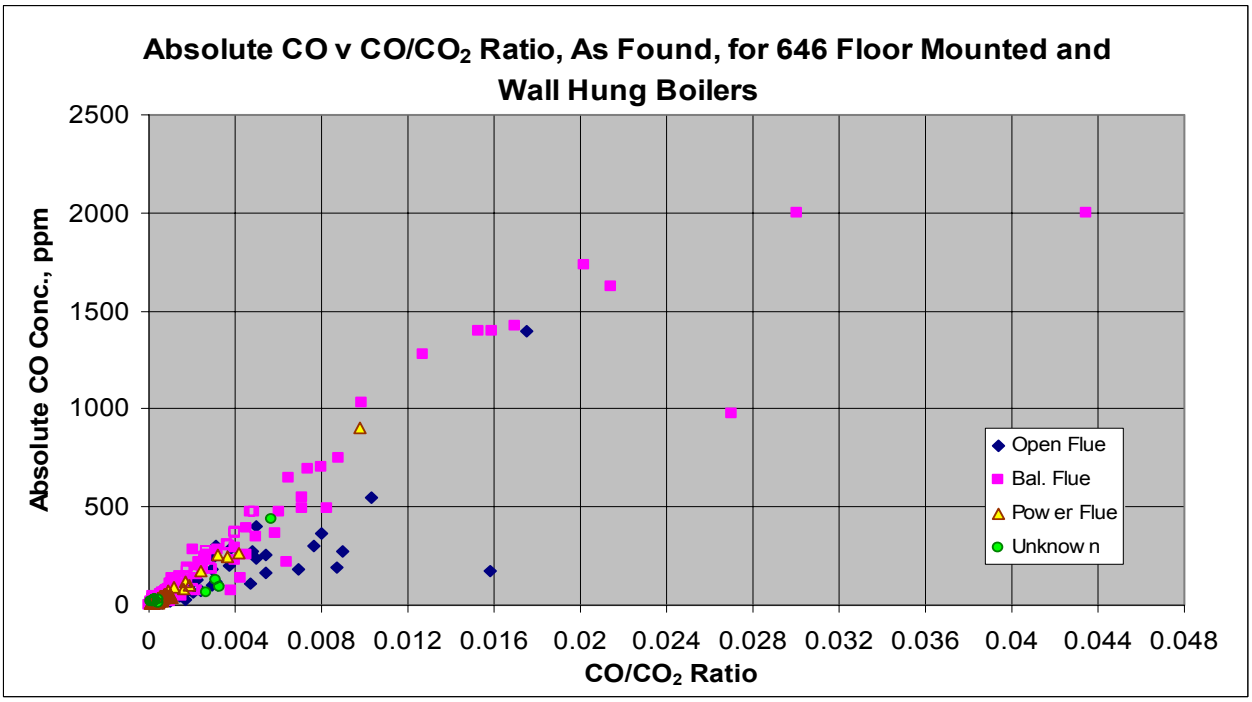

Figure 12. Central Heating Boilers "As-Left"

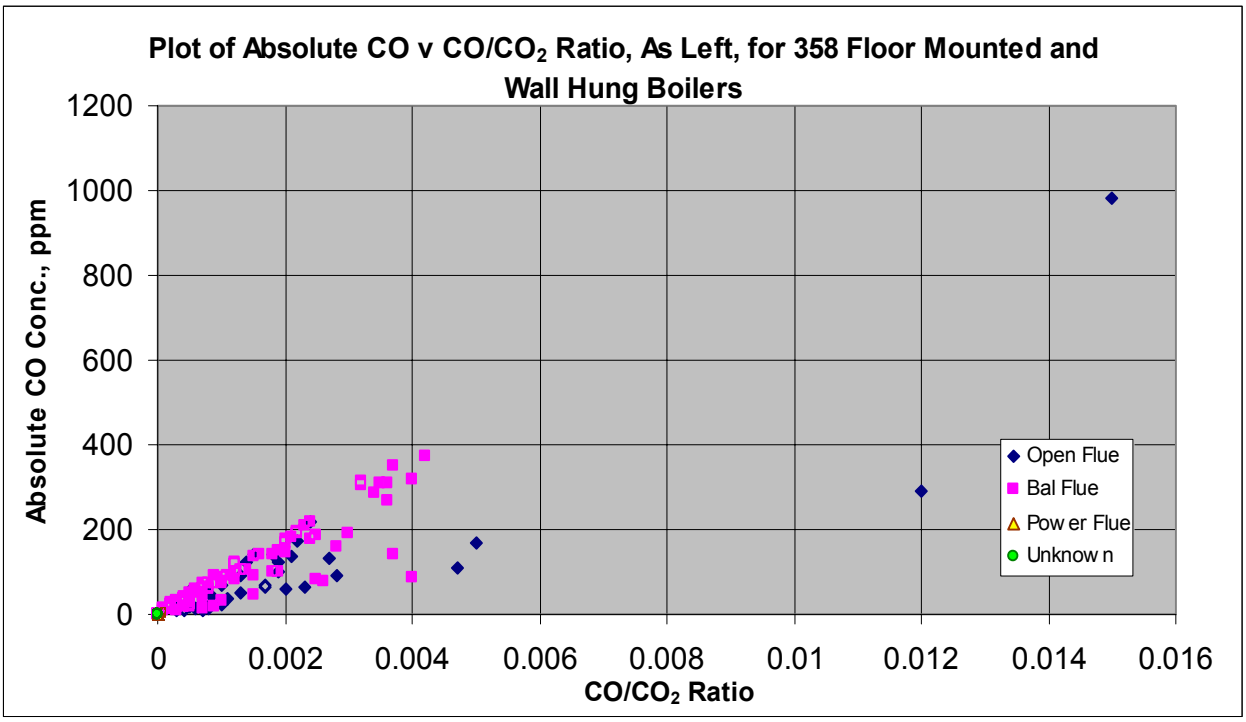

Figure 13. Combination Boilers "As-Found"

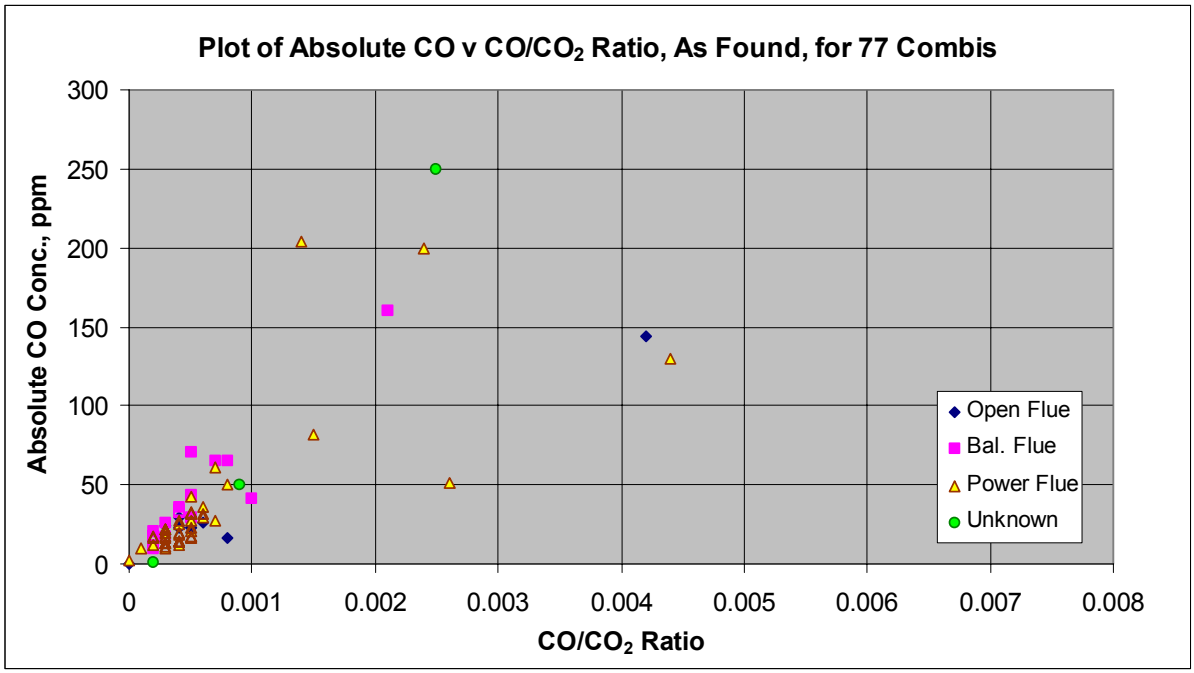

Figure 14. Combination Boilers "As-Left"

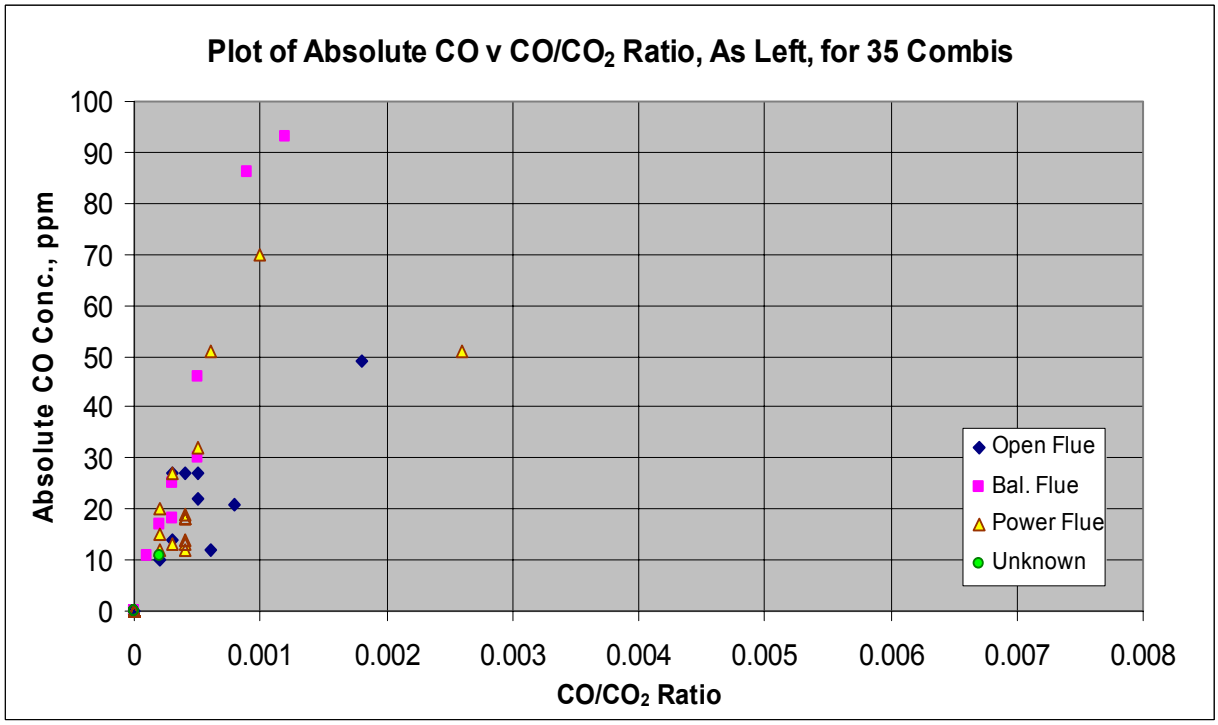

Figure 15. Warm Air Heaters "As-Found"

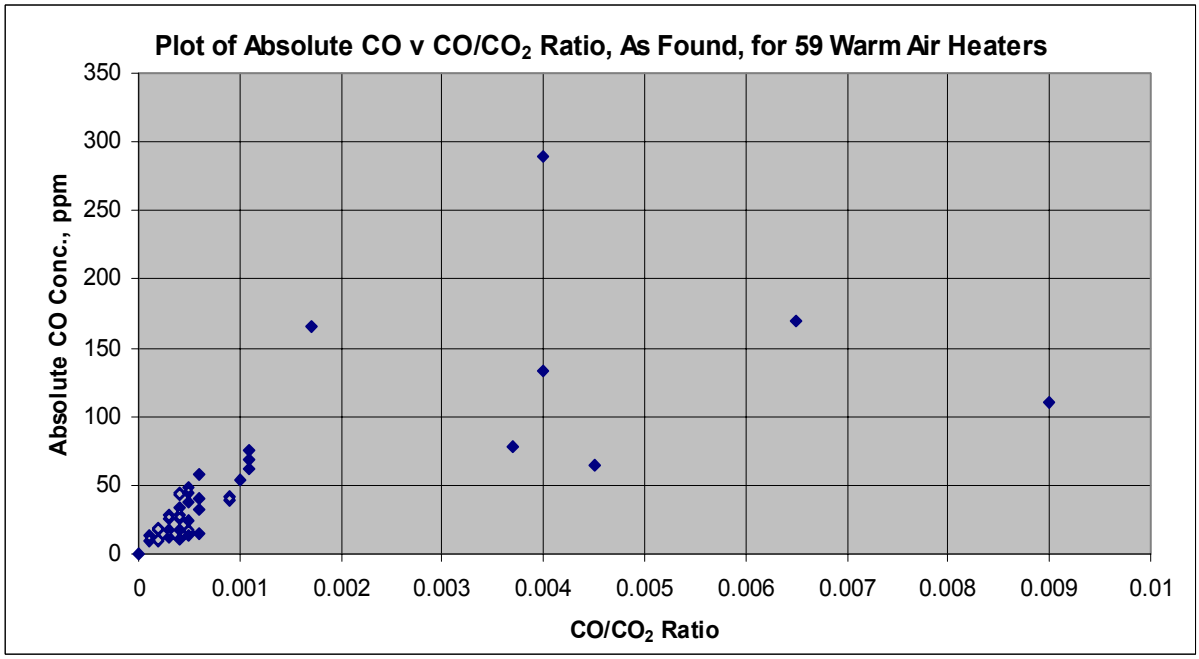

Figure 16. Warm Air Heaters "As-Left"

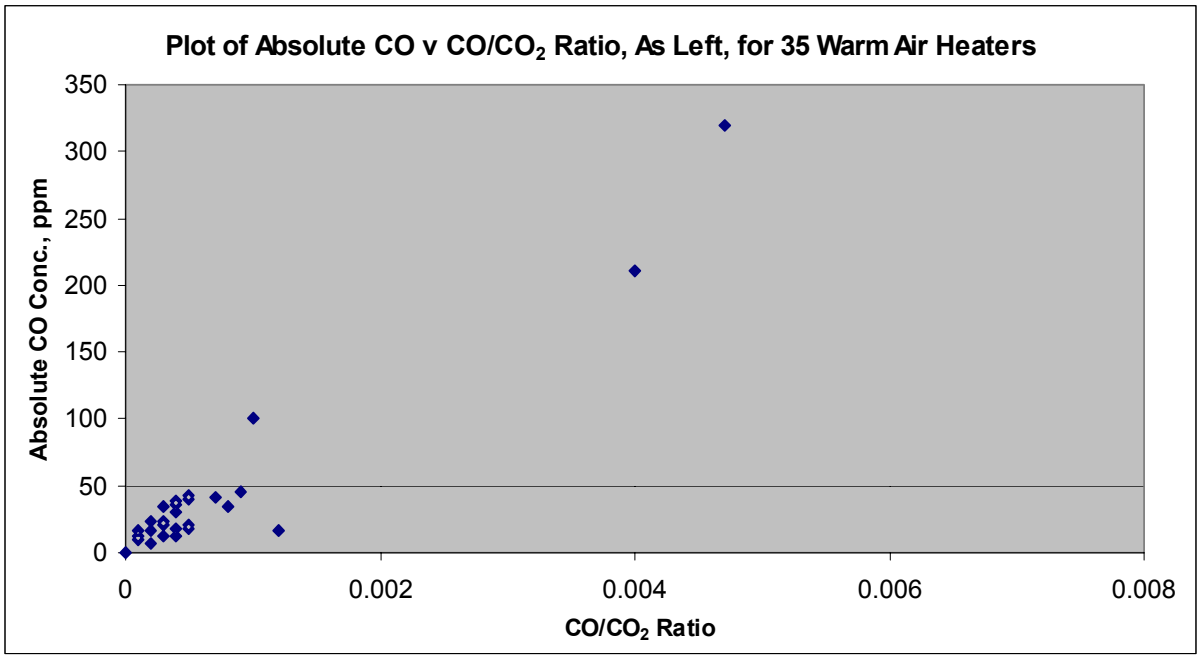

Figure 17. Water Heaters "As-Found"

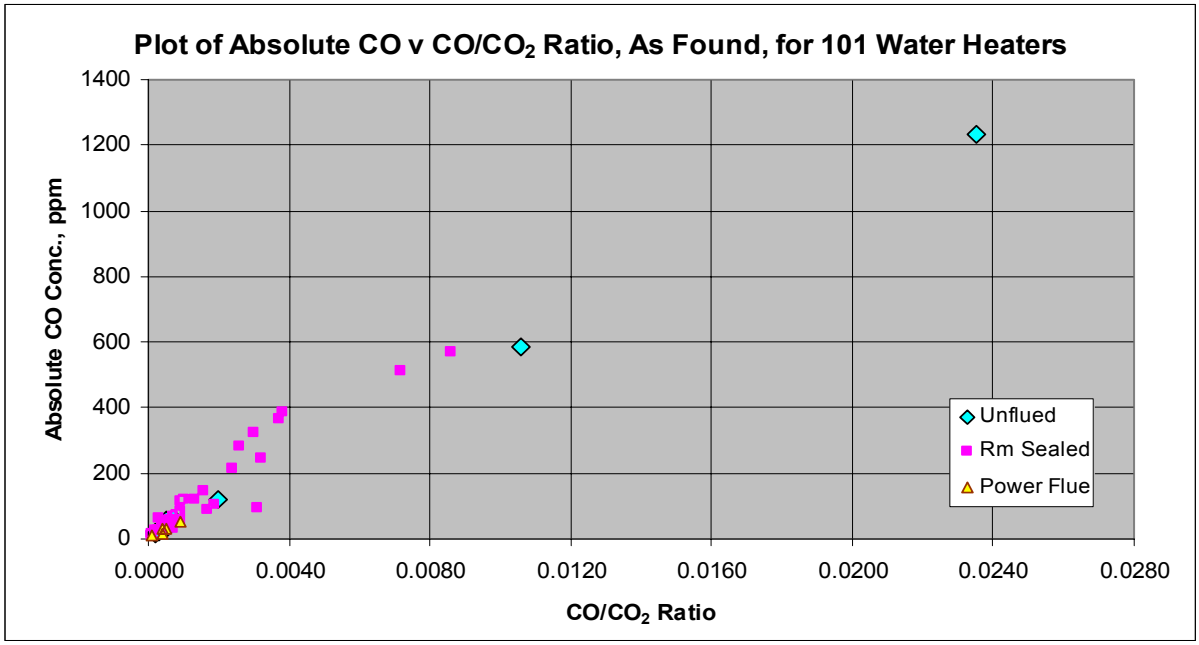

Figure 18. Water Heaters "As-Left"

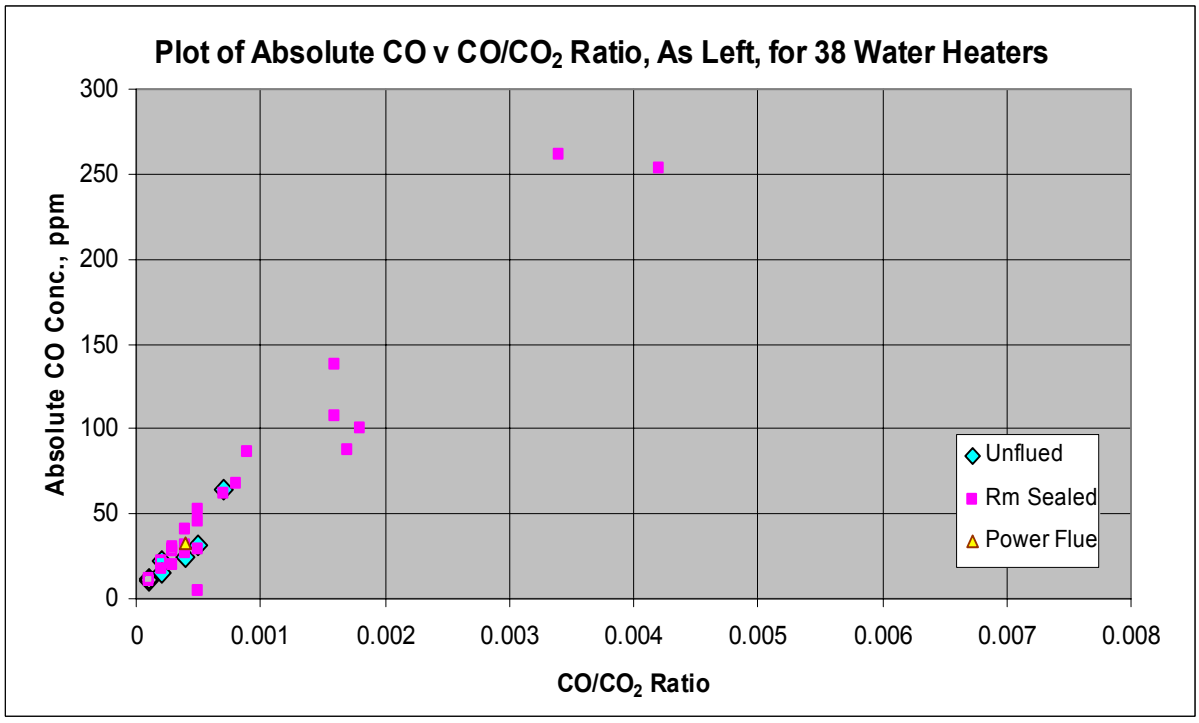

Figure 19. Cooker Grills "As-Found"

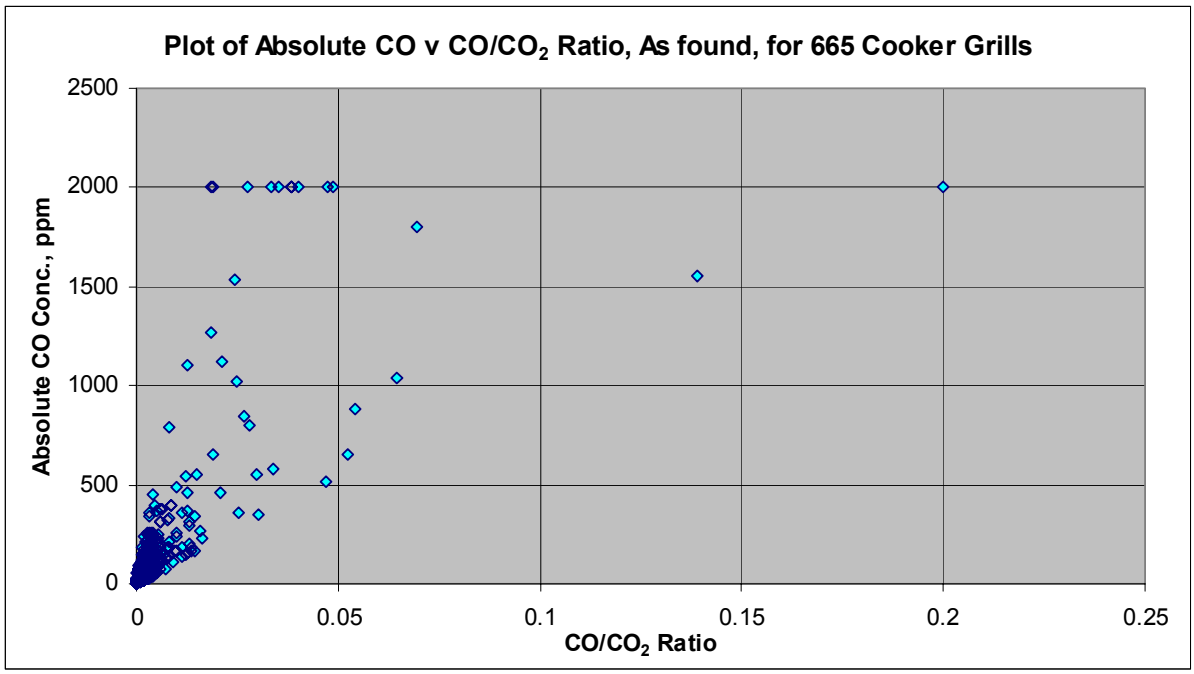

Figure 20. Cooker Grills "As-Found" - expanded

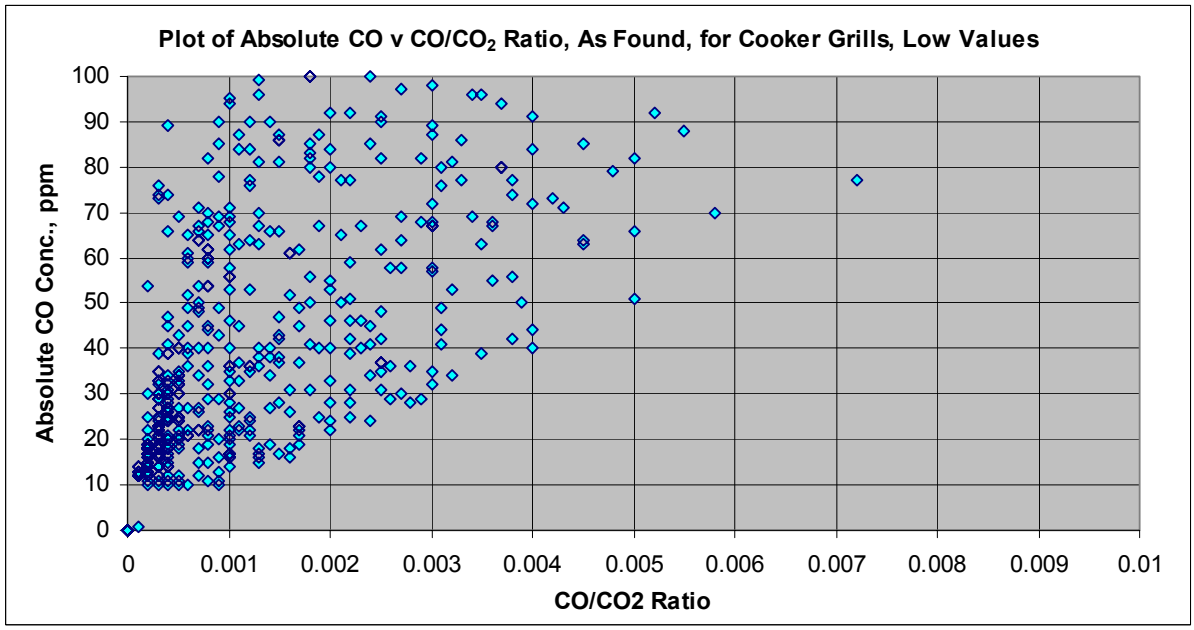

Figure 21. Cooker Grills "As-Left"

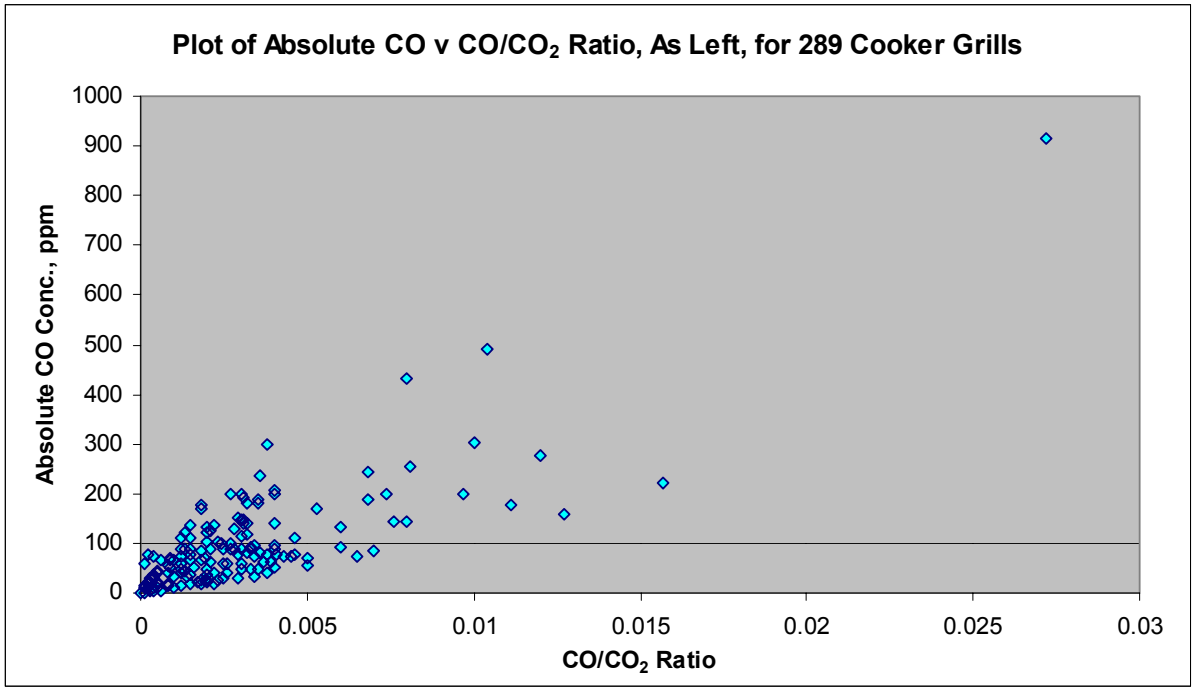

Figure 22. Cooker Grills "As-Left" - expanded

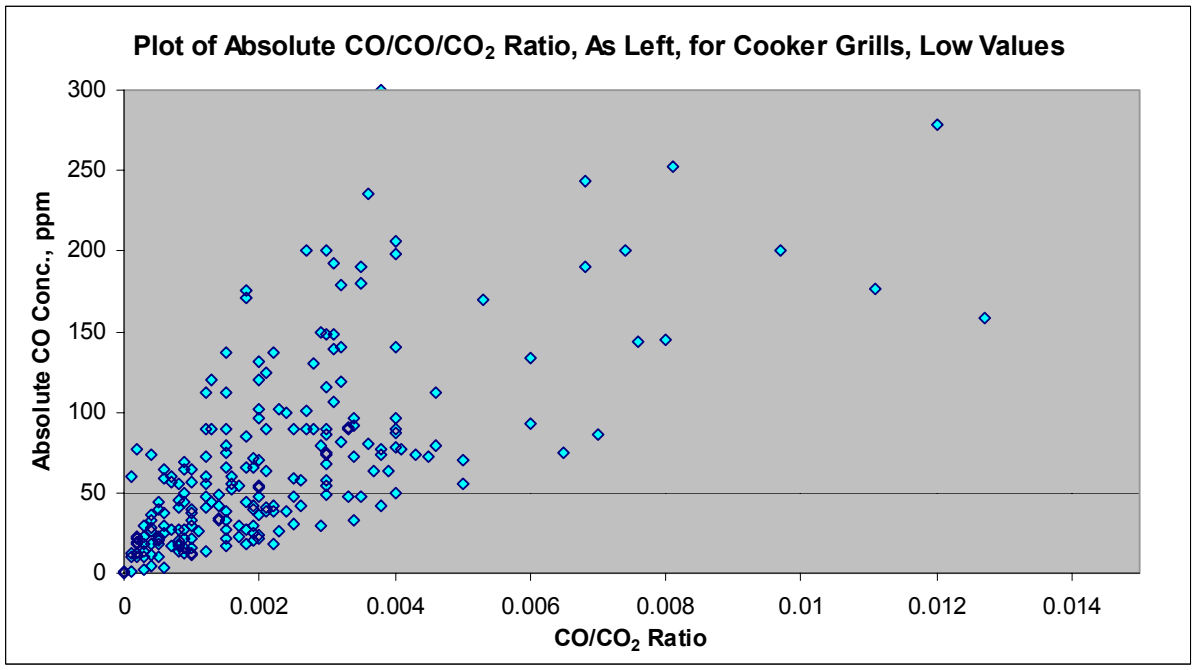

Figure 23. Fires Combustion Ratio

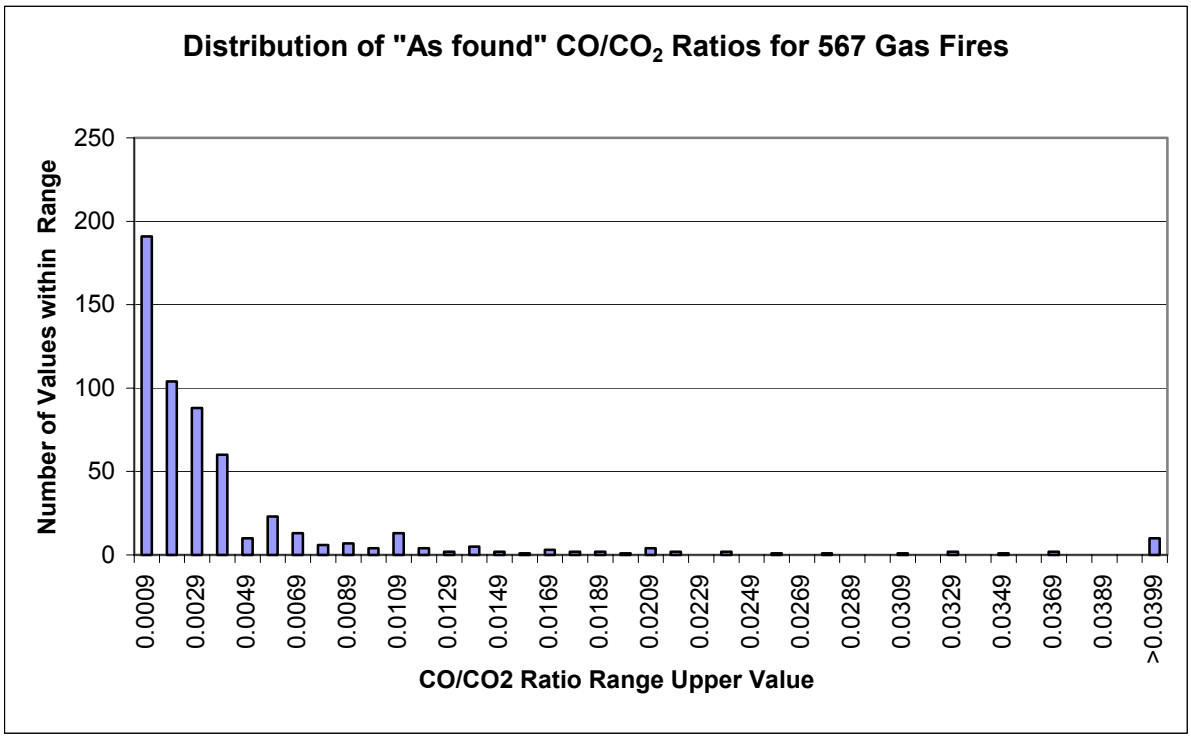

Figure 24. Fires Absolute CO