LIEE Standardization Report

Final Phase 4 Report on
Low Income Weatherization Program
Natural Gas Appliance Testing
Study Results

Study ID: SDG0132.01

Prepared for:

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Introduction

1.1 Overview

This report presents the results of an extensive study of carbon monoxide (CO) levels present in low income homes in California. It also provides a series of recommendations with respect to California Public Utilities Commission (Commission) policies and procedures relating to CO to be used in the Low Income Energy Efficiency (LIEE) Program. This report is part of the ongoing process of standardizing the LIEE Program across the service areas of the state's major utility program administrators. These administrators are Sempra Utilities (Sempra), Southern California Edison Company (SCE) and Pacific Gas & Electric Company (PG&E). Recommendations relating to program standardization are being developed by the Standardization Team (herein referred to as the "Team"), which consists of these three utility administrators and staff from the California Public Utilities Commission (CPUC). It should be noted that while CPUC staff have participated in Team meetings, they do not necessarily endorse the recommendations contained in this report.

1.2 Background

During the course of the LIEE Standardization Project, the Standardization Team has spent a considerable amount of time on two activities:

- Describing the utilities' current practices in the area of natural gas combustion appliance CO testing;[1] and
- Developing a minimum statewide standard for LIEE program natural gas appliance testing, which was adopted by the Commission on an interim basis in D. 01-03-028.

In D. 01-03-028, the Commission instructed the Standardization Team to "conduct a study of natural gas appliance safety conditions and alternative testing procedures" under Phase 4 of the Standardization Project. The Commission directed the Team to collect public input on this issue, and to file a proposed Phase 4 methodology, budget and schedule by September 4,

1 See the Standardization Team's *LIEE Program Standardization Project Phase II Follow-Up Report*, October 26, 2000.

2001. In its September 4, 2001 filing, the Standardization Team also recommended that Phase 4 be expanded to cover three other tasks:

- The standardization of weatherization pre-approval practices;
- The preparation of installation standards for refrigerator grounding; and
- The assessment of the cost-effectiveness of LIEE measures.

In his November 13, 2001 Assigned Commissioner's Ruling (ACR), Commissioner Wood authorized the first two of these tasks, as well as a portion of the third relating to the cost-effectiveness evaluation of current LIEE measures. The ACR also instructed the Standardization Team to modify and resubmit the Phase 4 work plan, schedule and budget after modifying them to reflect the instructions contained in the ACR. The Team did so in its November 23, 2001 filing. The Commission approved this plan when it adopted Commissioner Wood's February 19, 2002 Assigned Commissioner's Ruling.

The Team has already filed a number of reports relating to Phase 4. The first, which was filed on February 19, 2002, contained a set of refrigerator plug grounding standards. The Commission accepted this report and adopted new standards on April 22, 2002 in D. 02-04-049. The second set of reports dealt with LIEE measure cost-effectiveness analysis. These reports were filed on September 1, 2002 and April 1, 2003. This current report focuses exclusively on the analysis of the statewide LIEE household CO study and its implications for natural gas appliance CO testing and measure installation approval. The natural gas testing report was initially scheduled to be filed on April 1, 2003. However, the Commission approved an extension of that deadline to May 5, 2003 by adopting an Assigned Commissioner's Ruling dated February 24, 2003.

1.3 Objectives of the Natural Gas Appliance CO Testing Study

The general purpose of the CO study covered by this report was to obtain information that would allow the development of a uniform set of recommendations regarding LIEE Program standards, policies and procedures with respect to natural gas appliance CO testing. As noted in the work plan accepted by the Commission, the specific objectives relating to this element of Phase 4 were:

1. To identify the extent to which potentially hazardous carbon monoxide (CO) levels are present in a statewide sample of low-income homes before they are weatherized;
2. To determine the extent to which the installation of LIEE Program infiltration-reduction measures affects CO levels in participating homes;

3. To assess alternative testing procedures that can be used to identify high CO levels and their sources, and to identify actions that can be taken to mitigate these problems wherever possible;
4. If appropriate, to use the results of the study to:
   - Refine the recommended LIEE Program minimum standard for natural gas appliance CO testing;
   - Develop updated recommendations regarding policies and procedures for the detection and mitigation of high CO levels and other combustion-related hazards;
   - Design recommended statewide standards for LIEE program natural gas appliance CO testing;
   - Develop or refine related program policy and/or procedural recommendations; and
5. To develop recommendations for standardizing measure approval processes across the utilities.

1.4 Key Research Questions

Associated with the first four of the above objectives (those relating specifically to natural gas appliance testing) are several specific research questions that the Phase 4 study was designed to address:

1. In low-income homes in California, what are the pre-existing levels of CO in the following locations: a) in indoor ambient air, b) in the proximity of specific appliances, c) in flue gases, and d) in the surrounding outdoor air?
2. What effect does the installation of infiltration-reduction measures have on CO levels within the home?
3. Do pre-existing or post-installation CO levels found in low-income homes represent a potential hazard to the occupants? What is the frequency and duration of elevated CO levels?
4. Are the existing policies and procedures and Minimum Standard for natural gas appliance testing previously recommended by the Team and adopted on an interim basis by the Commission necessary, and, if so, are they appropriate to identify high levels of CO and other combustion-related hazards in the homes of LIEE weatherization recipients?
5. To what extent would the detection of CO problems be affected by the elimination, reduction, expansion or modification of steps included in the Minimum Standard (including the installation of CO alarms as an alternative or supplement to gas appliance testing)?

6. What modifications, if any, to the current natural gas appliance CO testing policies and procedures should be adopted for the LIEE Program?
7. How should the measure approval process be standardized across utilities?[2]

1.5 Summary of Approach

The approach used in this study involved the following elements:

- A review of the literature on CO levels and impacts;
- A survey of private contractor practices relating to combustion appliance testing;
- The analysis of data on CO testing under the PG&E LIEE Program;
- An extensive on-site survey of low-income homes, including extensive CO testing;
- Blower-door tests of infiltration reduction in a subsample of these homes; and
- An assessment of the performance of CO alarms in a subsample of these homes.

The specific methodology used in these elements of the study is described in Section 2. The results of these analyses are described in Sections 3 through 8.

Two workshops were conducted in order to receive public input on a draft Phase 4 report. A workshop summary is provided in Appendix F. Written comments were also provided by the Insulation Contractors' Association. These comments are contained in Appendix G.

1.6 Summary of Recommendations

The Standardization Team offers the following recommendations relating to combustion appliance testing within the LIEE Program:

- Combustion appliance assessments should be restricted to IOU natural gas appliances, and infiltration reduction measures could be deemed non-feasible for all homes with other combustion appliances. The Team also proposes that homes for which infiltration reduction measures are deemed non-feasible under this provision be referred to the Low Income Home Energy Assistance Program (LIHEAP), or, in the case of homes with non-IOU natural gas appliances, the relevant natural gas utility for full treatment.

- Visual examination steps currently taken under the Minimum Standard should be retained. These steps include flue and vent system checks as well as appliance component checks.

2 While this was not listed as a specific research question in the Phase 4 work plan, it flows from the study objectives cited above.

- Combustion air evaluation steps currently taken under the Minimum Standard should be retained.
- Room ambient CO testing or flue CO testing of heating appliances should be maintained as a standard step in the overall testing protocol.
- Room ambient or flue testing of water heaters should be conducted if the water heater is in the building envelope or in a closet abutting conditioned space.
- Room Ambient should be taken in the kitchen while kitchen appliances are operating.
- Flue tests should be conducted on gas logs.
- No ambient or flue tests should be conducted on dryers. However, visual inspections should be conducted to ensure that dryers are properly exhausted to the outside.
- Smoke tests should be used to test for proper drafting of appliances for which these tests are applicable.
- If a problem is identified through the application of the overall natural gas appliance testing protocol, the case should be referred to qualified utility-trained personnel for resolution.
- Combustion appliance assessments should be conducted after weatherization.
- The following actions when appliances are found to have problems associated with CO:
  - In owner-occupied homes, natural gas space heaters failing one or more of the tests covered by the new protocol should be repaired or replaced.
  - In owner-occupied homes, natural gas water heaters failing one or more of the tests should be repaired or replaced.
  - In owner-occupied homes, non-Program appliances failing one or more of the tests covered under the new protocol should be serviced. If servicing an appliances does not correct the problem in question, the appliance should be capped and reported to the owner.
  - In renter-occupied homes, appliances failing one or more of the tests covered by the new protocol should be serviced. If servicing an appliances does not correct the problem in question, the appliance should be capped and reported to the owner.
- CO alarms should not be offered as either a substitute for or a supplement of combustion appliance testing.
- The utilities should be permitted to retain their current option of conducting appliance assessments in-house or contracting with third parties to provide these services.

1.7 Organization of Report

The remainder of this report is organized as follows:

- Section 2 summarizes the tasks that were conducted as part of the analysis of natural gas appliance testing options.
- Section 3 examines the potential health impacts of CO and identifies threshold values used for the assessment of policy options.
- Section 4 examines the analysis of pre-existing ambient CO levels in low-income homes.
- Section 5 summarizes the evidence with respect to pre-existing flue CO levels (the CO concentrations found inside appliances' exhaust flues) and the performance of appliance flues and vents.
- Section 6 assesses the causes of high pre-existing CO levels and examines alternative methods of detecting potential CO-related problems.
- Section 7 considers the evidence collected on the impacts of installing infiltration reduction measures on household CO levels.
- Section 8 presents information on the performance of CO alarms during the NGAT project.
- Section 9 summarizes the study's conclusions and presents the Team's recommendations for natural gas appliance testing and measure installation pre-approval.
- Several appendices are attached to provide additional detail.

2

CO Assessment Methodology

2.1 Introduction

This section describes the analytical steps taken to support the development of recommendations on natural gas appliance CO testing policy for the LIEE Program. As noted in the original work scope for Phase 4, the analysis consisted of the following elements:

- A review of the literature on residential CO;
- A survey of private contractor practices in the area of CO assessment and mitigation;
- The analysis of data developed by PG&E as part of the combustion appliance safety (CAS) testing it has conducted as part of its LIEE Program;
- An on-site survey of low-income customer homes encompassing several elements relevant to the assessment of CO testing policies and procedures, including extensive CO testing and the assessment of the performance of CO alarms.

These components are described briefly below.

2.2 Review of the Literature on CO Levels and Impacts

In order to support the objectives of Phase 4, RER conducted a review of the relevant literature on existing residential CO-related studies. This literature review synthesized existing published findings with respect to a variety of issues relating to CO testing policies. The following specific issues were covered:

- Description of CO and its potential effects upon general health,
- CO levels found in residential buildings,
- CO emissions from specific residential combustion appliances,
- Policies and practices relating to appliance testing and CO measurement in other programs,
- Links between infiltration rates and CO concentrations, and
- CO detection and monitoring procedures and devices.

This literature review was designed to serve as a starting point for discussions of LIEE appliance CO testing standardization, to provide some guidelines for the appliance CO tests that were conducted in the Phase 4 study survey, and to provide a context in which the results of the appliance CO tests could be assessed. Insights gained from the review are interspersed throughout this report. The full interim literature review report is attached as Appendix E.

2.3 Survey of Private Contractor Practices

In March and April 2002, RER interviewed a number of independent HVAC and weatherization contractors in California to understand industry standard practices regarding appliance CO testing outside of utility-associated programs. Thirty-four interviews were conducted. Twelve of these interviews were with contractors who did furnace repair and furnace replacement work. Many of these contractors did only furnace-associated work or did furnace work in conjunction with some plumbing work. In addition, RER spoke with 22 contractors whose work focused on infiltration reduction (generally caulking and weatherstripping measures, in addition to some other handyman work). The results of these surveys are summarized in Appendix A.

2.4 Analysis of PG&E CO Testing Data

In the course of Phase 4, RER analyzed a database of appliance CO test results provided by PG&E. The database contains test results for over 21,000 homes tested as part of PG&E's 2001 LIEE Program. It provides information on home characteristics, ambient outside reads, ambient inside reads under four test conditions, appliance-specific CO reads, and appliance failures. The most salient of these analysis results are summarized in Sections 4 and 5 of this report.

2.5 Natural Gas Appliance Testing On-Site Survey

The centerpiece of Phase 4 of the Standardization Project was an on-site survey of over 800 LIEE-eligible low-income households throughout California. The on-site survey was designed to collect information pre-existing levels of CO and post-weatherization changes in CO for a representative sample of low-income homes throughout the four joint utilities' service areas. In this section, we describe the survey sample design, survey protocols, and survey forms used in that effort.

2.5.1. Sample Design

A stratified cluster sampling approach was used in the study. The design of the sample frame and stratification approach is illustrated in Figure 2-1. It was developed through the steps described below.

- First, current estimates of the percentage of homes eligible for the LIEE Program by Census block group was obtained by RER for the service areas of the participating utilities. There are roughly 22,000 Census block groups in the State of California, each an average of approximately 520 households.[1] Athens Research had developed estimates of the percent of households satisfying the LIEE income guidelines through the use of 1990 Census data and updates provided by private vendors. Athens Research disaggregated these estimates to the block group level and provided them to RER. RER screened out all block groups not falling into the service area of at least one of the participating utilities.
- Second, California Census block groups falling into the participating utilities' service areas were stratified by RER using general climate conditions and the estimated percentage of households eligible for the LIEE Program. Block groups with high percentages of eligible households were called "high-incidence" block groups, while those with low eligible percentages were referred to as "low-incidence" block groups. High-incidence tracts were defined as those in which at least 27% of all households were estimated to be eligible for LIEE.[2] Block groups were also divided into those facing "warm" and "cold" winter weather conditions using criteria established by RER. Using these estimates, all block groups were divided into four strata:
  - a high-incidence, warm climate stratum;
  - a high-incidence, cold climate stratum;
  - a low-incidence, warm climate stratum; and
  - a low-incidence, cold climate stratum.
- Third, a sample of block groups was chosen from each of these strata. In order to target households that were most likely to be eligible for LIEE, most of the block groups were selected from the high-incidence strata. The total number of block groups to be sampled was determined by two factors: the number of homes to be surveyed per block group, and the total number of homes to be surveyed. Based on budgetary considerations, the Team agreed that a target total of 850 homes would be surveyed, and that 10 homes would be surveyed per block group. As a result, RER sampled 85 block groups. The distribution of the sample among the strata was determined using a technique know as Neyman allocation.[3] The following distribution was obtained:

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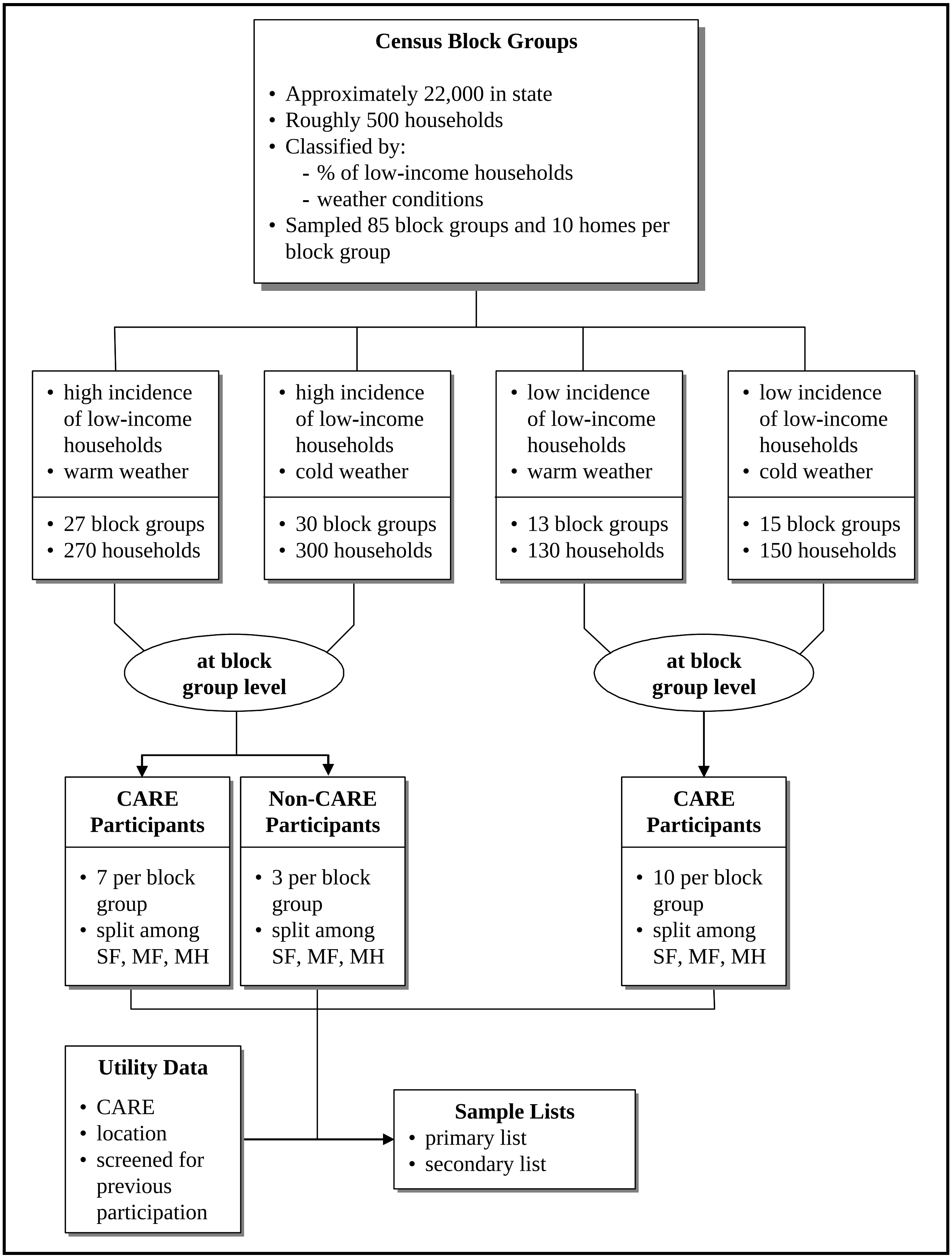
1 A Census block group is roughly one-third the size of a Census tract.

2 This threshold was chosen using the Dalenius-Hodges approach.

3 Neyman allocation is a means of optimizing precision at a given level of cost.

Figure 2-1: Overall Sample Design



  - 27 from the high-incidence, warm climate stratum;
  - 30 from the high-incidence, cold climate stratum;
  - 13 from the low-incidence, warm climate stratum;
  - 15 from the low-incidence, cold climate stratum.

- Fourth, within each of the sampled block groups, households were divided by RER into two types (substrata): CARE participant accounts and non-CARE accounts. Sample targets were developed for each of these substrata. In the interest of conserving screening costs, these sample targets were allocated disproportionately to CARE accounts, which are relatively likely to be eligible for LIEE. Specifically, we allocated 70% of the targeted sample points to CARE accounts and 30% to non-CARE accounts within high-incidence areas. That is, within each sampled block group in the high-incidence areas, a target sample of seven CARE accounts and three non-CARE accounts was established. In the low-incidence block groups, all sample targets were allocated to CARE participants. This essentially ignores low-income customers in low-incidence areas who are not currently participating in CARE. While this approach leaves out one segment of the low-income population, it was used to reduce recruiting costs in low-incidence areas. The Team does not believe that the exclusion of this segment significantly biased any results of the study.
- Fifth, participating utilities provided customer lists identifying CARE participants to RER. These lists were screened to remove recent LIEE participants, either by the utility or by RER.[4] Using these screened customer lists, RER drew initial samples of individual households. For each block group, the initial samples were split into a primary list equal in size to the stratum target and a secondary (backup) list. These sample lists were given to the utilities to provide to their (LIEE program service provider) outreach workers.[5] These outreach workers were instructed to target households on the primary list first, and then move to the backup lists as necessary. As primary and secondary lists were exhausted, additional sample lists were provided to outreach workers.

This sampling process yielded a sample mix very similar to the one included in the Phase 4 work scope.

2.5.2. Participant Recruitment

Once the sample targets were determined by strata and substrata, the process of recruiting participants for the survey began. While the initial sample had already been screened for recent participants, it was necessary to do additional screening in the course of recruitment. Specifically, outreach workers had to screen households for program eligibility and eligibility

4 PG&E provided a list of LIEE participants for RER to use in screening these households out of the sample lists. Other utilities did this screening prior to providing the customer lists to RER.

5 One exception to this procedure was that SoCalGas used employee gas service people to do the outreach.

for infiltration-reduction measures. Outreach workers were instructed to screen the following types of households out of the study group:

- Households that could not provide documentation of income-eligibility.
- Households who do not purchase their space heating fuel from one of the four sponsoring utilities (and who would therefore be ineligible to receive infiltration-reduction measures under LIEE).
- Homes with unvented combustion heaters.
- Homes with combustion water heaters in bedrooms.
- Homes that need fewer than the minimum number of LIEE measures required to qualify for the program.

Homes that would otherwise qualify for LIEE Program weatherization measures, but who did not currently need infiltration-reduction measures, were <u>not</u> screened out of the sample.

Outreach workers used the following recruitment procedure:

- The stratum-specific targets and an initial sample of prospective survey participants were provided to outreach workers covering the targeted survey areas. The sample information included contact names and telephone numbers from utility billing records. For each block group and substratum (CARE v. non-CARE), a primary list equal to the substratum target and a secondary list equal to some multiple of the substratum target were provided. Outreach workers were instructed to exhaust the primary list before moving to the secondary list.
- In some block group areas, recruiters were required to recruit eligible homes for three subsamples: a subsample of 30 homes that were to receive CO alarms and data loggers; a subsample of homes that were to receive CO alarms but not data loggers; and a subsample of 50 homes that were subjected to blower door air infiltration tests.
- Starting with the primary list and moving to the secondary list when necessary, outreach workers contacted households and solicited participation in the survey. At the same time, outreach workers documented income and household eligibility.
- Outreach workers maintained records of households that were contacted but did not participate, either because they refused or because they were deemed ineligible for the LIEE Program. They also recorded the reason for ineligibility (income, heating fuel, insufficient need for measures, presence of unvented heaters, water heater in a bedroom, etc.).

2.5.3. Completed Sample Structure

Table 2-1 and Table 2-2 provide some summary information on the structure of the completed sample. Two points should be noted with respect to Table 2-1.

- First, the total completed sample size is somewhat smaller than the targeted sample size. This resulted from difficulties experienced in the recruitment process, especially in the SCE service area.[6] Survey field work had to be suspended prior to the completion of the survey for 850 sites in order to keep the study from falling too far behind schedule.
- Second, the distribution of the surveyed sample across block group types (the strata of the initial sample design) differed slightly from the design distribution. This resulted from the need to provide outreach workers some flexibility toward the end of the outreach process in order to accelerate the outreach process.

Table 2-1: Sample Design and Completed Sample

Block Group Types	CARE Status	Initial Sample Distribution	Final Sample Distribution
Block Groups with high incidence of low-income households and warm Weather	CARE	189	180
	Non-CARE	81	73
	Both	270	253
Block Groups with high incidence of low-income households and cold Weather	CARE	210	210
	Non-Care	90	93
	Both	300	303
Block Groups with low incidence of low-income households and warm Weather	CARE	130	119
	Non-CARE	0	4
	Both	130	123
Block Groups with low incidence of low-income households and cold Weather	CARE	150	129
	Non-CARE	0	7
	Both	150	136
Total Sample		**850**	**815**

As indicated by Table 2-2, the distribution of surveyed homes across residence types and utility service areas also differed somewhat from the sample design. SCE outreach workers were unsuccessful in recruiting homes that qualified for the program and had combustion appliances. As a result, SCE stopped the outreach process. The sample design's targeted distribution across residence types was based on preliminary assumptions about the mix of low-income homes. However, the selection of homes targeted for recruitment had to be done without information on residence types. While outreach workers were encouraged to attempt to recruit a reasonable mix of residence types, no specific quotas could be established in

[6] SCE reported that it completed a total of 262 NGAT surveys between May and Dec 2002. Out of the 262 surveys, only one customer was eligible to participate. Of the others, 195 were ineligible due to having an all electric home (no combustion appliances) or non-electric space heating. The rest either could not be contacted after three attempts, or refused to participate.

practical terms. The Team and its support consultants believe that the actual mix of the final sample provides a good representation of all residence types.

Table 2-2: Sample Breakdown by Utility and Residence Type

	Utility				
Dwelling Type	**PG&E**	**SoCal**	**SDG&E**	**SCE**	**All Utilities**
Initial Sample Design					
Single Family	150	197	38	14	399
Multi-family	112	147	28	11	298
Mobile Homes	58	76	14	5	153
All Residence Types	**320**	**420**	**80**	**30**	**850**
Completed Sample					
Single Family	190	300	54	0	544
Multi-family	91	92	40	0	223
Mobile Homes	36	12	0	0	48
All Residence Types	**317**	**404**	**94**	**0**	**815**

The completed sample size of 815 homes provided a level of statistical precision very close to that which would have been achieved with the target sample size of 850. At any given level of confidence (say 90%), the error bands would have been roughly 2.1% smaller with the targeted sample size. Slightly narrower error bands would have had no material influence on the conclusions reached in this study.

Given the stratified design of the sample, it was necessary to develop expansion weights to ensure that estimates based on the sample reflected the overall population of low-income households. Expansion weights are shown below in Table 2-3. These weights reflect the ratio of the total number of homes in the stratum to the total number of homes in the sample.

Table 2-3: Expansion Weights

Stratum	Sample Size	Estimated Population	Expansion Weight
Block Groups with high incidence of low-income households and warm Weather	253	626,144	2,475
Block Groups with high incidence of low-income households and cold Weather	303	746,982	2,465
Block Groups with low incidence of low-income households and warm Weather	123	457,016	3,716
Block Groups with low incidence of low-income households and cold Weather	136	548,229	4,031

2.5.4. Survey Protocols

Overview

In this section, we outline the protocols that were followed in conducting the on-site survey. For convenience, we can break these protocols into two types: those that are associated with coordination with other parties to implement the survey; and those specific protocols associated with the collection of on-site data and the assessment of various CO testing options.

Coordination with Utility Staff and Installation Contractors

CO testing, a major part of the on-site survey, was conducted before and after the installation of LIEE weatherization measures. As a result, it was necessary to coordinate survey (CO testing) activities with utility staff and their LIEE Program measure installation contractors. RHA and the utilities used the following protocol for testing and treating participating homes.

- Once participants were recruited and income qualification was established, RHA installed CO alarms (and data loggers, where relevant) in a subsample of homes. These alarms were left in the homes for approximately three months prior to implementing the next step of the on-site survey process.
- Arrangements were made for RHA to visit the homes and conduct pre-installation appliance CO tests. These arrangements were made in the course of outreach for homes not receiving CO alarms, and were made later (three months after CO alarm installation) by RHA staff for those receiving alarms.
- Next, pre-installation CO tests were conducted by RHA. In the PG&E service area, where PG&E's Central Inspection Program (CIP) staff employees conduct pre-weatherization CAS tests, these CAS tests were waived in favor of the battery of RHA appliance CO tests in order to minimize the inconvenience to survey participants. PG&E CIP staff had the option to accompany RHA staff to ensure that the CO tests were acceptable to the utility.

- As soon as RHA had conducted the pre-weatherization CO tests, the utilities' LIEE weatherization contractors installed all feasible measures in the participating homes. These measures were installed prior to the repair/replacement of appliances causing potential CO problems. The reason for this is that the research plan required testing for the impact of installing infiltration-reduction measures on appliance CO levels. However, it should also be noted that, to protect the safety of participants, all potentially hazardous appliances were not permitted to be operated in the interim between the pre-weatherization and post-weatherization CO tests.
- As soon after the installation of LIEE Program measures as possible (generally the same day), RHA returned to the weatherized homes to conduct post-installation CO tests. If a new or pre-existing hazardous condition were found, the offending appliance was repaired or replaced. If the appliance repair/replacement could not occur immediately, the appliance was disconnected and red-tagged until it could be repaired or replaced at that time. All faulty combustion appliances identified, including propane appliances, were repaired or replaced as needed as part of the Phase 4 study. This work was conducted by RHA, utility gas service staff, or an HVAC contractor under contract with the utility. The HVAC contractor and RHA billed the respective utilities directly for these repairs and replacements. In the event that potentially hazardous CO conditions were found, the offending appliance was disconnected and "red-tagged." Otherwise, no CO problems found in surveyed home were initially corrected. If a space heater was red-tagged during the heating season, electric space heaters were provided for the participants to use until the faulty appliances were repaired or replaced. It should be noted that the repair or replacement of appliances not currently covered by the LIEE program (non-natural gas combustion appliances, furnaces in rental units, and natural gas appliances other than furnaces) was done on a one-time-only basis solely to support this research project. Such non-Program appliance repairs or replacements do not constitute precedents for such repairs as part of the regular ongoing LIEE program.
- Utility inspection staff then had the option to conduct any post-weatherization inspections.
- In homes with CO alarms, RHA returned roughly three months after the installation of weatherization measures to conduct another round of post-installation tests and to remove the test CO alarms.
- In a subsample of 50 homes, RHA conducted blower door household air infiltration tests before and after the installation of infiltration-reduction measures. These tests were conducted at the same times as the pre-installation CO tests and the first post-installation CO tests.

<u>On-Site Survey Protocols</u>

A set of uniform protocols was developed by the Standardization Team to guide the activities of statewide survey personnel. These on-site protocols included the following:

- Guidelines for assessment of the structure and data related to structural statistics;
- Procedures for occupant demographic data collection;
- Natural gas appliance examination and testing procedures;
- Procedures for blower door tests;
- Data collection associated with natural gas appliance examination and testing.

These protocols allowed survey personnel to evaluate a matrix of testing procedures and equipment.

<u>CO Testing Protocols</u>

Several CO testing procedures were implemented in the course of the on-site visits. The six procedures for the six levels of testing are outlined below. Detailed protocols are contained in Appendix B.

Procedure 1: Ambient CO Alarms as an Alternate or Supplement to Testing

This procedure was designed to evaluate the installation of CO alarms as an alternative or supplement to natural gas appliance safety testing. CO alarms were installed in a subset (100) of the homes included in the Natural Gas Appliance Testing Study. The alarms were installed during, or immediately after, the outreach and assessment process. Two to five months later, these homes underwent CO testing using the complete pre- and post-testing protocol. Thirty of these 100 homes were equipped with data loggers that continuously monitored CO levels for five to six months.

Data obtained from the CO testing, the data loggers, and a customer survey were analyzed and compared to the performance of the CO alarms, to assess the feasibility of CO alarms as an alternative or supplement to testing. The specific procedures used in this process are described in Section 6.

Procedure #2: Visual and Olfactory Checks and Customer Interviews

This minimal procedure included a visual and olfactory check of combustion appliances with none of the equipment operating. A visual inspection was conducted for each combustion appliance for potential hazards, such as:

- Appliance, combustion chamber, burner, gas valve, flue and vent system defects;
- Defective mechanical or gravity ventilation in mobile home kitchens with gas cooking;
- Combustible and flammable items stored on or near appliances;
- Evidence of improper combustion; and

- Duct disconnections visible from appliance locations, and plenum leaks near open combustion appliances.

An olfactory check for aldehydes and gas leaks was also conducted near each appliance.

Procedure #3: Room Ambient Test in Winter Conditions without Fans

This procedure included the following procedures.

- First, room ambient CO measurement #1 was conducted to determine the CO level (ppm) in each room having a gas appliance. Appliances that were operating when the technician arrived were turned off for the purposes of this test. The home (doors and windows) were left as found for this test only.
- Second, gas valves and fittings were checked for leakage with a leak-detection solution.
- Third, gas appliances were operated with exterior doors closed and interior doors open (winter conditions) and exhaust fans off. In this mode of appliance operation, a series of tests were conducted, including visual checks of flame characteristics, observations for flame interference on forced air units (FAUs) and short-cycling after warm-up, observation for ignition characteristics (delayed and/or rollout), smoke test for draft, and tactile test for spillage.
- Fourth, room ambient CO measurement #2 was conducted in each room containing a combustion appliance, after the appliance had warmed up. Ambient readings were taken in the same locations as before, still under winter conditions with fans not operating.
- Fifth, a second olfactory test for aldehydes was conducted after appliances had been operating for a minimum of five minutes.

Procedure #4: Appliance Ambient CO Test in Winter Conditions without Fans:

Procedure #4 added an appliance ambient CO test in which the ambient air was tested above the heat exchanger of each non-ducted combustion appliance and inside the supply register nearest the furnace for each forced air unit.

Procedure #5: Flue Gas CO Test in Winter Conditions with Fans:

This procedure added the following steps to the basic analysis of the home.

- Exterior doors and windows were closed, and interior doors were set in “assumed” worst case (default) positions.
- All exhaust devices were turned on.

- An evaluation of combustion air was made, including number, location and size of vents, room/residence volume, and (when applicable) number, location and size of vents to adjacent volume.
- A visual inspection of heat exchangers during operation (as applicable) was conducted.
- For FAUs, a visual inspection of the air distribution system (as applicable) was conducted, covering supply leaks, return leaks, and depressurization caused by door closing.
- Visual check in attic and crawlspace (as applicable) was conducted for flue/vent defects.
- Testing flue gas for CO: The flue gas in each combustion appliance was tested before dilution air to determine the level of CO in parts per million (ppm). Both "as measured" and "air-free" readings were recorded.
- An instrumented draft test was conducted on open combustion appliances (as applicable).
- Instrumented CO and draft tests were performed with appliance enclosure doors open, and again with them closed (as applicable).

Procedure #6: Complete Testing Procedure in Worst Case Condition:

The procedure will included all those activities outlined in Procedures #2- #5 above, with the addition of diagnostic procedures designed to determine house conditions for appliance testing at this level. These procedures included the determination of "true" worst-case conditions and the use of these conditions in draft and CO tests; Combustion Appliance Zone (CAZ) tests; and pressure measurement in three modes of fan/appliance operation

<u>Procedures for Blower Door Tests</u>

Fifty-four households in this study were randomly selected for pressure diagnostic measurement with a blower door. A blower door pressurizes (or depressurizes) the structure to determine the amount of shell leakage present in the residence. One of the primary goals of weatherization is to reduce the amount of shell leakage and tighten the structure. This part of the study was designed to determine the extent of shell tightening and a possible relationship to the amount of ambient CO present in a residence.

Pressure diagnostic procedures (blower door) were conducted immediately after the pre- and post-weatherization natural gas appliance testing (NGAT) survey protocols were concluded. By conducting this procedure at the end of the NGAT survey process the residence could be flushed out of any residual CO and heat (as running the combustion appliances heated up residences to an uncomfortable level during the process) and the induction of outside air into the structure after the survey would not interfere with ambient air readings.

The blower door is attached, usually to the front door, preparing the house to be in the pressurized mode. All windows, doors, and dampers are closed or sealed and the residence is pressurized. When the pressure stabilizes the technician reads the pressure differential between the inside and outside and adjusts the blower door fan speed to maintain a 50 pascal pressure differential. The blower door has an opening of known size and together with the fan speed, the leakage CFM (cubic feet per minute) can be determined. This reading (in CFM-50 pascals) was then noted on the blower door form and the equipment shut off and removed.

The same procedure was used after the post-weatherization NGAT Survey was conducted.

2.5.5. Data Collection Forms

The general information collected during the on-site visit included the following:

- Housing type;
- Appliance types, fuels used by each appliance, and number of appliances serving each home;
- Adequacy of combustion air venting;
- Condition of heat exchanger, flue, and vent system;
- Inspection for other potential hazards, such as:
  - Presence of gas leaks;
  - Inadequate draft;
  - Spillage;
  - Burner abnormalities;
  - Abnormal ignition/flame;
  - Return system leaks;
  - Inadequate combustion system air;
  - Flue and/or venting system defects;
  - Supply and return air system leaks;
  - Use of unvented appliance as a heater;
  - Inoperable mobile home kitchen exhaust fan.
- Depressurization caused by duct system abnormalities.

CO information included:

- Levels of CO, measured before and after weatherization measures are installed, at the following locations:

  - Outdoors;
  - Indoor ambient air;
  - Indoors proximate to specific appliances;
  - In-flue gases.[7]
- Levels of CO associated with:
  - Type of appliance and type of fuel used by the appliance;
  - Amount of combustion air;
  - Byproducts of combustion;
  - Supply and return duct leakages.

A copy of the data collection form is included in Appendix C.

2.5.6. Instruments Used in the Survey

Introduction

The NGAT study required the use of CO testing and measurement equipment to analyze appliance exhaust flue gas and ambient CO levels in participating residences. NGAT technicians relied on two pieces of test equipment, the Testo 325-1 Flue Gas Analyzer and the Dräger PAC III Gas Monitor equipped specifically to detect ambient CO.

Review of existing equipment

Most weatherization contractors currently conducting combustion gas safety testing use the Bacharach Monoxor II. This low-cost flue gas analyzer has been a standard weatherization industry tool for a number of years. The Monoxor II is a single gas analyzer and will only detect CO. For the NGAT Study, the Monoxor II had too many limitations, as this study required a flue gas analyzer that could measure CO, O_2, draft and temperature, and could calculate air-free CO.

Selection of NGAT Study Test Equipment

The NGAT Study needed test equipment that could read CO levels in side appliance exhaust flue gases as well as the ambient air. This was at least partly because one of the utilities, PG&E, has tested both flue and ambient CO levels. The flue gas analyzer was also required to read "air-free" measurements which require the ability to read oxygen levels in combustion air. Because flue-gas analyzers are not designed to measure ambient air, the committee decided that a second CO analyzer was needed to read ambient air levels of CO.

[7] CO was tested in the flues of all combustion appliances.

In actual field situations, both pieces of equipment should not be necessary. These sophisticated testing instruments cost approximately $1,000 each. A comparison analysis was incorporated into the design of the NGAT Study to determine if the flue gas analyzer could adequately read CO levels in the ambient air in addition to appliance exhaust gases, as compared to a gas monitor designed to read only ambient air CO levels.

Cost was also an issue in the Team's equipment purchase decisions. A reasonably priced CO testing tool had to be chosen if this testing protocol was to be institutionalized in the future. Flue-gas analyzers range in price from a few hundred dollars to many thousands of dollars.

The two CO testing tools selected to be used in this study were the Testo 325-1 Flue Gas Analyzer and the Dräger PAC III for ambient CO levels.

Testo 325-1. This flue gas analyzer is designed to take readings from flue gases of combustion appliances. The accuracy, as indicated by the manufacturer for this equipment is ± 20 ppm for reads under 400 ppm and ± 5% above 400 ppm (see Appendix D). The resolution listed by the manufacturer was 1.0 ppm. This accuracy would make any ambient reading from -20 to 20 ppm suspect and below the level of detection, indicating that this equipment could not reliably measure ambient CO levels.

The Testo 325-1 self "zeros" upon start-up. This means that whatever the Testo reads in the ambient air becomes the baseline or "zero" point. Since most ambient air readings are typically less than 20 ppm (which is the accuracy of the device) and the flue readings are relatively high, this "zeroing" procedure does not significantly affect flue gas readings. However, it can affect the level of confidence in ambient readings.

Dräger PAC III. The Dräger PAC III was recommended to the committee based on its use in measuring ambient CO for OSHA compliance and worker safety. This equipment can be used with a variety of sensors for different gases. The Dräger CO sensor (XS EC CO - 68 09 105) was used in this study (see technical specifications in Appendix D). The model chosen for the surveys was also chosen for the datalogging activities as it has a datalogger built into the unit so all readings can be recorded and downloaded to a computer for analysis. The datalogger mode was not used for the NGAT Surveys. The resolution for this equipment was listed by the manufacturer as 1 ppm or 0.5% of measured value, whichever value is greater.

Drägers are "zeroed" at the factory with nitrogen and that "zero" value is stored in the memory to be used as the baseline or reference reading. The Dräger can be field-set to "zero" using a procedure described in the technical handbook either to ambient air or to an inert gas. This process was not used in the current study. The Team consulted with the manufacturer, and was told that recalibration would not be necessary given the relative short period of time over which the tests were conducted.

Problems Encountered

Not all of the equipment (Testos and Drägers) functioned properly throughout the Study. RHA purchased brand-new equipment from manufacturer's representatives and the equipment was shipped directly from the factory.

Testo 325 Problems. Two of the new Testos had to be returned to the manufacturer at the start of the study. These pieces of equipment provided erroneous readings during the training course conducted in Stockton. After they were repaired they were returned in working order and used in the study.

During the course of the survey, three additional Testo units malfunctioned (at different times and with different technicians) and had to be sent back to the manufacturer. Technicians reported towards the end of the study that the equipment started to fall apart from the amount of use the equipment received during the testing period. Probes were coming loose and had to be reinserted and "jiggled" every so often to get readings. The fittings to which the probes attached were the main problem when these broke or came loose.

Dräger PAC III Problems. The Drägers used by the technicians maintained operability throughout the course of the study. One Dräger began to measure higher levels than its previous average and was used in 12 studies before it was replaced. When Dräger equipment is started, it requires up to ten minutes for the sensor to warm up to achieve accurate readings. During this time, the readings "bounce" between negative and positive values before settling. Depending on when the technician read the Dräger during this initial period, the value might have varied by a range of 1 – 4 ppm. However, this "bounce" in the CO level was not found to affect the results significantly.

Technical Data

Technical data relating to the Testo 325 and the Drager PAC III are contained in Appendix D.

3

Defining Potentially Hazardous Levels of Ambient CO

3.1 Overview

Before assessing the level of potential customer risk associated with household CO in the low-income community, it is necessary to understand the potential hazards associated with various levels of ambient CO. This section briefly discusses potential health impacts of CO and reviews the literature relating to potentially hazardous levels of the gas.

3.2 Health Impacts of CO

Several studies have indicated that prolonged exposure to high levels of CO can have dire consequences on human health. CO's affinity to bind with blood hemoglobin is 200 times higher than that of oxygen. When CO is present in the body, it binds with hemoglobin to produce carboxyhemoglobin (COHb), and therefore inhibits the delivery of oxygen in the body (EPA, 2000 and Clancy, 1996). In general, as blood COHb levels become higher, the symptoms of CO poisoning become more severe. Blood COHb levels vary as a function of time and level of exposure, respiratory rate, age of the patient, and presence of underlying illness. Initial symptoms of CO poisoning include headache, fatigue, shortness of breath, nausea, and dizziness. Extended exposure to high levels of CO leads to cardiovascular and neurological damage that can eventually result in unconsciousness and death.

Inkster (2000) states that the Health Sciences staff at the Consumer Products Safety Commission consider levels above 20% COHb an immediate threat of death or permanent neurological damage. As a general rule, Health Sciences staff considers that keeping COHb levels from reaching 10% protects the majority of healthy adults. The lowest exposure that can result in 10% COHb is about 65-70 ppm for at least four to five hours and is dependent on activity level.

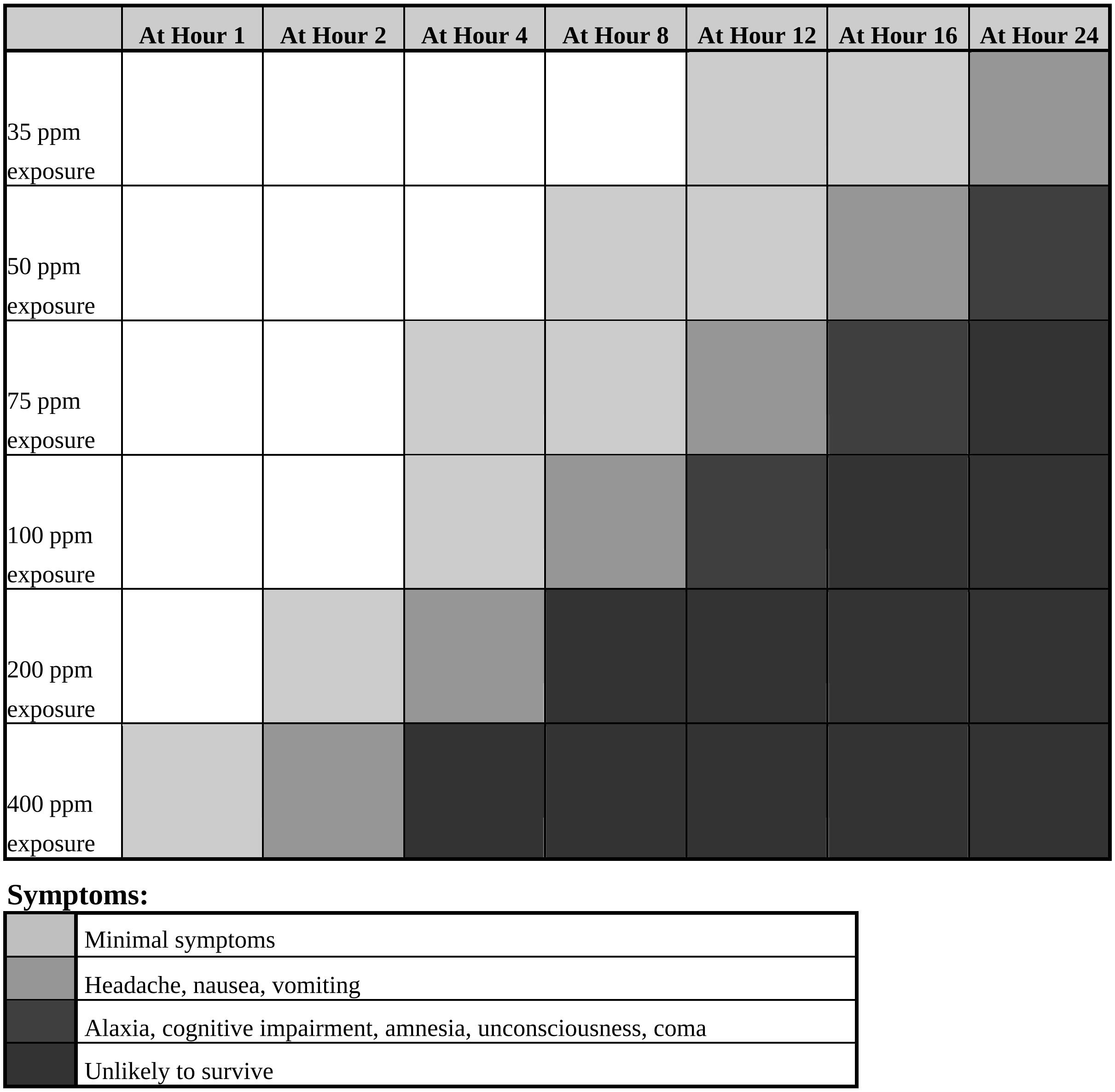
The U.S. Environmental Protection Agency (2000) conducted an extensive review of published results of controlled-exposure studies and population-exposure studies on the effects of CO on health. Since the studies summarized were examining CO levels in the human body, the unit of measurement was COHb levels in the blood. For comparison purposes, it should be noted again that the lowest exposure that can result in 10% COHb is about 65-70 ppm for at least four to five hours.

The EPA (2000) overview of the effects of CO on health found that:

- No effects were observed during submaximal exercise in healthy individuals at COHb levels as high as 15 to 20%. However, maximal exercise duration and performance in healthy individuals has been shown to be reduced at COHb levels of 2.3% to 4.3% -- these decrements, however, were small and likely to effect only competing athletes.
- Decreased exercise tolerance has been observed consistently in patients with coronary artery disease and reproducible exercise-induced angina (chest pain) at COHb levels of 3 to 6%.
- Recent analyses indicate that significant behavioral impairments in healthy individuals should not be expected until COHb levels exceed 20%; however, mild central nervous system effects have been reported in the historical CO literature at COHb levels between 5 and 20%.
- Ambient levels of CO are not known to have any direct effects on lung tissue.

The health effects of CO depend on both level and duration. Prolonged exposure may increase symptoms. For example, at 400 ppm for one hour, most adults will have minimal symptoms. At 400 ppm for two hours, most adults will feel a slight headache, be drowsy, and may begin vomiting. At 400 ppm for four hours, for most adults, death is certain. Figure 3-1, which is drawn from the web site of North American Detectors, Inc., a CO alarm manufacturer, shows the relationship between toxicity level and length of exposure. While these data are from an alarm manufacturer, this graphic illustrates the relatively important point that carbon monoxide poisoning is a function of levels of exposure as well as length of exposure.

Figure 3-1: CO Toxicity Levels and Length of Exposure



Notes: Based on data obtained from The Toronto Hospital and the Occupational Safety and Health Administration (OSHA)
Source: www.nadi.com (North American Detectors, Inc. webpage)

3.3 Standards Relating to Ambient CO

There are no U.S. agency standards for CO levels in indoor residential environments. However, varieties of organizations do have published standards for ambient CO in other environments. Standards vary across agencies for a variety of reasons, including the specific populations to which they apply. Most standards recognize the susceptibility of sensitive population segments like those with heart disease, anemia, blood disorders, or chronic lung disorders, as well as pregnant women, fetuses, and children. Table 3-1 presents several standards relating to ambient CO. The length of time over which the CO level in question is experienced is indicated in parentheses. These standards are discussed below.

U.S. Environmental Protection Agency (USEPA). The USEPA sets national standards for outdoor air, which applies to the overall population and recognizes the susceptibility of some segments of the population. As shown in Table 3-1, the eight-hour CO standard is 9 ppm and the one-hour standard is 35 ppm. While this standard applies to outdoor air, USEPA recognizes the potential risks of indoor CO.

U.S. Department of Labor Standards (USDoL). The USDoL sets Occupational Safety and Health Administration sets standards for industrial work places. These standards relate to adults and pertain to exposures in the work place during a typical work week. USDoL's eight-hour CO standard is 50 ppm.

World Health Organization (WHO). The WHO standard is an international standard for indoor ambient CO. The WHO eight-hour CO standard is 10 ppm and the one-hour standard is 25 ppm.

U.S. Centers for Disease Control (USCDC). The USCDC is an agency of the Department of Health and Human Services. It assists in the development and application of disease prevention and control, environmental health, and health promotion and education activities. Its eight-hour CO standard for industrial environments is 35 ppm.

California Air Resources Board (CARB). The CARB is a part of the California Environmental Protection Agency, an organization that reports directly to the Governor's Office in the Executive Branch of California State Government. CARB's ambient air quality standard, which was developed by the Department of Health, is 9 ppm (eight hours) and 20 ppm (one hour). Note that CARB's one-hour standard is somewhat lower than the comparable EPA standard.

Canadian Ministry of Health. The Canadian Ministry of Health has published a set of CO guidelines developed by the Canadian Federal-Provincial Advisory Committee on Environmental and Occupational Health. These guidelines were developed in a way that recognizes the vulnerability of sensitive populations.

Consumer Product Safety Commission (CPSC). CPSC worked with Underwriters Laboratories (UL) to help develop the safety guideline for CO alarms. CPSC also works with industry to develop voluntary and mandatory standards for fuel-burning appliances. According to CPSC, "effects from exposure to CO levels of approximately 1 to 70 ppm are uncertain, but most people will not experience any symptoms. Some heart patients might experience an increase in chest pain. As CO levels increase and remain above 70 ppm, symptoms may become more noticeable (headache, fatigue, nausea). As CO levels increase above 150 to 200 ppm, disorientation, unconsciousness, and death are possible." (See CPSC Document #466).

Table 3-1: Comparison of Threshold Levels of CO

Organization	Type of Environment	Ambient CO Standard
U.S. Environmental Protection Agency	outdoor environments	35 ppm (1 hr.) 9 ppm (8 hrs.) Not to be exceeded more than once per year
U.S. Department of Labor (Occupational Safety and Health Administration)	Industrial environments	50 ppm (8 hrs.)
World Health Organization	indoor environments	90 ppm (15 mins.) 50 ppm (30 mins.) 25 ppm (1 hr.) 10 ppm (8 hrs.)
U.S. Centers for Disease Control	Industrial environments	200 ppm (ceiling over 8 hrs.) 35 ppm (8 hrs.)
California Air Resources Board	outdoor environments	20 ppm (1 hour) 9 ppm (8 hours)
Consumer Product Safety Commission	Indoor environments	See text above
Canadian Ministry of Health	Indoor environments	25 ppm (1 hour) 11 ppm (8 hours)

3.4 Choice of Threshold Levels for Ambient CO

As discussed above, the health effects of CO vary across levels and durations of exposure as well as across individuals subject to exposure. Standards, which are generally set to protect the safety of individuals with relatively high susceptibility to CO, also vary across applications and jurisdictions. Technical staff supporting the Standardization Team may differ in opinion with respect to the appropriate choice of a level to represent the presence of a potential hazard. For the purposes of our analysis, however, the Team chose two thresholds, as follows:

- An ambient threshold of ***10 ppm*** was chosen as an ***action level***, or a level that should prompt more extensive investigation and analysis of the source of CO.

- An ambient level ***35 ppm*** was chosen as a ***threshold level*** at which the home should be ventilated, the occupants should be advised to evacuate, and the technician should restrict exposure to 15 minutes. In these cases, the offending appliance was made inoperable pending repair or replacement.

We should note that the Commission's current Minimum Standard for natural gas appliance testing prescribes the use of these two levels for the purposes in question. This is because the Minimum Standard was set at least partly on the basis of the evidence presented above.

3.5 Choice of Threshold Levels for Appliance Exhaust Flue CO

Threshold levels were also adopted for appliance exhaust flue CO (the CO concentration found inside an appliance's exhaust flue). Table 3-2 depicts the ANSI standards for air-free measurements of flue CO as well as the as-measured thresholds currently used by the gas utilities for gas service. These thresholds will be used in the analysis of appliance exhaust flue CO levels in Section 5.

Table 3-2: Threshold Levels for Flue CO

	Utility As-Measured CO Thresholds (ppm)			ANSI Air-Free
Appliance	**PG&E**	**SoCalGas**	**SDG&E**	**Standard (ppm)**
Forced Air Unit	100	275	275	400
Gravity Furnace	100	275	275	400
Floor Furnace	100	275	275	400
Wall Furnace (natural draft)	100	125	125	400
Wall Heater (direct vent)	100	275	275	400
Water Heater	100	125	125	200
Oven/Broiler	100 (225 after service)	225	225	400 (800 after service)
Cook Top Burners	100	25	25	800
Clothes Dryer	100	275	275	400
Gas Log	100	25	25	400

4

Pre-Existing Ambient CO Levels

4.1 Overview

This section summarizes the pre-weatherization ambient CO levels found in the homes participating in the NGAT survey. Indoor ambient readings measure the CO in the air in participating homes. Particular attention will be given to homes with ambient CO levels above the critical values established in Section 3. As noted in that section, the Team established two thresholds for ambient CO: 1.) an ambient threshold of 10 ppm was chosen as an action level, or a level that should prompt more extensive investigation and analysis of the source of CO; and 2.) an ambient level 35 ppm was chosen as a threshold level at which the home should be ventilated, the occupants should be advised to evacuate, and the technician should restrict exposure to 15 minutes. In these cases, the relevant appliances were capped and scheduled for repair or replacement.

In keeping with the specific research objective presented in Section 1, two general types of readings of ambient CO levels were taken in the course of the survey:

- Indoor ambient readings in the middle of rooms with combustion appliances (hereafter called room ambient readings); and
- Indoor ambient readings taken near combustion appliances (called appliance ambient readings).

As explained below, these readings were also taken under a variety of conditions with respect to appliance operation, exhaust fan operation, and window and door positions. For each type of reading, we have developed full frequency distributions as well as a variety of summary statistics characterizing these distributions. These frequency distributions indicate the percentage of specific CO readings that fall within various intervals, specified in parts per million (ppm). Given that readings were taken at different times and in different places in the surveyed homes, a relatively large number of distributions and averages are presented.

Ambient readings were taken with two instruments: Testos and Drägers. As indicted in the previous section, the Drägers have better resolution at the levels of CO typically found in ambient readings. As a result, we have used these readings to develop the results presented in this section.

Note that the results presented here and elsewhere in this report have been weighted to represent the population of all low-income homes. The expansion weights used in this process were described in Section 2.

4.2 Indoor Room Ambient CO Levels

4.2.1. Overview

Tests of ambient CO in rooms with combustion appliances were conducted under two conditions:[1]

- ***Room Ambient Test #1*** was conducted with appliances turned off and with doors and windows in the conditions in which they were found. The CO reading was taken in the middle of each room with a combustion appliance (other than gas logs and dryers), but no closer than ten feet from the appliance.
- ***Room Ambient Test #2*** was taken with appliances operating for at least five minutes, and with the following conditions: all entrance doors and windows closed; fireplace dampers closed; interior doors open except to appliance enclosures; and exhaust fans and air handlers off. Room Ambient Test #2 was taken in the same locations as Room Ambient Test #1.

As previously stated, room ambient tests were conducted with two instruments: Drägers and Testos. Again, however, attention should be restricted for now to the Dräger readings, in that they should be more precise at the levels of CO likely to be confronted in ambient tests. It is also noteworthy that ambient CO levels depicted in this section are net levels, in the sense that they are differences between indoor and outdoor readings. In practical terms, this convention has little impact on the results, insofar as outdoor ambient readings are generally low.[2]

4.2.2. Room Ambient Test #1

Table 4-1 presents the result of Room Ambient Test #1. The first three numerical columns present the *average* read for the rooms in which ambient measurements were taken, the fourth column presents the average read for over all rooms, while the last column depicts the *maximum* read across these rooms. Again, results are shown in four forms:

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1 During the testing procedure, room ambients were also to be taken under what is called “worst case” conditions for homes with forced air furnaces and/or natural draft combustion appliances, and for which default worst case conditions and actual worst case conditions differed. However, these tests were applied in only two homes, and are consequently ignored in this report.

2 Outdoor ambient readings taken with Drägers prior to the conduct of indoor tests had an arithmetic mean of 0.50 and a geometric mean of 0.04.

- Percentage distributions of indoor CO levels;
- Percentages of indoor CO reads over critical values (10 ppm and 35 ppm);
- Arithmetic and geometric average room ambient CO reads across all surveyed homes (in bold);
- Confidence intervals for the arithmetic and geometric means.

An arithmetic average (or arithmetic mean) is simply the sum of all readings divided by the number of readings. Arithmetic averages are perhaps the most common type of measure of "central tendency" of a distribution, but are most appropriate for symmetric distributions. A geometric average (mean) is the anti-log of the arithmetic average of logarithms of the individual readings. Geometric averages are more appropriate for the kind of distribution generally exhibited by the readings taken in the NGAT survey.[3] In general, arithmetic averages tend to be more influenced by extreme values than geometric averages. In a sense, geometric averages are similar to medians.

Note that the confidence intervals represent the ranges of values within which we can be 90% certain that the true average (arithmetic or geometric) falls.

We offer the following observations on these results:

- The arithmetic mean of the average across rooms of the Room Ambient Test #1 CO levels is 0.29 ppm, while the arithmetic mean of the maximum reading is 0.38 ppm.
- The geometric mean of the average across rooms of the Room Ambient Test #1 CO levels is 0.07 ppm, and the geometric mean of the maximum reading is 0.08 ppm.
- As shown, 0.16% of all homes have at least one Room Ambient Test #1 reading in excess of the action level of 10 ppm. None of the readings was above the threshold level of 35 ppm.

[3] Such distributions are called log-normal distributions, and tend to be characterized by a preponderance of values at the low end of the range and a few high values.

Table 4-1: Results of Room Ambient Test #1

CO Read in ppm	Readings by Room Groups			Average across Rooms	Maximum across Rooms
	Kitchen	Other Conditioned Rooms	Garage		
<0	3.78%	5.31%	8.93%	5.10%	4.03%
0	79.07%	75.71%	71.21%	76.04%	74.54%
1	6.47%	8.76%	13.12%	9.50%	9.36%
2	5.22%	5.09%	5.12%	4.99%	6.36%
3	3.31%	3.21%	1.01%	2.83%	3.30%
4	0.57%	0.87%	0.62%	0.61%	1.04%
5	0.59%	0.32%	0.00%	0.18%	0.50%
6	0.41%	0.18%	0.00%	0.27%	0.27%
7	0.16%	0.24%	0.00%	0.11%	0.22%
8	0.16%	0.00%	0.00%	0.11%	0.11%
9	0.00%	0.12%	0.00%	0.11%	0.11%
10-19	0.25%	0.00%	0.00%	0.16%	0.00%
20-34	0.00%	0.18%	0.00%	0.00%	0.16%
35+	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
10+	**0.25%**	**0.18%**	**0.00%**	**0.16%**	**0.16%**
Arithmetic Mean CO (ppm)	0.32	0.31	0.17	0.29	0.38
90% confidence interval on arithmetic mean CO (ppm)	0.23 to 0.4	0.23 to 0.4	0.06 to 0.28	0.23 to 0.35	0.31 to 0.47
Geometric Mean CO (ppm)	0.06	0.07	0.07	0.07	0.08
90% confidence interval on geometric mean CO (ppm)	0.05 to 0.08	0.06 to 0.08	0.04 to 0.09	0.06 to 0.08	0.07 to 0.09
Number of Homes w CO Reads	530	699	129	786	786

4.2.3. Room Ambient Test #2

Table 4-2 summarizes the results of Room Ambient Test #2 for all rooms with combustion appliances. The tests were conducted with appliances operating. As indicated in Table 4-2:

- The arithmetic mean of readings for individual room types varies from 0.59 ppm in the garage to 3.96 ppm in the kitchen. The arithmetic mean of the maximum reading was 3.24 ppm.
- The geometric mean of readings for individual room types varies from 0.13 ppm in the garage to 1.26 ppm in the kitchen. The geometric mean of the maximum reading was 0.83 ppm.
- The arithmetic and geometric means for the kitchen readings exceed the comparable overall means of the maximum across rooms because kitchen appliances tend to emit the highest levels of CO, but not all households have gas appliances in the kitchen.

- In the kitchen, 8.35% of the homes had reads at or above 10 ppm, while in the garage, 0.00% of the homes had reads at or above 10 ppm. Approximately 6.30% of the homes had one or more maximum readings of 10 ppm or higher.
- Roughly 0.33% of the homes had kitchen readings at or above the threshold value of 35 ppm.

Table 4-2: Results of Room Ambient Test #2 for All Rooms with Combustion Appliances

	Readings by Room Groups				
CO Read in ppm	**Kitchen**	**Other Conditioned Rooms**	**Garage**	**Average across Rooms**	**Maximum across Rooms**
<0	1.33%	2.62%	7.29%	2.38%	1.90%
0	30.46%	47.13%	62.58%	37.73%	37.21%
1	3.39%	8.12%	14.22%	10.54%	6.42%
2	8.32%	10.34%	6.05%	12.11%	9.33%
3	12.33%	9.82%	4.89%	10.94%	10.72%
4	10.92%	8.27%	2.17%	8.68%	9.28%
5	8.29%	3.68%	0.62%	4.23%	5.76%
6	5.50%	3.29%	0.00%	4.02%	4.89%
7	3.99%	1.68%	0.62%	2.34%	2.97%
8	4.30%	1.04%	0.62%	2.09%	3.25%
9	2.82%	1.10%	0.93%	0.97%	1.98%
10-19	6.94%	2.55%	0.00%	3.25%	5.15%
20-34	1.09%	0.24%	0.00%	0.38%	0.83%
35+	**0.33%**	**0.12%**	**0.00%**	**0.33%**	**0.33%**
10+	**8.35%**	**2.92%**	**0.00%**	**3.96%**	**6.30%**
Arithmetic Mean CO (ppm)	3.96	1.94	0.59	2.43	3.24
90% confidence interval on arithmetic mean CO (ppm)	3.56 to 4.36	1.72 to 2.15	0.36 to 0.81	2.2 to 2.67	2.89 to 3.59
Geometric Mean CO (ppm)	1.26	0.45	0.13	0.68	0.83
90% confidence interval on geometric mean CO (ppm)	1.09 to 1.45	0.39 to 0.52	0.09 to 0.19	0.6 to 0.76	0.73 to 0.94
Number of Homes w CO Reads	529	697	129	785	785

Table 4-3 presents the results of the Room Ambient Test # 2 for just those rooms with combustion space heating and/or water heating appliances. These readings are net of outdoor CO. These results are presented in order to facilitate a comparison of this test with the Appliance Ambient Test, which is conducted only for rooms with combustion space heating and/or water heating appliances.[4]

Table 4-3: Results of Room Ambient Test #2 for Rooms with Combustion Space Heating and/or Water Heating Appliances

	Readings by Room Groups				
CO Read in ppm	**Kitchen**	**Other Conditioned Rooms**	**Garage**	**Average across Rooms**	**Maximum across Rooms**
<0	1.06%	2.68%	7.36%	2.78%	2.38%
0	39.18%	47.60%	63.22%	45.99%	45.75%
1	1.60%	8.13%	13.34%	9.52%	7.34%
2	3.20%	10.08%	6.11%	11.60%	9.23%
3	16.14%	9.92%	4.94%	9.79%	10.57%
4	8.51%	8.21%	2.19%	7.87%	9.05%
5	13.48%	3.70%	0.63%	3.31%	4.45%
6	3.20%	3.18%	0.00%	2.95%	3.79%
7	1.74%	1.70%	0.63%	1.45%	1.41%
8	1.07%	0.87%	0.63%	1.31%	1.04%
9	2.80%	1.25%	0.94%	1.27%	1.35%
10-19	4.27%	2.30%	0.00%	1.52%	2.89%
20-34	2.67%	0.25%	0.00%	0.52%	0.52%
35+	**1.07%**	**0.12%**	**0.00%**	**0.12%**	**0.23%**
10+	**8.01%**	**2.67%**	**0.00%**	**2.16%**	**3.64%**
Arithmetic Mean CO (ppm)	3.85	1.91	0.58	1.89	2.27
90% confidence interval on arithmetic mean CO (ppm)	2.61 to 5.09	1.69 to 2.13	0.35 to 0.81	1.67 to 2.1	1.97 to 2.58
Geometric Mean CO (ppm)	0.92	0.44	0.13	0.45	0.51
90% confidence interval on geometric mean CO (ppm)	0.61 to 1.37	0.38 to 0.51	0.09 to 0.18	0.39 to 0.51	0.45 to 0.58
Number of Homes with CO Reads	81	681	128	731	731

4 Again, we note that the overall average of the maximum CO across all rooms is lower than the average kitchen CO read. This apparent anomaly is caused by the fact that kitchen reads tend to be relatively high, but relatively few homes have water heaters or space heaters located in the kitchen.

4.3 Appliance Ambient CO Levels

Appliance ambient tests were conducted on furnaces, space heaters, and water heaters. These tests were conducted under winter conditions, defined as follows: all entrance doors and windows closed; fireplace dampers closed; interior doors open except to appliance enclosures; and exhaust fans and air handlers off.[5] Prior to taking the appliance ambient CO readings, appliances were allowed to operate for at least five minutes. For forced air units, the reading was taken inside the supply register nearest the furnace. For other covered appliances, readings were obtained above the heat exchanger.

Tests were conducted with Testo and Dräger instruments both before and after weatherization. As was the case for room ambients, the focus here is exclusively upon the Dräger reads conducted prior to weatherization. The results of the appliance ambient tests are shown in Table 4-4 and are summarized below:

- Overall arithmetic average readings vary from 0.37 ppm to 3.08 ppm, depending upon the room. The arithmetic average maximum value across all rooms was 1.90 ppm.
- Geometric means vary from 0.08 ppm to 0.61 ppm, and the geometric mean of the overall maximum across rooms is 0.39.[6]
- Roughly 3.22% of all homes with appliance ambient readings had at least one reading in excess of 10 ppm.
- Approximately 0.19% of all homes had at least one appliance ambient reading at or above the threshold of 35 ppm.
- In general, Appliance Ambient test CO levels are slightly lower than Room Ambient Test 2 levels for rooms with combustion space heating and/or water heating appliances (Table 4-3).

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5 Appliance ambient measurements were also to be taken under what is called "worst case" conditions for homes with forced air furnaces and/or natural draft combustion appliances, and for which default worst case conditions and actual worst case conditions differed. However, these tests were applied in only two homes, and are consequently ignored in this report.

6 Note that the arithmetic and geometric average of the highest read is lower than the respective average of the kitchen read because the maximum across rooms was computed using only those rooms with the subject appliances (water heaters or space heaters), and not all homes had combustion appliances in the kitchen.

Table 4-4: Results of Appliance Ambient Test

	Readings by Room Groups				
CO Read in ppm	**Kitchen**	**Other Conditioned Rooms**	**Garage**	**Average across Rooms**	**Maximum across Rooms**
<0	2.13%	4.94%	8.93%	5.16%	4.03%
0	46.12%	51.22%	69.73%	50.40%	50.31%
1	4.79%	6.06%	8.78%	8.00%	6.02%
2	5.86%	9.64%	7.45%	10.09%	9.21%
3	10.13%	8.92%	2.27%	8.33%	8.73%
4	6.39%	6.53%	0.63%	6.12%	7.25%
5	9.21%	4.47%	0.63%	4.22%	4.48%
6	1.07%	2.27%	0.00%	1.80%	2.85%
7	0.00%	2.14%	0.00%	1.76%	1.68%
8	3.87%	0.83%	1.57%	1.31%	1.36%
9	1.74%	0.91%	0.00%	0.83%	0.86%
10-19	6.94%	1.83%	0.00%	1.76%	2.80%
20-34	0.00%	0.25%	0.00%	0.23%	0.23%
35+	**1.74%**	**0.00%**	**0.00%**	**0.00%**	**0.19%**
10+	**8.68%**	**2.08%**	**0.00%**	**1.99%**	**3.22%**
Arithmetic Average CO (ppm)	3.08	1.62	0.37	1.57	1.90
90% confidence interval on arithmetic average CO (ppm)	2.04 to 4.12	1.44 to 1.80	0.17 to 0.56	1.39 to 1.74	1.69 to 2.11
Geometric Average CO (ppm)	0.61	0.35	0.08	0.34	0.39
90% confidence interval on geometric average CO (ppm)	0.39 to 0.92	0.30 to 0.40	0.05 to 0.12	0.3 to 0.39	0.34 to 0.45
Number of Homes with CO Reads	81	680	128	730	730

4.4 Comparison of NGAT Results with Results of PG&E CO Testing

4.4.1. Introduction

As mentioned in Section 1, the Team's consultants also conducted an analysis of CO levels found by PG&E in the course of conducting combustion appliance safety (CAS) testing in its 2001 LIEE Program. This section compares the results of the NGAT tests with comparable tests conducted by PG&E prior to weatherization.

PG&E conducts ambient CO tests under four conditions:

- ***Condition 1:*** Appliances off, with windows closed (winter conditions) and measurement taken in the center of the living area. Condition 1 does not correspond to any of the setups used in the NGAT tests.

- ***Condition 2:*** Heating system operating, with windows closed (winter conditions) and measurement taken in the center of the living area. Condition 2 is similar to the NGAT Room Ambient Test #2, except that only the heating system is operating.
- ***Condition 3:*** Heating system operating, with windows closed (winter conditions) and measurement taken close to the heater (inside the first supply register closest to the supply plenum for forced air systems). Condition 3 is similar to the NGAT Appliance Ambient Test, except that only the heating system is operating.
- ***Condition 4:*** Heating system operating, with windows closed (winter conditions) and measurement taken close to the second heater (used only in case of multiple heaters). Condition 4 is similar to the NGAT Appliance Ambient Test, except that only the space heaters are operating.

Comparisons of PG&E tests under conditions 2 and 3 with the NGAT Room Ambient Test #2 and the NGAT Appliance Ambient Test are presented in Table 4-5. As shown, the distributions of the NGAT ambients and the PG&E ambients are similar, except that the latter distributions tend to have more concentration in the 1-2 ppm range. The arithmetic means of the PG&E tests are somewhat lower than those of the NGAT readings, but the geometric means are very similar. The small differences in these distributions may be attributable to two differences: First, all appliances were operating for the two NGAT tests, whereas only the space heating appliances were operating at the time of the Condition 1 and Condition 2 PG&E tests. Second, the NGAT ambient readings were taken in all rooms with combustion appliances, whereas the PG&E Condition 2 readings were taken in the middle of the living space and Condition 3 readings were taken only at the supply register closest to the supply plenum. As shown earlier, NGAT room and appliance ambients tended to be higher in kitchens than in other rooms. Recognizing these differences, we would conclude that the NGAT findings with respect to ambient CO levels are very consistent with those associated with the 2001 PG&E program.

Table 4-5: Comparisons of NGAT Tests and PG&E Tests

	NGAT Tests		PG&E CO Tests	
	Room Ambient Test #2 (average across rooms)	Appliance Ambient Test (average across rooms)	Condition 2	Condition 3
<0	2.78%	5.16%	.01%	0.01%
0	45.99%	50.40%	43.58%	43.37%
1	9.52%	8.00%	36.82%	36.94%
2	11.60%	10.09%	12.38%	12.27%
3	9.79%	8.33%	3.97%	4.05%
4	7.87%	6.12%	1.52%	1.50%
5	3.31%	4.22%	0.69%	0.69%
6	2.95%	1.80%	0.41%	0.41%
7	1.45%	1.76%	0.27%	0.28%
8	1.31%	1.31%	0.18%	0.18%
9	1.27%	0.83%	0.07%	0.07%
10-19	1.52%	1.76%	0.08%	0.10%
20-34	0.52%	0.23%	0.03%	0.06%
35+	**0.12%**	**0.00%**	**0.00%**	**0.06%**
10+	**2.16%**	**1.99%**	**0.10%**	**0.22%**
Arithmetic Mean CO (ppm)	1.89	1.57	0.90%	0.96
90% confidence interval on arithmetic mean CO (ppm)	1.67 to 2.1	1.39 to 1.74	0.88 to 0.92	0.93 to 0.99
Geometric Mean CO (ppm)	0.45	0.34	0.36	0.36
90% confidence interval on geometric mean CO (ppm)	0.39 to 0.51	0.3 to 0.39	0.35 to 0.36	0.35 to 0.37
Number of Homes w CO Reads	731	730	15,425	15,294

4.5 Summary and Conclusions

This section addresses two specific research questions:

- In low-income homes in California, what are the pre-existing levels of CO in indoor ambient air and in the proximity of specific appliances?
- What is the frequency and duration of elevated CO levels?

In the tables presented so far, several types of ambient CO readings were presented. In general, readings varied across rooms and types of test. In order to analyze this information further, the highest ambient reading for any room and type of test has been determined, and the distributions of these highest readings have been summarized. Table 4-6 depicts the results of this exercise. The last column of the table is the distribution of the maximum of all readings. This is based on the highest reading from all ambient tests, regardless of the room and the type of test.[7]

Table 4-6: Distribution of Highest Net Reads for Ambient Tests

CO Read in PPM	Test #1 Room Ambient	Test #2 Room Ambient	Appliance Ambient	Maximum Across All Tests
Percent with Ambient CO at or above the action level of 10 ppm	0.16%	6.30%	3.22%	**7.1%**
90% confidence interval on Percent with Ambient CO at or above the action level of 10 ppm	-0.07% - 0.39%	4.99% - 7.79%	2.12% - 4.32%	5.59% - 8.61%
Percent with Ambient CO at or above the threshold level of 35 ppm	0.00%	0.33%	0.19%	**0.50%**
90% confidence interval on Percent with Ambient CO at or above the threshold level of 35 ppm	-	-0.01% - 0.67%	-0.07% - 0.45%	0.09% - 0.91%
Arithmetic Average CO (ppm)	0.38	3.239	1.90	3.51
90% confidence interval on arithmetic average CO (ppm)	0.31 to 0.46	2.89 to 3.59	1.69 to 2.11	3.14 to 3.87
Geometric Average CO (ppm)	0.08	0.83	0.39	0.96
90% confidence interval on geometric average CO (ppm)	0.07 to 0.09	0.73 to 0.94	0.34 to 0.45	0.85 to 1.08
Number of Homes w CO Reads	786	785	730	786

Two conclusions may be drawn from the summary statistics shown in the final column.

- First, as shown, 7.1% of all homes had one or more reading at or above the action level of 10 ppm.[8] It should be kept in mind that this is a weighted percentage, and should be interpreted as indicating that 7.1% of the homes in the low income population would have one or more ambient readings above 10 ppm. To illustrate, in a population of 1,000 homes, 71 (on average) would have at least one ambient reading at or above 10 ppm and would require further investigation of CO sources in the home. There were 55 such homes in the statewide NGAT sample.
- Second, 0.50% of all homes had one or mere reading at or above the threshold level of 35 ppm.[9] That is, in a population of 1,000 homes, five homes (on average) would have an ambient reading of 35 ppm or greater. In the statewide NGAT sample, there were four such homes.

[7] Table 4-6 was also developed for the 29 homes in the sample with at least one propane appliance. About 3.6% of these homes had ambient CO at or above 10 ppm; none had ambient CO at or above 35 ppm.

[8] It should be noted that 7.7% would have had ambient CO above the action level had we used gross ambient CO rather than net.

[9] The use of gross rather than net ambient CO would not have affected this conclusion.

5

Pre-Existing Flue CO Levels

5.1 Introduction

In the course of the NGAT survey, additional CO tests were performed in appliance flues (exhaust gas vent pipes). These tests were conducted under default worst case conditions, defined as follows: exterior doors and windows closed, fireplace damper closed; some interior doors open, some closed (see NGAT Procedure #5); fans and exhaust devices turned on; with appliances operating (appliances were permitted to warm up prior to the tests).[1] Furthermore, appliance flue tests were conducted for most (but not all) appliances under two alternative conditions: as-measured and air-free. Flue tests were taken with the Testo instrument, which is designed for use in high-CO environments.

Appliance flue CO tests were conducted as part of this statewide LIEE programs survey in order to test the role of such tests in detecting potentially hazardous levels of CO. At present, one of the participating utilities, PG&E, conducts exhaust flue CO tests as a standard procedure, while the other natural gas utilities conduct this type of test as part of their regular LIEE program testing procedures only if ambient appliance CO tests indicate that a potential problem exists in a particular customer's home.

5.2 Results of Appliance Exhaust Flue CO Tests

5.2.1. Testing Protocols

The following locations were selected for Testo measurements by type of unit:

- ***Natural-draft furnaces/heaters*:** Inside each exhaust port before dilution air. When there was a baffle present, CO was checked on both sides of the baffle.
- ***Induced-draft open combustion units*:** Through a hole drilled in the flue/vent pipe or inside the flue/vent termination on the roof.
- ***Direct vent units*:** Inside the flue termination.
- ***Water heaters:*** Inside the center tube on both sides of the baffle.

[1] Flue tests were also to have been conducted under actual worst case conditions, defined in terms of air handler operation, exhaust fan operation, and positions of interior doors. Insofar as only two homes received such tests, these results will be ignored here.

- ***Clothes dryers:*** Inside vent termination, or in the lint screen cavity if located on top of the dryer.
- ***Gas logs:*** Inside the top edge of the fireplace opening.
- ***Gas fireplace units:*** In the dilution air intake below the dilution air inlet.
- ***Cook top burners:*** 12" above the open flame with grate in place.
- ***Griddles:*** Inside the port opening with griddle in place.
- ***Ovens and Broilers:*** Inside the oven exhaust termination on top of stove.

5.2.2. Flue CO for Space Heating Appliances

For space heating appliances, flue tests were performed under open (no) door conditions and sometimes under closed door conditions. Open (no) door tests were administered on all appliances. For those appliances in enclosures, enclosure doors were left open. Closed door tests were administered for forced air units in enclosures with enclosure doors closed. Results of both open-door and closed-door space heating appliance flue tests are presented in Table 5-1 through Table 5-3. Note that if more than one read of a particular kind is recorded for a home, the maximum read of that type of test is used to develop the distributions. Additionally, there were some cases where air free readings were missing, presumably because of Testo equipment malfunctions. In these cases, air-free values were inferred from the as-measured readings using the ratio of air-free to as-measured reads for all homes with both readings. Results are discussed below.

<u>Natural-Draft Furnaces/Heaters</u>

First for consideration are natural-draft furnaces/heaters. As shown in Table 5-1, the overall arithmetic average of the maximum open (no) door CO reads for these heating appliances ranges from 87 ppm for as-measured to 140 ppm for air-free. However, 4.44% of all homes (22 homes in the sample) exhibited open (or no) door air-free flue readings above the ANSI standard of 400 ppm. Roughly the same percentages exceeded the as-measured standards used by the utilities (100 ppm and 275 ppm). Moreover, 2.25% of the homes (12 in the sample) demonstrated air-free readings in excess of 2,000 ppm. Due to the highly skewed nature of the data, the geometric average was also calculated. The geometric average of maximum open (no) door CO reads for natural-draft heating appliances is 7.90 ppm for as-measured and 16.74 ppm for air-free.

Results for the closed door natural draft space heating appliance CO flue tests under default worst-case conditions are also shown in Table 5-1. These tests were performed in relatively few homes, because they apply only to homes with forced air furnaces in closets. As per the NGAT protocols, if more than one read is recorded for a home, the maximum read was used to develop the distributions. Average closed door arithmetic averages range from 123 ppm to

238 ppm, depending upon the specific test. One home (depending on the test utilized) had CO in excess of 2000 ppm. That one home was the only case found to exceed the ANSI and utility standards for space heating flue CO.

Table 5-1: Maximum Flue CO Reads for Natural Draft Furnaces/Heaters

	Open (No) Door Tests				Closed Door Tests			
	As-Measured		Air Free		As-Measured		Air Free	
CO Level	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd
0-49	90.07%	422	78.83%	370	97.07%	25	88.24%	23
50-99	5.13%	23	9.73%	46	0.00%	0	4.41%	1
100-149	0.29%	1	3.84%	17	0.00%	0	0.00%	0
150-199	0.45%	2	1.34%	6	0.00%	0	4.41%	1
200-249	0.18%	1	0.56%	2	0.00%	0	0.00%	0
250-299	0.18%	1	0.74%	3	0.00%	0	0.00%	0
300-349	0.00%	0	0.53%	3	0.00%	0	0.00%	0
350-399	0.47%	2	0.00%	0	0.00%	0	0.00%	0
400-449	0.00%	0	0.00%	0	0.00%	0	0.00%	0
450-499	0.18%	1	0.56%	2	0.00%	0	0.00%	0
500-999	0.45%	2	1.27%	6	0.00%	0	0.00%	0
1000-1499	0.71%	4	0.18%	1	0.00%	0	0.00%	0
1500-1999	0.00%	0	0.18%	1	0.00%	0	0.00%	0
2000+	1.89%	10	2.25%	12	2.93%	1	2.93%	1
Thresholds								
100+ As Meas	4.79%	24	-	-	2.93%	1	-	-
275+ As Meas	3.70%	19	-	-	2.93%	1	-	-
400+ Air Free	-	-	4.44%	22	-	-	2.93%	1
Arithmetic Average CO	87.06	0	140.32	0	123.52	0	237.71	0
90% Confidence Interval	52.02 to 122.1	0	89.95 to 190.7	0	-81.88 to 328.92	0	-157.33 to 632.75	0
Geometric Average CO	7.90	0	16.74	0	11.69	0	21.59	0
90% Confidence Interval	6.92 to 9.01	0	14.62 to 19.18	0	7.13 to 19.11	0	12.93 to 36.02	0
No. With CO Reads	469	469	469	469	26	26	26	26

Induced-Draft Open Combustion Units

Maximum flue CO reads for induced draft open combustion space heaters are depicted in Table 5-2. As shown, arithmetic averages for open (no) door tests range from 60 ppm for as-measured to 83 ppm for air-free. Geometric averages for these two readings are 6.99 ppm and 14.37 ppm, respectively. One home in the survey was found to have an open (no) door flue CO reading above the ANSI standard of 400 ppm. That same home exceeded the utility standards of 100 ppm and 275 ppm. These standards were discussed in Section 3. Only eight homes with induced draft furnaces required closed door tests, and all air-free readings were well below the ANSI standard.

Table 5-2: Maximum Flue CO Reads for Induced Draft Furnaces/Heaters

	Open (No) Door Tests				Closed Door Tests			
	As-Measured		Air Free		As-Measured		Air Free	
CO Level	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd
0-49	94.96%	70	81.76%	61	100.00%	8	89.74%	7
50-99	3.36%	3	7.44%	5	0.00%	0	0.00%	0
100-149	0.00%	0	4.63%	3	0.00%	0	10.26%	1
150-199	0.00%	0	0.00%	0	0.00%	0	0.00%	0
200-249	0.00%	0	3.36%	3	0.00%	0	0.00%	0
250-299	0.00%	0	1.12%	1	0.00%	0	0.00%	0
300-349	0.00%	0	0.00%	0	0.00%	0	0.00%	0
350-399	0.00%	0	0.00%	0	0.00%	0	0.00%	0
400-449	0.00%	0	0.00%	0	0.00%	0	0.00%	0
450-499	0.00%	0	0.00%	0	0.00%	0	0.00%	0
500-999	0.00%	0	0.00%	0	0.00%	0	0.00%	0
1000-1499	0.00%	0	0.00%	0	0.00%	0	0.00%	0
1500-1999	0.00%	0	0.00%	0	0.00%	0	0.00%	0
2000+	1.69%	1	1.69%	1	0.00%	0	0.00%	0
Thresholds								
100+ As Meas	1.69%	1	-	-	0.00%	0	-	-
275+ As Meas	1.69%	1	-	-	0.00%	0	-	-
400+ Air Free	-	-	1.69%	1	-	-	0.00%	0
Arithmetic Average CO	59.98		83.72		9.58		23.75	
90% Confidence Interval	-11.18 to 131.14		8.22 to 159.22		4.57 to 14.59		-8.49 to 41.83	
Geometric Average CO	6.99		14.37		6.04		12.40	
90% Confidence Interval	5.23 to 9.32		10.4 to 19.84		-0.06 to 919.58		5.93 to 25.81	
No. with CO Reads	74	74	74	74	8	8	8	8

Direct-Vent Units

Table 5-3 presents the flue CO readings taken for direct-vent space heaters. Arithmetic average flue CO readings for the closed door tests were 13.55 ppm and 30.22 ppm, respectively, for the as-measured and air-free tests. The corresponding geometric averages were 4.35 ppm and 8.67 ppm, respectively. None of these homes had flue CO in excess of the ANSI standard. Two (3.12%) of the homes had as-measured CO above PG&E's in-house utility standard of 100 ppm.

Table 5-3: Maximum Flue CO Reads for Closed Combustion Units

	Open (No) Door Tests				Closed Door Tests			
	As-Measured		Air Free		As-Measured		Air Free	
CO Level	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd
0-49	91.20%	50	85.53%	47	50.00%	1	50.00%	1
50-99	5.68%	3	5.67%	3	50.00%	1	0.00%	0
100-149	1.56%	1	3.13%	2	0.00%	0	50.00%	1
150-199	0.00%	0	1.56%	1	0.00%	0	0.00%	0
200-249	1.56%	1	0.00%	0	0.00%	0	0.00%	0
250-299	0.00%	0	2.55%	1	0.00%	0	0.00%	0
300-349	0.00%	0	1.56%	1	0.00%	0	0.00%	0
350-399	0.00%	0	0.00%	0	0.00%	0	0.00%	0
400-449	0.00%	0	0.00%	0	0.00%	0	0.00%	0
450-499	0.00%	0	0.00%	0	0.00%	0	0.00%	0
500-999	0.00%	0	0.00%	0	0.00%	0	0.00%	0
1000-1499	0.00%	0	0.00%	0	0.00%	0	0.00%	0
1500-1999	0.00%	0	0.00%	0	0.00%	0	0.00%	0
2000+	0.00%	0	0.00%	0	0.00%	0	0.00%	0
Thresholds								
100+ As Meas	3.12%	2	-	-	0.00%	0	-	-
275+ As Meas	0.00%	0	-	-	0.00%	0	-	-
400+ Air Free	-	-	0.00%	0	-	-	0.00%	0
Arithmetic Average CO	13.55	-	30.22	-	31	-	68.33	-
90% Confidence Interval	-0.98 to 28.09	-	15.69 to 44.76	-	-10.13 to 72.13	-	-11.17 to 147.84	-
Geometric Average CO	4.35	-	8.67	-	18.40	-	48.32	-
90% Confidence Interval	3.12 to 6.04	-	6.04 to 12.43	-	2.89 to 114.6	-	11.29 to 205.84	-
No. With CO Reads	55	55	55	55	2	2	2	2

5.2.3. Exhaust Flue CO Levels for Water Heaters

Water heater flue CO tests were also conducted under enclosure open (no) door and closed door conditions. The results of these tests are contained in Table 5-4. As shown, overall arithmetic average open (no) door CO levels range from 30.17 to 38.56. Fourteen homes (with a weighted percentage of 1.94%) had open (no) door air-free readings in excess of the ANSI standard of 200 ppm. Roughly the same number of open (no) door readings (with slightly different weighted percentages) failed the utility as-measured standards. None of the closed door readings exceeded the ANSI standard.

Table 5-4: Distribution of Maximum Flue CO Reads for Water Heaters

	Open (No) Door Tests				Closed Door Tests			
	As-Measured		Air Free		As-Measured		Air Free	
CO Level	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd	% weighted	# unwtd
0-49	96.72%	703	94.28%	690	98.29%	141	96.64%	139
50-99	1.33%	11	2.31%	15	1.14%	2	2.17%	3
100-149	0.12%	1	0.69%	6	0.57%	1	1.19%	2
150-199	0.35%	3	0.41%	3	0.00%	0	0.00%	0
200-249	0.71%	5	0.62%	4	0.00%	0	0.00%	0
250-299	0.17%	1	0.41%	3	0.00%	0	0.00%	0
300-349	0.00%	0	0.14%	1	0.00%	0	0.00%	0
350-399	0.17%	1	0.43%	2	0.00%	0	0.00%	0
400-449	0.00%	0	0.00%	0	0.00%	0	0.00%	0
450-499	0.00%	0	0.00%	0	0.00%	0	0.00%	0
500-999	0.00%	0	0.21%	1	0.00%	0	0.00%	0
1000-1499	0.00%	0	0.00%	0	0.00%	0	0.00%	0
1500-1999	0.12%	1	0.00%	0	0.00%	0	0.00%	0
2000+	0.31%	2	0.50%	3	0.00%	0	0.00%	0
Thresholds								
100+ As Meas	1.94%	14	-	-	0.57%	1	-	-
125+ As Meas	1.83%	13	-	-	0.00%	0	-	-
200 Air Free	-	-	2.31%	14	-	-	0.00%	0
Arithmetic Average CO	30.17		38.56		6.30		11.39	
90% Confidence Interval	6.76 to 53.58		17.68 to 59.44		4.7 to 7.9		8.99 to 13.78	
Geometric Average CO	2.52		7.45		3.20		7.099416 636	
90% Confidence Interval	2.36 to 2.91		6.98 to 8.17		2.79 to 3.9		6.36 to 8.14	
No. with CO Reads	728	728	728	728	144	144	144	144

5.2.4. Exhaust CO Levels for Ovens, Broilers and Cook Tops

Exhaust/flue CO test were conducted on all kitchen appliances; however cook tops and most ranges were physically constructed in such a manner that it was virtually impossible to sample flue gases before dilution air. For cook tops measurements were taken 12" above the cook top and was labeled as a flue measurement. Flue CO test were conducted on all ovens; however when units were manufactured using a configuration where the byproducts of combustion were not channeled into a single exhaust port (to the interior or exterior) it was virtually impossible to test byproducts of combustion before dilution air entered the exhaust stream. When possible, tests were conducted inside exhaust terminations or as near to the oven exhaust as possible. In the case of built-in units, the probe was extended inward as far as possible and the test labeled as a flue test. While we will continue to refer to these tests as exhaust/flue tests, we note here that they are in many respects more similar to appliance ambient tests.

Both as-measured and air-free readings were taken for ovens and broilers. The distributions of exhaust CO levels in these kitchen appliances are presented in Table 5-5 through Table 5-7. As indicated in Table 5-5, exhaust CO readings for ovens were 92 and 343 ppm for as-measured and air-free readings respectively, while the geometric average was 59 and 231 ppm respectively. Over 26% of all homes had as-measured exhaust CO levels above the ANSI standard of 400 ppm.

Table 5-5: Maximum Exhaust CO Reads for Ovens

	As Measured		Air Free	
CO Level	**% weighted**	**# unweighted**	**% weighted**	**# unweighted**
0-49	42.36%	241	5.83%	31
50-99	31.07%	183	12.31%	71
100-149	11.11%	62	13.20%	76
150-199	5.53%	33	11.78%	69
200-249	4.57%	25	13.09%	75
250-299	1.82%	10	8.18%	49
300-349	0.64%	3	5.84%	33
350-399	0.45%	3	3.39%	21
400-449	0.75%	4	4.33%	25
450-499	0.30%	2	2.19%	13
500-999	1.16%	6	14.52%	81
1000-1499	0.24%	1	2.79%	15
1500-1999	0.00%	0	1.78%	10
2000+	0.00%	0	0.75%	4
Threshold				
100+ As Measured	26.58%	149	-	-
225+ As Measured	9.93%	54	-	-
400+ Air Free	-	-	26.36%	148
Arithmetic Average CO	91.98		342.69	
90% Confidence Interval on Arithmetic Average	84.29 to 99.66		316.65 to 368.74	
Geometric Average CO	58.57		224.43	
90% Confidence Interval on Geometric Average	54.84 to 62.56		210.48 to 239.3	
No. with CO Reads	573	573	573	573

As indicated in Table 5-6, maximum as-measured exhaust CO readings for broilers were found to be in the vicinity of 168 ppm, while average air-free levels exceeded 521 ppm. Roughly 28% of all homes registered air-free exhaust CO readings at or above the ANSI standard of 400 ppm.

Table 5-6: Maximum Exhaust CO Reads for Broilers

	As Measured		Air Free	
CO Level	**% weighted**	**# unweighted**	**% weighted**	**# unweighted**
0-49	41.49%	27	4.49%	3
50-99	31.73%	21	15.07%	9
100-149	8.33%	6	10.87%	8
150-199	5.13%	3	12.18%	9
200-249	3.37%	2	9.94%	6
250-299	1.93%	1	8.82%	5
300-349	0.00%	0	6.74%	4
350-399	2.09%	1	3.83%	3
400-449	1.28%	1	5.12%	4
450-499	0.00%	0	7.05%	4
500-999	2.09%	1	5.93%	4
1000-1499	0.00%	0	7.38%	4
1500-1999	0.00%	0	0.00%	0
2000+	2.57%	2	2.57%	2
Threshold				
100+ As Measured	26.78%	17	-	-
225+ As Measured	12.04%	7	-	-
400+ Air Free	-	-	28.05%	18
Arithmetic Average CO	167.99		521.32	
90% Confidence Interval on Arithmetic Average	71.96 to 264.02		260.38 to 782.26	
Geometric Average CO	67.46		246.80	
90% Confidence Interval on Geometric Average	54.1 to 84.36		200.35 to 304.27	
No. with CO Reads	65	65	65	65

Only as-measured readings (which were taken 12 inches above the open flame) are relevant to cook tops. As shown in Table 5-7, maximum CO levels average approximately 21 ppm. Of these homes, 167 (25.18% on a weighed basis) had cook top CO readings of 25 ppm or greater (the SoCalGas and SDG&E standard), while seven (1.06%) exceeded PG&E's as-measured standard of 100 ppm.

Table 5-7: Maximum CO Reads for Cook Tops

	As Measured	
CO Level	**% weighted**	**# unweighted**
0-49	92.83%	611
50-99	6.11%	41
100-149	0.73%	5
150-199	0.20%	1
200-249	0.00%	0
250-299	0.00%	0
300-349	0.00%	0
350-399	0.13%	1
400-449	0.00%	0
450-499	0.00%	0
500-999	0.00%	0
1000-1499	0.00%	0
1500-1999	0.00%	0
2000+	0.00%	0
Thresholds		
25+ As Measured	25.18%	167
100+ As Measured	1.06%	7
Arithmetic Average CO	21.25	
90% Confidence Interval on Arithmetic Average	19.75 to 22.75	
Geometric Average CO	14.41	
90% Confidence Interval on Geometric Average	13.63 to 15.45	
No. with CO Reads	659	659

5.2.5. Exhaust Flue CO Reads for Natural Gas Dryers

Flue CO reads for dryers are shown in Table 5-8. No air-free readings were taken for dryers, and the as-measured readings cannot be compared against ANSI standards. However, it may be noted that none of the dryer readings exceeded the utility thresholds for as-measured exhaust flue CO levels.

Table 5-8: Maximum Flue CO Reads for Dryers

	In the Lint Screen		In the Exhaust	
CO Level	**% weighted**	**# unweighted**	**% weighted**	**# unweighted**
0-49	100.00%	56	100.00%	250
50-99	0.00%	0	0.00%	0
100-149	0.00%	0	0.00%	0
150-199	0.00%	0	0.00%	0
200-249	0.00%	0	0.00%	0
250-299	0.00%	0	0.00%	0
300-349	0.00%	0	0.00%	0
350-399	0.00%	0	0.00%	0
400-449	0.00%	0	0.00%	0
450-499	0.00%	0	0.00%	0
500-999	0.00%	0	0.00%	0
1000-1499	0.00%	0	0.00%	0
1500-1999	0.00%	0	0.00%	0
2000+	0.00%	0	0.00%	0
Thresholds				
100+ As Measured	0.00%	0	0.00%	0
275+ As Measured	0.00%	0	0.00%	0
Arithmetic Average CO	4.26		5.12	
90% Confidence Interval on Arithmetic Average	3.85 to 5.14		4.7 to 5.53	
Geometric Average CO	2.09		3.06	
90% Confidence Interval on Geometric Average	1.46 to 2.98		2.65 to 2.42	
No. with CO Reads	56	56	250	250

5.2.6. Exhaust Flue CO Levels for Gas Logs

Table 5-9 presents Flue CO values for gas logs. The arithmetic average of readings was slightly over 20 ppm, and the geometric average was just under 6 ppm. Between 3.11% and 24.12% of the reads exceeded the as-measured threshold values established by the utilities.

Table 5-9: Maximum Flue CO Reads for Gas Logs

	As Measured	
CO Level	**% weighted**	**# unweighted**
0-49	87.15%	22
50-99	9.74%	2
100-149	3.11%	1
150-199	0.00%	0
200-249	0.00%	0
250-299	0.00%	0
300-349	0.00%	0
350-399	0.00%	0
400-449	0.00%	0
450-499	0.00%	0
500-999	0.00%	0
1000-1499	0.00%	0
1500-1999	0.00%	0
2000+	0.00%	0
Thresholds		
25+ As Measured	24.12%	6
100+ As Measured	3.11%	1
Arithmetic Average CO	20.22	
90% Confidence Interval on Arithmetic Average	11.58 to 28.86	
Geometric Average CO	5.94	
90% Confidence Interval on Geometric Average	2.85 to 12.3	
No. with CO Reads	25	25

5.3 Relationship of NGAT Flue/Exhaust CO Results to PG&E Results

Table 5-10 compares the levels of flue/exhaust CO estimated based on the NGAT study to the comparable levels derived from the analysis of PG&E PY 2001 data. The overall averages of space heating related CO readings are used for both datasets in order to maintain comparability. As shown, the results of the two analyses are reasonably comparable. The main difference is that the average levels of exhaust CO for kitchen appliances are higher under the NGAT study than shown with the analysis of PG&E data. This could be attributable to differences in specific protocols and/or testing instruments used in the two studies.

Table 5-10: Comparison of Flue/Exhaust CO Levels for NGAT and PG&E Analysis

	NGAT Study (As-Measured)		Analysis of PG&E Data	
Appliance	**Arithmetic Average (ppm)**	**% above 100 ppm**	**Arithmetic Average (ppm)**	**% above 100 ppm**
Space Heating	76.95	4.25%	50.06	3.74%
Water Heating	30.17	1.94%	18.61	1.56%
Ovens	91.98	26.58%	90.37	13.28%
Broilers	167.99	26.78%	92.70	6.71%
Cooktops	21.25	1.06%	10.13	0.22%
Dryers	5.12	0.00%	3.04	0.04%
Gas Fireplaces	20.22	3.11%	40.37	3.83%

5.4 Summary

This section has discussed the level of CO found in the exhaust flues vents of combustion appliances tested in the course of the NGAT survey. As shown, flue/exhaust CO levels vary widely across appliances and homes. Table 5-11 summarizes the findings of this section. As indicated, the flue CO levels tend to exceed ANSI standards most frequently for ovens and broilers. Percentages failing the utility standards vary sharply because of the differences across these standards. In general, the results of the NGAT survey with respect to flue CO levels are consistent with the results of the Team's analysis of PG&E data on flue readings. In Section 6, the relationship between flue CO and ambient CO will be assessed.

Table 5-11: Summary of Flue CO Levels

Appliance	% of appliances for which Flue CO is above ANSI Standard (Open or No Door Test)	% of appliances for which Flue CO is above Utility Standard (Open or No Door Test)
Natural Draft Furnaces/Heaters	4.44%	3.70% – 4.79%
Induced Draft Furnaces/Heaters	1.69%	1.69%
Direct Vent heaters	0.00%	0.00% - 3.12%
Water Heaters	2.31%	1.83% - 1.94%
Ovens	26.36%	9.93% - 26.58%
Broilers	28.05%	12.04% - 26.78%
Cook Tops	NA	1.06% - 25.18%
Dryers	NA	0.00%
Gas Logs	NA	3.11% -24.12%

6

Sources and Detection of Pre-Existing Ambient CO

6.1 Introduction

This section assesses the sources of preexisting room and appliance ambient air CO levels in LIEE participants' homes. Subsection 6.2 discusses the possible causes of ambient CO for survey homes with one or more ambient reading at or above the threshold levels discussed in Section 3. Subsection 6.3 discusses the effectiveness of alternative protocols for detecting ambient CO above these threshold levels.

6.2 Causes of Levels of Ambient CO above Threshold Levels

6.2.1. Introduction

This section examines the causes of ambient CO exceeding the thresholds identified in Section 3 in homes tested in the NGAT survey. As may be recalled, 10 ppm was defined as an action level beyond which further investigation is needed. Further, 35 ppm was defined as a threshold level beyond which the home should be ventilated, the occupants should be advised to evacuate, and the technician should restrict exposure to 15 minutes. Subsection 6.2.2 focuses on the 55 homes found to equal or exceed the ambient CO action level of 10 ppm. Subsection 6.2.3 concentrates on the four homes in the survey determined to have room or appliance ambient CO levels at or above 35 ppm.

6.2.2. Analysis of Homes with Maximum Net Ambient CO at or above 10 ppm

Table 6-1 examines the indirect evidence found on the sources of ambient CO for homes with at least one ambient CO reading at or above the action level of 10 ppm. It suggests the following findings.

- Of these 55 homes, it was found that the two rooms that were by far most likely to have a room ambient CO level at or above 10 ppm were kitchens (80% of the time) and living rooms (32.73%).
- Of these 55 action level homes, 42.82% had appliance ambient CO above 10 ppm for water heating or space heating, suggesting that most cases of action level ambient CO levels were associated with kitchen appliances.

- Within the group of homes exceeding action levels for ambient CO, air-free exhaust flue CO levels exceeded ANSI standards most frequently for ovens and natural draft furnaces/heaters.
- The percentage of homes failing one or more of the draft/spillage tests was actually higher for homes below the action level than for those above it.

Table 6-1: Potential Appliance Sources of Ambient CO at or above 10 ppm

Characteristics	Homes below Action Level (10 PPM)	Homes at or above Action Level (10 PPM)
% of Homes with Room Ambient Test #2 at or above 10 PPM in the following rooms:		
Kitchen	0%	80.00%
Garage	0%	0%
Basement	0%	1.82%
Dining Room	0%	1.82%
Hall	0%	1.82%
Living Room	0%	32.73%
Laundry	0%	5.45%
% of Homes with Appliance Ambient at or above 10 PPM for the following appliances		
Space Heating	0%	27.27%
Water Heating	0%	18.18%
Space Heating or Water Heating	0%	41.82%
% of Homes with Air Free Flue CO at or above ANSI Standard for the following appliances:		
Natural Draft furnaces/heaters	2.19%	12.73%
Induced Draft furnaces/heaters	0.14%	0%
Closed-Combustion Heaters	0%	0%
Water Heaters	1.64%	3.64%
Cook Tops	NA*	NA*
Ovens	4.10%	27.27%
Broilers	0.68%	1.82%
% of Homes Failing Open Door Draft and/or Spillage Test		
Space Heating	3.01%	3.64%
Water Heating	7.66%	0%
% of Homes with Air Free Flue CO at or above ANSI Standard and Failing Draft and/or Spillage Test		

* There is no air-free measurement for cook tops.

Table 6-2 identifies the specific action items identified by NGAT technicians for repair or replacement for the 55 homes with ambient CO at or above 10 ppm. As shown, the most common reasons for repair for these homes were problems with the inadequate size of the combustion air supply vent or non-conforming room volume, excessive exhaust flue CO, and flue/vent system defects. Burner and pilot malfunctions were also fairly common. It should be emphasized that not all of these repairs had any connection with the presence of ambient CO above the action level. Many repairs were recommended for other reasons.

6.2.3. Analysis of Homes with Maximum Net Ambient CO at or above 35 ppm

This section focuses on homes with one or more readings at or above the threshold of 35 ppm. There were four such homes in the sample. Further investigation of the survey records for these homes indicated the following:

- REPG35370. The high reading was traced to a water heater problem (burner misaligned and clogged with soot and rust)
- RESD123180. In this case, the broiler was not operating properly. It had a flame on the metal grid.
- RESG361479. The source of high CO in this home was a wall heater that had not been operating for the last 10 years and had a broken thermostat.
- RESG61355. The cause of high CO was an oven with high flue CO. The flue CO level was higher than the utility standard, but the appliance was not referred for repair by the technician. The technician also didn't identify any visual problems with the oven, which is highly unusual considering high CO problems with ovens are usually a result of readily visible burner problems.

Table 6-3 summarizes some salient diagnostic results for these homes. The following results are notable:

- Within the group of homes with ambient CO above 35 ppm, Room Ambient Test #2 exceeds 35 ppm in kitchens in two cases and in the living room in one case. The other case was one in which the appliance ambient test was above 35 ppm but none of the Room Ambient Tests were above this threshold.
- One of four of these homes had appliance ambient CO above 35 ppm for water heating or space heating.

Table 6-2: Repairs Recommended for 55 Homes with Net Ambient CO at or above 10 ppm

Repair	Heater	Water Heater	Oven	Range	Cook Top	Total
Appliance needs to be replaced, due to need for extensive repairs	1	1	0	0	0	**2**
Main burner malfunction, defect, improper flame, won't light	2	0	0	5	0	**7**
Pilot or igniter malfunction, improper flame, inability to ignite main burner	3	0	0	3	1	**7**
Dirty/clogged burner	0	1	0	2	0	**3**
Combustion air vent size or room volume is non-conforming	6	9	0	0	0	**15**
Combustion air obstructed	0	0	0	0	0	**0**
CO (in flue, oven/cook top, dryer) above threshold	6	1	2	3	0	**12**
Component broken/missing (other than vent system parts)	2	1	0	0	0	**3**
Cleaning or clean & tune and/or adjustment needed	2	0	0	3	0	**5**
Dirty-dust, lint, cobwebs, debris, etc. present	1	0	0	0	0	**1**
Duct disconnection or major defect	2	0	0	0	0	**2**
Draft inadequate and/or spillage present	0	0	0	0	0	**0**
Duct sealing and/or duct replacement needed	0	0	0	0	0	**0**
Enclosure problem (leak/gap/defect; unneeded vents)	0	0	0	0	0	**0**
Gas pressure too high/low and/or regulator defect	0	0	0	2	0	**2**
Heat exchanger defect	0	1	0	0	0	**1**
Roll-out	0	0	0	0	0	**0**
Unvented appliance	0	0	0	0	0	**0**
Vent/flue system defect (pipe, draft hood, etc. defective/missing)	3	8	0	0	0	**11**
Total of all conditions	**28**	**22**	**2**	**18**	**1**	**71**

Table 6-3: Potential Appliance Sources of Ambient CO at or above 35 ppm

Characteristics	Homes below Threshold of 35 ppm	Homes at or above Threshold of 35 ppm
% of Homes with Room Ambient Test #2 at or above 35 ppm in the following rooms:		
Kitchen	0%	50.00%
Garage	0%	0%
Basement	0%	0.00%
Dining Room	0%	0.00%
Hall	0%	25.00%
Living Room	0%	0.00%
Laundry	0%	0.00%
% of Homes with Appliance Ambient at or above 35 ppm for the following appliances		
Space Heating	0%	0.00%
Water Heating	0%	25.00%
Space Heating or Water Heating or both	0%	25.00%
% of Homes with Air Free Flue CO at or above ANSI Standard for the following appliances:		
Natural Draft Furnaces/Heaters	2.81%	25.00%
Induced Draft Furnaces/Heaters	0.13%	0%
Closed-Combustion Heaters	0%	0%
Water Heaters	1.66%	25.00%
Cook Tops	NA*	NA*
Ovens	5.63%	25.00%
Broilers	0.64%	25.00%
% of Homes Failing Open Door Draft and/or Spillage Test		
Space Heating	3.07%	0.00%
Water Heating	7.16%	0.00%
% of Homes with Air Free Flue CO at or above ANSI Standard and Failing Draft and/or Spillage Test	26.3%	100.00%

* There is no air-free measurement for cook tops.

- Within the group of homes with ambient CO levels above 35 ppm, air-free flue CO exceeded ANSI standards in one case each for natural draft furnaces/heaters, water heaters, ovens, broiler, and cook tops (note that the Team used an as-measured CO level of 240 ppm as a proxy for the air-free standard of 800 ppm for kitchen appliances).
- The percentage of homes failing one or more of the draft/spillage tests was actually higher for homes below the action level than for those above it.

Table 6-4 summarizes the reasons given by NGAT technicians for capping appliances pending repairs or replacements. The most common reason for repairs or replacements was the presence of appliance exhaust flue CO above the threshold. Again, note that some of these repairs may have been recommended for reasons other than the presence of CO above the threshold values.

Table 6-4: Repairs Recommended for 4 Homes with Net Ambient CO at or above 35 ppm

Repair	Heater	Water Heater	Oven	Range	Total
Appliance needs to be replaced, due to need for extensive repairs	0	0	0	0	**0**
Main burner malfunction, defect, improper flame, won't light	0	0	0	2	**2**
Pilot or igniter malfunction, improper flame, inability to ignite main burner	0	0	0	0	**0**
Dirty/clogged burner	0	0	0	0	**0**
Combustion air vent size or room volume is non-conforming	0	0	0	0	**0**
Combustion air obstructed	0	0	0	0	**0**
CO (in flue, oven/cook top, dryer) above allowable limit	1	1	0	1	**3**
Component broken/missing (other than vent system parts)	0	0	0	0	**0**
Cleaning or clean & tune and/or adjustment needed	0	0	0	0	**0**
Dirty-dust, lint, cobwebs, debris, etc. present	0	0	0	0	**0**
Duct disconnection or major defect	1	0	0	0	**1**
Draft inadequate and/or spillage present	0	0	0	0	**0**
Duct sealing and/or duct replacement needed	0	0	0	0	**0**
Enclosure problem (leak/gap/defect; unneeded vents)	0	0	0	0	**0**
Gas pressure too high/low and/or regulator defect	0	0	0	0	**0**
Heat exchanger defect	0	0	0	0	**0**
Roll-out	0	0	0	0	**0**
Unvented appliance	0	0	0	0	**0**
Vent/flue system defect (pipe, draft hood, etc. defective/missing)	0	0	0	0	**0**
Total of all conditions	**2**	**1**	**0**	**3**	**6**

6.2.4. Relationship between Flue and Ambient CO Levels

This section analyzes the relationship between the level of CO in appliance exhaust flues and ambient CO levels. It is meant to provide some evidence with respect to the potential influence of flue CO on ambient levels.

Table 6-5 presents ambient and flue average readings for households whose maximum flue CO measurement is less than 100 ppm and for appliances whose flue CO levels (either as-measured or air-free) exceeds 100 ppm. Note that these readings are defined at the appliance level. The average household ambient for households with As-Measured flue reads below 100 ppm is 3.17 ppm and the average household ambient in rooms with an As Measured flue read above 100 ppm is 7.67 ppm. This suggests some correlation between flue CO and ambient CO. The relationship between ambient and flue CO readings will be further investigated in Subsection 6.3.

Table 6-5: Household Maximum Ambient CO and Flue CO

	Ambient	Flue Test	
	Test #2	**As-Measured**	**Air Free**
Average CO for Appliances with Flue As Measured < 100	3.17	20.81	
Number of Appliances	1814	1814	
Average CO for Appliances with Flue As Measured >= 100	7.67	499.56	
Number of Appliances	184	184	
Average CO for Appliances with Flue Air Free < 100	2.29		19.95
Number of Appliances	948		948
Average CO for Appliances with Flue Air Free >= 100	5.15		528.34
Number of Appliances	526		526

6.3 Detection of Threshold Levels of Ambient CO

6.3.1. Overview

One of the main objectives of this project is to determine the level of testing, if any, that is needed to detect CO above the threshold levels for LIEE Program participants. Associated with this objective are three specific research questions:

1. Are the existing policies and procedures and Minimum Standard for natural gas appliance testing previously recommended by the Team and adopted on an interim basis by the Commission necessary, and, if so, are they appropriate to identify high

levels of CO and other combustion-related hazards in the homes of LIEE weatherization recipients?

2. To what extent would the detection of CO problems be affected by the elimination, reduction, expansion or modification of steps included in the Minimum Standard (including the installation of CO alarms as an alternative or supplement to gas appliance testing)?
3. What modifications, if any, to the current natural gas appliance testing policies and procedures should be adopted for the LIEE Program?

These questions are addressed below.

6.3.2. Design of the Current Minimum Standard

All of the utilities currently use the Commission's adopted Minimum Standard for natural gas appliance testing. This Standard was developed by the Standardization Team, although not all utilities necessarily endorse it. PG&E supplements this type of testing with other steps. The Commission's adopted interim Minimum Standard involves the specific procedures identified in Table 6-6. Several things should be noted about this Standard:

- The Standard entails a series of visual examinations focusing on flue/vent systems and appliance components. These elements of the Standard are most relevant to space heating and water heating, although at least some utilities may do other checks not included in the Standard on other appliances.
- The Standard includes indoor ambient CO tests similar to those used in the NGAT survey. However, under the Minimum Standard Room Ambient Test 2 is conducted with only the space heating system in operation, whereas this test was conducted with all combustion appliances operating under the NGAT protocols. Further, the Standard Room Ambient Test 2 is conducted in the middle of the living space away from registers and appliances, whereas this test was conducted in several rooms under the NGAT protocols.
- The Standard includes tactile and smoke draft tests, but not an instrument test.

In the next three sections, we assess the adequacy of the Minimum Standard to detect pre-weatherization ambient CO levels above the action level of 10 ppm. In doing so, we analyze this issue separately for three classes of appliances: space heating systems, water heaters, and other appliances. In order to accommodate this appliance-specific focus, the full range of NGAT results was analyzed for all 55 homes, and appliances responsible for ambient CO were identified.

Table 6-6: Current Minimum Standard for Gas Appliance Testing

General Procedure	Specific Procedures
Olfactory Test	Smell for natural gas leaks.
Visual Examinations	Flue and Vent System—Check for: ▪ Draft hood defects: Multiple, missing or improperly installed ▪ Holes in pipe or other hazardous conditions. ▪ Connection with a solid fuel appliance chimney. ▪ Flue/vent cap missing or damaged. ▪ Inadequate distance from an evaporative cooler inlet.
	Appliance Components—Check for: ▪ Furnace combustion chamber door(s) <u>not</u> present. ▪ Water Heater combustion chamber cover (rollout shield <u>or</u> access door) <u>not</u> present. ▪ Excessive amounts of carbon or rust in/around heat exchanger, draft hood or flue/vent pipe.
Combustion Air Evaluation	Combustion Air Vents—Check for: ▪ Vents are absent or inadequate (size and location) ▪ Source of combustion air is inadequate and/or obstructed.
Indoor Ambient CO Tests	▪ CO tester zeroed outdoors. ▪ **[A]** Equipment-*Off* Indoor Ambient CO sample: Taken in an open location away from duct registers and appliances. All combustion appliances are turned off. ▪ **[B]** Equipment-*On* Indoor Ambient CO sample: Taken after all space-heating systems have been operating at least five minutes. Measured in the same location as [A]. ▪ **[C]** Equipment-*On* Appliance Ambient CO sample: *Forced-air units:* inside the register nearest the supply plenum. *Non-ducted units:* in the atmosphere just above the heat exchanger. Investigative action, and correction if needed, is required when: [A] or [B] CO level exceeds 10 ppm. [C] CO level exceeds [B] CO level. ▪ Gas heating system(s) shall be repaired/replaced when required.
Draft Tests	▪ Visual (non-instrument) test (smoke test) ▪ Tactile test

6.3.3. Application of the Minimum Standard to Space Heating

Table 6-7 summarizes the application of the Minimum Standard to Space Heating. As shown, separate results are provided for two sets of homes: those for which space heating appliances appeared to be responsible for CO at or above the action level, and those for which this was not the case. For the purposes of this analysis, we refer to the first set of homes as space heating action level homes and the others as space heating non-action level homes. As shown, there were 7 homes in the first category and 711 homes in the second.

Each entry in Table 6-7 depicts the percentage (and number, in parentheses) of the homes in question that failed a specific test or combination of tests in the Minimum Standard. For instance, one (14.29%) of the space heating action level homes had holes in the space heating vent pipe or other potentially hazardous conditions relating to the vent.

As shown, the differences in visual examination results between space heating action level and non-action level homes are minimal. The combustion air evaluation is actually failed more frequently for the non-action homes than for the action homes, although this difference is not statistically significant. Failures in non-action homes are affected by the fact that combustion air requirements have changed over time, and thus a significant percent of all homes will fall short of the current standards.[1] While three (43%) of the space heating action level homes failed one or more of the visual examination or combustion air tests, 169 (24%) of the space heating non-action level homes failed one or more of these tests.

The combination of visual and combustion air tests identifies three of the seven space heating action level homes. The addition of ambient tests is required to identify all of these homes, which should not be particularly surprising given that ambient tests were used to define the set of 55 homes from which these were drawn, and given that this element of the Minimum Standard was included for this purpose. It should be noted that the Room Ambient Test 2 results listed in Table 6-7 are limited to those taken in the living room, the family room, or the dining room. This limitation was designed to approximate the Minimum Standard protocol, which calls for the room ambient reading to be taken in the center of the living space, away from registers and appliances. Given this limitation, it is unsurprising that Room Ambient Test 2 identifies only three (43%) of the space heating action level homes. One other result that should be noted is that draft tests identify only one (14.29%) of the seven space heating action level homes. While the Minimum Standard does not involve the use of instruments, it was found elsewhere in this report that tactile and smoke tests give virtually identical results to those yielded by instruments.

[1] See Chapter 7 of the 1998 California Mechanical Code, which is the 1997 Uniform Mechanical Code with California. additions.

As shown in Table 6-7, the flue tests on space heating systems do discriminate between homes under and over the action level, but identify only six (86%) of those over this level. However, the combination of the draft test and the flue test identified all seven space heating action homes. On the other hand, failed flue tests also occur in 19 (2.67%) of the homes without ambient CO above 10 ppm.

In one home, ambient CO above 35 ppm was found to be traceable to the space heater. Both ambient tests conducted under the Minimum Standard detected this case, as would a flue test on the space heating unit.

Table 6-7: Application of Minimum Standard for Space Heating System

General Procedure	Specific Procedure	Space Heating Ambient: At or Above Action Level (7 homes)	Space Heating Ambient: Below Action Level (711 homes)
Visual Examinations	Flue and Vent System - Check for		
	Draft hood defects: Multiple, missing or improperly installed	0.00% (0)	0.70% (5)
	Holes in pipe or other hazardous conditions	14.29% (1)	3.66% (26)
	Connection with a solid fuel appliance chimney		
	Flue/Vent cap missing or damaged		
	Inadequate distance form an evaporative cooler inlet	0.00%	2.39% (17)
	Failed one or more Flue/Vent System Check	14.29% (1)	5.20% (37)
	Appliance Components – Check for		
	Excessive amounts of carbon or rust in/around heat exchanger, draft hood or flue/vent pipe.	28.57% (2)	5.91% (42)
	Failed one or more Visual Examination	42.86% (3)	10.4% (74)
Combustion Air Evaluation	Inadequate combustion air	0.00%	14.91% (106)
	Failed the visual examination and/or the combustion air evaluation	**42.86% (3)**	**23.77% (169)**
Indoor Ambient CO	Tests Under 3 Conditions		
	A. Test 1 in Living Space	0.00%	0.14% (1)
	B. Test 2 in Living Space	42.86% (3)	2.11% (15)
	C. Space Heating Appliance Ambient	85.71% (6)	1.27% (9)
	Take Action if:		
	Test on A or B indicates ambient CO of 10 PPM or more	42.86% (3)	2.25% (16)
	Test C Exceeds Test B	85.71% (6)	14.77% (105)
Subtotal	**Failed Visual Examination and/or Combustion Air Evaluation Test and/or Ambient CO Test**	**100.00% (7)**	**36.57% (260)**
	Failed tactile and/or smoke test	14.29% (1)	3.09% (22)
Summary	**Failed one or more of the minimum standards Tests**	**100.00% (7)**	**36.85% (262)**
Potential Additional Tests	Failed Appliance on Tests of Burner and Pilot	28.57% (2)	10.55% (75)
	Failed Space Heater Flue Test	85.71% (6)	2.67% (19)
	Failed Space Heater Flue Test and/or Draft Tests	100.00% (7)	5.63% (40)

6.3.4. Application of the Minimum Standard to Water Heating

Table 6-8 summarizes the results of the application of the minimum standard to homes with and without water heating appliances that were responsible for ambient CO levels at or above the action level. There were 3 homes for which water heating appeared to be responsible for CO at or above this action level and 373 for which this was not the case (the others did not have combustion water heating in a space subject to ambient tests). Again, we note that visual examinations and combustion air evaluations do not differ appreciably between these two groups. (Due to the small sample of homes above the action level, none of the differences is statistically significant.) Both groups tend to fail at least one visual examination in 18-33% of all cases, and both groups fail one or more elements of the combustion air evaluation in 48-67 % of all cases. It appears that these tests—while valuable in their own rights—do not act as indicators of high ambient CO associated with water heaters.

The indoor ambient CO results derived from the Minimum Standard do not provide any additional information on the contribution of water heating to action levels of ambient CO, for a very simple reason: only Room Ambient Test #1, which is taken with all appliances off, applies to water heating. Room Ambient Test #2 is taken after the space heater has been turned on, but with water heating still in the off position; as a result, it does not differ from Room Ambient Test 1. Additionally, the appliance ambient reading is not applicable to water heating, since the Minimum Standard calls for no such test.

In sum, the Minimum Standard does not provide sufficient information to identify all water heaters responsible for ambient CO readings at or above 10 ppm.

If water heating appliance ambient readings were added to the protocol, all three homes would have been identified. The use of room ambient tests would identify one of three cases where the water heater was responsible for ambient CO at or above 10 ppm. The use of flue CO readings above the ANSI standard would identify two of three (67%) of these homes. But these flue reads are also above the ANSI standard (as interpreted for this study) for four homes without ambient CO attributable to the water heater.

In one home, ambient CO above 35 ppm was found to be traceable to the water heater. While the Minimum Standard would not have detected this case, it was detected by the relevant room ambient test, the appliance ambient test, and the flue test.

Table 6-8: Application of Minimum Standards for Water Heating

General Procedure	Specific Procedure	Water Heating Ambient: At or Above Action Level (3 homes)	Water Heating Ambient: Below Action Level (373 homes)
Visual Examinations	Flue and Vent System - Check for		
	Draft hood defects: Multiple, missing or improperly installed	0.00%	7.24% (27)
	Holes in pipe or other hazardous conditions	33.33% (1)	8.85% (33)
	Connection with a solid fuel appliance chimney Flue/Vent cap missing or damaged Inadequate distance form an evaporative cooler inlet	33.33% (1)	2.95% (11)
	Failed one or more Flue/Vent System Check	33.33% (1)	14.75% (55)
	Appliance Components – Check for		
	Excessive amounts of carbon or rust in/around heat exchanger, draft hood or flue/vent pipe.	33.33% (1)	4.29% (16)
	Failed one or more Visual Examination	33.33% (1)	18.2% (68)
Combustion Air Evaluation	Inadequate combustion air	33.33% (1)	38.07% (142)
	Failed the visual examination and/or the combustion evaluation	66.67% (2)	47.72% (178)
Indoor Ambient CO	Tests Under 3 Conditions		
	A. Test 1 in Living Space	0.00%	0.27% (1)
	B. Test 2 in Living Space	NA	NA
	C. Space Heating Appliance Ambient	NA	NA
	Take Action if:		
	Test on A or B indicates ambient CO of 10 PPM or more	0.00%	0.27% (1)
	Test C Exceeds Test B	NA	NA
Subtotal	**Failed Visual Examination and/or Combustion Air Evaluation Test and/or Ambient CO Test**	**66.67% (2)**	**47.99% (179)**
	Failed tactile and/or smoke test	0.00%	5.36% (20)
Summary	**Failed one or more of the Minimum Standard Tests**	**66.67% (2)**	**48.53% (181)**
Potential Additional Tests	Failed Room Ambient Test #2 in room w water heater	33.33% (1)	2.14% (8)
	Failed Appliance Ambient Test on Water heater	100.00% (3)	1.88% (7)
	Failed Visual Tests of Burner and Pilot	0.00%	2.95% (11)
	Failed Water Heater Flue Test	66.67% (2)	1.07% (4)
	Failed Water Heater Flue and/or Draft Tests	66.67% (2)	6.43% (24)

6.3.5. Application of the Minimum Standard to Kitchen Appliances

In most of the homes with ambient CO levels at or above the action level, the cause of the CO appeared to be a kitchen appliance (generally an oven). Of the 595 homes with combustion kitchen appliances, 47 (7.9%) had a kitchen appliance determined to be responsible for ambient CO at or above the action level, and 548 (92.1%) did not. At present, the Minimum Standard used by the utilities does not explicitly conduct visual examinations, combustion air evaluations, or Room Ambient Tests 2 for kitchen appliances. As a result, the Minimum Standard is not designed to assess the performance of these appliances. The frequency with which ambient CO readings above the action level were traceable to kitchen appliances would seem to warrant implementation of one or more tests. Table 6-9 provides information on the results of certain diagnostic tests on the identification of homes for which action levels of CO were associated with kitchen appliances. Of particular interest is the performance of exhaust/flue tests. As shown, these tests revealed air-free CO above the ANSI standard in 35 (74.5%) of the 47 cases where kitchen appliances were responsible for ambient readings above the action level, but were also failed in 124 (22.63%) of the 548 cases where kitchen appliances did not yield ambient CO levels above the action level.

In two homes, ambient CO above the threshold of 35 ppm traceable to kitchen appliances was found. The Minimum Standard would have detected only one case. Either a room ambient conducted in the kitchen, or an exhaust/flue test on kitchen appliances would have detected both cases.

Table 6-9: Application of the Minimum Standard to Kitchen Appliances

General Procedure	Specific Procedure	Kitchen Ambient	
		At or Above Action Level (47 homes)	Below Action Level (548 homes)
Visual Examinations in Min Standard	All	NA	NA
Combustion Air Evaluation in Min Standard	Inadequate combustion air	NA	NA
Indoor Ambient CO	Tests Under 3 Conditions		
	A. Test 1 in Living Space (LR, DR, FR)	2.13% (1)	0.00%
	B. Test 2 in Living Space	NA	NA
	C. Heating Appliance Ambient	NA	NA
	Take Action if:		
	Test on A or B indicates ambient CO of 10 PPM or more	2.13% (1)	0.00%
	Test C Exceeds Test B	NA	NA
Subtotal	**Failed Visual Examination and/or Combustion Air Evaluation Test and/or Ambient CO Test**	**2.13% (1)**	**0.00%**
	Failed tactile and/or smoke test	NA	NA
Summary	**Failed one or more of the Minimum Standard Tests**	**2.13%**	**0.00%**
Potential Additional Tests	Failed Room Ambient Test #2 in room w kitchen appliance	93.26% (44)	0.36% (2)
	Failed Visual Tests of Burner and Pilots	23.40% (11)	14.42% (79)
	Failed Appliance On Tests of Burner and Pilots	29.79% (14)	23.72% (130)
	Failed Kitchen Appliance Exhaust/Flue Tests	74.47% (35)	22.63% (124)

6.3.6. Application of the Minimum Standard to Other Appliances

Only 26 homes had gas logs. One of these homes (3.8%) was found to have ambient CO above the action level of 10 ppm in the room in which the gas logs were located. Again, however, the Minimum Standard does not explicitly apply to gas logs, so it is not capable of discerning such cases.

The NGAT survey gave no evidence of any ambient CO associated with combustion dryers. Moreover, as seen in Section 5, none of these appliances exceeded the utility standards for as-measured flue CO.

6.4 Detection of Inadequate Appliance Draft

As shown in Section 5, the relationship between exhaust flue CO levels and ambient CO levels appears to be fairly weak. However, it may be argued that exhaust flue CO could present a problem if there is ever inadequate draft, and that this may not show up in ambient tests under certain weather conditions. That is, the instrument draft test is designed to indicate whether or not appliance draft problems could occur under more adverse weather conditions than experienced at the time of the survey tests. Combustion appliance drafting tends to be somewhat minimized in warmer weather, so readings taken on relatively warm days (like those experienced during most of the survey period) may not be accurate indicators of appliance draft performance under winter conditions. One question to be addressed by this study is the adequacy of a less rigorous testing (i.e., the tactile test and the smoke test) to detect the potential draft problems that could be revealed by instrumented tests.

Table 6-10 presents a cross-tabulation of the results for these three tests involving space heating for all cases where all three tests could be performed. There were a total of 243 such cases. Each entry is the number (and percent) of homes falling into the specific category in question, as defined by the row and column headings. For instance, the first numerical entry indicates that 233 homes (95.71% of all those tested) passed both the instrument test and the tactile test. As shown, the tactile test, smoke test and instrument test gave the same results for all cases (in the sense that all three either passed or failed for the same appliances).

Table 6-10: Cross-Tabulation of Results of Draft/Spillage Tests: Space Heat

	Appliance/Test			
	Tactile Test		Smoke Test	
Instrument Test	**Pass**	**Fail**	**Pass**	**Fail**
Pass	233 (95.71%)	0 (0.00%)	233 (95.71%)	0 (0.00%)
Fail	0 (0.00%)	10 (4.29%)	0 (0.00%)	10 (4.29%)

Table 6-11 presents the cross-tabulation for draft/spillage tests on water heaters for those homes for which all three tests could be applied. There are 393 such homes in the sample. As indicated, the correlation across tests is virtually perfect, with only a few cases where the smoke test and/or tactile test was failed but the instrument test was passed.

Table 6-11: Cross-Tabulation of Results of Draft/Spillage Tests: Water Heat

	Appliance/Test			
	Tactile Test		Smoke Test	
Instrument Test	**Pass**	**Fail**	**Pass**	**Fail**
Pass	369 (93.89%)	3 (0.76%)	369 (93.89%)	3 (0.76%)
Fail	0 (0.00%)	21 (5.34%)	1 (0.25%)	20 (5.09%)

7

Impacts of Installation of Infiltration-Reduction Measures on CO Levels

7.1 Overview

One of the key research questions to be addressed in this study is the potential impact of infiltration reduction on ambient CO levels. In this section, changes in ambient household CO levels from the pre-weatherization period to the post-weatherization period are analyzed. Our attention is focused on room ambient readings, since these are the readings that one would expect to be influenced by changes in infiltration. Subsection 7.2 considers observed changes in room ambient CO levels for the overall NGAT sample. Subsection 7.3 focuses on the homes for which changes in air infiltration levels were estimated through the application of blower door tests. Subsection 7.4 summarizes the evidence and draws conclusions.

7.2 Observed Changes in Room Ambient CO

Changes in two types of ambient tests were analyzed: Room Ambient #1, which was taken with appliances off and Room Ambient #2, which was conducted with appliances on and the home in a “typical” condition.

7.2.1. Changes in Room Ambient Test #1

Table 7-1 presents changes in Room Ambient Test # 1 average and maximum readings. Both the number of homes in the sample and the estimated overall population frequencies are shown.

Table 7-1: Changes in Room Ambient Test #1

Change in CO in ppm	Change in Average Reading		Change in Maximum Reading	
	Unweighted Household Numbers	Weighted Household Percentage	Change in CO in ppm	Unweighted Household Numbers
<-5	6	0.76%	7	0.87%
-5	1	0.11%	4	0.43%
-4	7	0.82%	8	1.00%
-3	24	3.00%	25	3.30%
-2	48	6.37%	56	7.21%
-1	67	8.82%	60	7.85%
0	552	69.56%	550	69.48%
1	55	7.27%	41	5.43%
2	16	1.97%	19	2.41%
3	5	0.60%	8	0.99%
4	2	0.28%	4	0.50%
5	0	0.00%	0	0.00%
> 5	3	0.43%	4	0.54%
Average Change	-0.21	-0.21	-0.21	-0.21
% with Positive Change	10.68%	10.89%	9.44%	9.58%
% with Negative Change	21.99%	23.06%	22.24%	23.11%
Average Positive Change	1.46	1.45	2.07	2.10
Average Negative Change	-1.82	-1.79	-2.03	-2.02
Total Number of Homes	786	786	786	786

7.2.2. Changes in Room Ambient Test #2

Table 7-2 presents the changes in room ambient test #2 from the pre-weatherization period to the post-weatherization period.

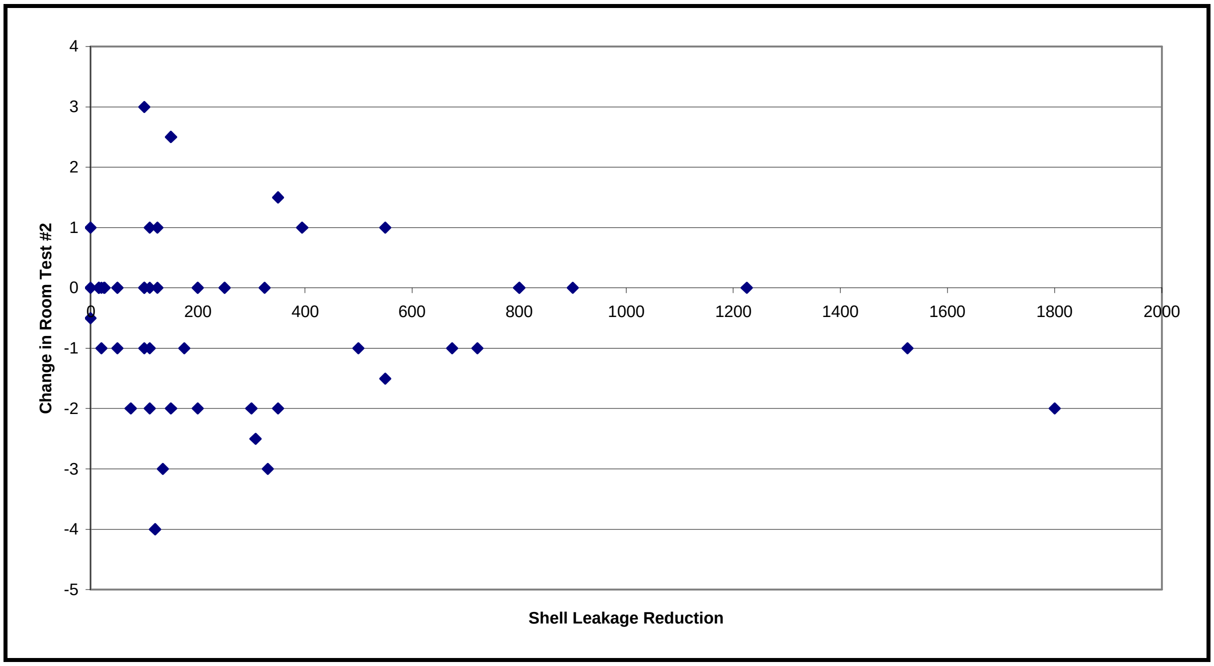
Table 7-2: Changes in Room Ambient Test #2

	Change in Average Reading		Change in Maximum Reading	
Change in CO in ppm	Unweighted Household Numbers	Weighted Household Percentage	Unweighted Household Numbers	Weighted Household Percentage
<-5	15	1.79%	29	1.81%
-5	16	2.03%	21	37.94%
-4	37	4.69%	36	7.02%
-3	48	5.82%	66	9.29%
-2	81	10.46%	71	9.37%
-1	114	14.94%	86	8.96%
0	325	41.60%	318	5.89%
1	80	9.79%	71	4.51%
2	36	4.55%	42	3.09%
3	13	1.65%	17	3.75%
4	5	0.59%	12	1.83%
5	4	0.61%	2	5.36%
> 5	11	1.48%	14	0.99%
Average Change	-0.53	-0.50	-0.67	-0.64
% with Positive Change	19.75%	19.46%	19.63%	19.24%
% with Negative Change	42.36%	42.81%	40.87%	41.30%
Average Positive Change	1.98	2.04	2.54	2.64
Average Negative Change	-2.27	-2.216	-3.01	-2.95
Total Number of Homes	785	785	785	785

7.3 Relationship between Infiltration Reduction and Room Ambient CO Levels

The changes in household air infiltration rates associated with weatherization undoubtedly varied considerably across participating homes. In order to more directly test the relationship between infiltration reduction and ambient CO, blower door tests were conducted on a sample of 55 NGAT homes both pre- and post-weatherization. Figure 7-1 plots the changes in the blower-door results (differences in cubic feet per minute, or CFM) against the corresponding changes in Room Ambient Test #2. There appears to be no systematic relationship between these two changes. Indeed, ambient household CO levels actually fell in the two cases with reductions in infiltration in excess of 1400 CFM. It is unclear why this result occurs.

Figure 7-1: Relationship between infiltration Reduction and Changes in Ambient CO



7.4 Change in Homes at or Above the Action Level

In section 4, it was concluded that 55 homes equaled or exceeded the action level of 10 ppm on at least one ambient CO test conducted prior to weatherization. In reviewing the post-weatherization tests, it was found that this number fell to 41 homes. However, some of these homes had not been at or above 10 ppm in the pre-weatherization tests. Table 7-3 provides a cross tabulation of the results of the pre-and post-weatherization ambient tests. Each numerical entry indicates the number of homes falling into the category defined the entry's row and column headings. For instance, the first numerical entry indicates that 29 homes had ambient CO levels at or above 10 ppm in both the pre-weatherization test (first row) and the post-weatherization test (first column). The sensitivity of the results to the timing of the tests is attributable to a variety of factors, including changing conditions, dust buildup in appliances that have not operated for some time, and the tolerance of the Dräger instrument used to take ambient readings.

Table 7-3: Cross Tabulation of Pre-Weatherization and Post-Weatherization Action Homes

	Post-Weatherization Tests		
Pre-Weatherization Tests	**At or above 10 ppm**	**Below 10 ppm**	**Total Homes**
At or above 10 ppm	29	26	55
Below 10 ppm	12	738	750
Total Homes	41	764	805

7.5 Concerns over Potential Impact of Weatherization on Appliance Drafting Characteristics

7.5.1. Overview

The NGAT Survey protocol included testing procedures to identify problems associated with flue gas exhaust vent systems of open combustion appliances (both natural draft and induced draft). These tests were conducted to assess spillage and drafting of gas combustion appliances.

Definition of Spillage

Normally with open combustion appliances, dilution air is introduced into the vent system through the draft hood. The draft hood is located at the top end of the combustion chamber or immediately outside of the appliance. Combustion products (gases) mix with dilution air and flow upward through the vent pipe, and the mixture exits through the vent cap into the atmosphere. Flue gases normally flow out of (“spill” from) the draft hood and enter the Combustion Appliance Zone–a condition called “spillage” during the initial warm-up period. Once the combustion gases are hot enough to sustain a “draft” through the vent pipe, the gases stop spilling and dilution air is drawn into the vent system through the draft hood. However, if spillage continues to occur after the appliance has reached steady-state conditions, combustion byproducts may present a health and safety hazard to occupants if the appliance is located within the home’s envelope. Spillage testing is intended to identify presence of such a condition.

Purpose of Spillage Testing

The purpose of Spillage Testing is to:

- Determine if spillage is occurring,
- Assess the relative magnitude of pressure within the vent pipe (normally a negative value), and

- Determine whether performance of the vent system is normal or is compromised by either: depressurization of the combustion appliance zone, the area from which the appliance draws combustion air, or a defect within the vent system.

The NGAT Survey protocol also included a check of induced-draft appliances with single-wall vent connectors to obtain drafting information when feasible. The primary focus of the study was on natural draft appliances—because the presence of a draft hood establishes the possibility for spillage of CO and other combustion products into the living space.

7.5.2. Causes of Spillage

Spillage can be caused by a number of situations, from windy conditions to obstructions in the vent pipe to depressurization of the conditioned space. These situations are planned for in the design of the appliance, hence the draft hood. The draft hood functions as a protection device to keep the pilot or flame from being extinguished upon start-up. Long-term spillage, which may constitute a health and safety hazard, may be caused by any of several unacceptable conditions that need to be remedied before tightening a building. These causes generally fall into two categories: 1) Combustion Appliance Zone (CAZ) depressurization and, 2) vent system defects and design flaws.

CAZ Depressurization. One cause of spillage is depressurization of the Combustion Appliance Zone or CAZ, which may be created by:

1. Mechanical ventilation:
   a. bathroom exhaust fans
   b. utility room exhaust fans
   b. range hoods and other types of kitchen exhaust fans
   c. central vacuum system
2. Forced-air unit (FAU) air handler effects:
   a. supply leaks outside the living space (that depressurize the living space)
   b. return leaks within the living space
   c. imbalance within the return system (e.g., overly-tight doors separating supply registers from a central return)
3. The evacuative (drafting) effect of open combustion natural draft appliances (both gas-fired and solid-fuel)

Vent System Defects and Design Flaws. Inadequate flow of flue gases up the vent pipe may also be caused by conditions within the pipe, rather than the influence of external forces (depressurization). They may include the following:

1. Obstructions in the vent system, such as a crushed pipe or vent cap

2. Holes, partial disconnections, and complete disconnections
3. Improper vent termination, which may be: inside the attic, too low to the roof, or below the roof line, or too close to an adjacent wall or other obstruction
4. Improper vent system design/construction, such as inadequate slope of a horizontal run, excessive use of elbows, and improper vent material.

7.5.3. Spillage Test Procedures

The NGAT Survey protocol was designed to 1) determine if combustion appliance spilled combustion byproducts, and 2) compare three separate test procedures related to spillage. These tests were the tactile test for spillage; a visual draft test using smoke; and an instrumented draft test. All three tests were performed after the appliance had warmed up for at least five minutes, giving the appliance and vent system a chance to reach steady state operating temperature.

The Tactile Test for Spillage is the simplest and most basic of the three procedures because it requires no tools or equipment. The test is accomplished by moving one's hand (usually the back side, which is more sensitive) along the draft hood opening while the appliance is operating and checking for the presence of combustion products spilling out of the draft hood. Because water vapor is a component in flue gas, spillage is detected by a hot, moist feeling on the hand.

The Visual Draft Test (known in the field as the "smoke test") is accomplished by introducing smoke along the entire draft hood opening (this was done with a chemical smoke "puffer" in the NGAT Survey). If smoke is drawn into the draft hood (by the inward movement of dilution air), spillage is not present and movement of combustion products upward through the vent pipe is considered adequate.

The Instrumented Draft Test is the most sophisticated and complex test of the three. It requires drilling a test hole in the vent pipe and inserting an instrument to measure the pressure inside the vent pipe with respect to the pressure in the CAZ. The test hole is placed 12 to 21 inches above the draft hood in a straight section of pipe and the probe is inserted to the center of the pipe. The pressure is measured by the instrument and compared with acceptable values (see Table H-2) for the current outdoor temperature (measured in the shade).

Buoyancy of the flue gas varies inversely with the outdoor temperature (the warmer it is outdoors, the less tendency flue gases have to rise). Therefore, the higher the ambient temperature is, the smaller the amount of negative pressure inside the vent pipe is required—as illustrated in the following table from Section H of the NGAT On-Site Survey Protocol:

Table H-2. Instrumented Draft Test Temperature & Pressure Parameters

Outdoor Temperature	*Minimum Negative Pressure*	
Below 30°F	- 0.02 iwc	- 5.0 Pa
30 to 80°F	- 0.01 iwc	- 2.5 Pa
Over 80°F	- 0.005 iwc	- 1.25 Pa

7.5.4. Appliances Tested

The following open combustion appliances were checked for spillage:

1. Heating System Appliances
    a. Furnace
    b. Wall Heater
    c. Floor Furnace
2. Water Heating Systems

Closed combustion appliances (except those with single wall vents), cook top burners, griddles, oven/broiler combinations, and clothes dryers were not checked for spillage.

If the appliance was located in an enclosed space (closet or appliance cabinet), separate tests were conducted with the door open and again with the door closed. For the closed-door test to be conducted, the space had to be large enough for the technician to get inside and perform the test with the door closed.

Initial Check

The appliance was operated for a minimum of five (5) minutes and was then checked for spillage via the tactile spillage test and the visual draft test (smoke test). The tests were performed for both the open and closed-door mode.

Winter Conditions

The homes were put in simulated worst-case scenario winter conditions, which meant that:

1. All exterior doors and windows were closed
2. Fireplace damper was closed
3. Interior doors were open
4. Exhaust fan devices (including the dryer) were turned on
5. Forced air handler on

Again, appliances were turned on and allowed to warm up before the tactile spillage and visual draft tests were repeated. The instrumented draft test was also completed following the other two tests. If the numbers from the second set of tactile and visual tests were less than the first set of tests, the results were recorded along with the results of the instrumented draft test.

Pre-Post Difference

Of the 1,110 pre-weatherization and post- weatherization spillage tests conducted, there were two instances (.018% of all spillage tests) in which the appliance "passed" the tactile, smoke, and instrumented draft tests during the pre-weatherization survey and "failed" during the post- weatherization survey. These cases are considered below.

REPG60206. The water heater in this house passed all three tests (tactile, smoke, and instrumented draft) on the pre-weatherization test and failed all three on the post-weatherization test. The residence had broken windows, which allow adequate draft, and when they were replaced with other filtration related measures the water heater did not draft properly during the open door test.

REPG184632. This home's water heater passed all three tests on the pre-inspection, but failed all three tests on the post-inspection. The home failed only under the worst-case winter condition scenario. Due to the abnormality of such a finding, the home was chosen for a case study to identify the cause of inadequate draft. The post-weatherization instrumented draft test measurement was recorded as 0.00 iwc (inches water column) and the minimum draft standard for an outdoor temperature of 80^{o}F was -0.005 iwc.

7.6 Summary and Conclusions

The results shown in Table 7-1 and Table 7-2 indicate that CO levels fell very slightly on average between the pre- and post-weatherization periods for homes tested under this statewide survey. This change is too small to be considered particularly meaningful, given that the Dräger has a tolerance of $\pm$1 ppm. The more direct examination of the relationship between changes in infiltration and changes in CO also yielded no significant findings.

It must be noted that the association between infiltration reduction and ambient CO could have been confounded to some extent by other factors. For instance, it could have stemmed from the fact that some appliances had not been operating for some time when pre-weatherization tests were conducted. Initial operation of these appliances may have caused a temporary discharge of CO as a consequence of dust buildup or other factors that did not have as strong an influence on the post-weatherization tests. While the testing protocols called for a minimum warm-up period, this period may not have been adequate.

It should also be noted that any effect of infiltration reduction on ambient CO may take a considerable amount of time to take effect. Theoretically, if reductions in infiltration increase CO concentrations, it is because the reduction in air changes lowers the dilution of CO. However, the spot tests taken pre- and post-weatherization in this study may not span long enough periods of time to fully reveal this impact.

In summary, the analysis reveals no clear evidence that weatherizing LIEE Program homes significantly impacts the overall level of ambient CO. However, in view of the above caveats, the Team does not consider the analysis of the impacts of infiltration reduction on ambient CO levels to be conclusive.

8

CO Alarm Study

8.1 Introduction

One of the components of the Phase IV Natural Gas Appliance Testing (NGAT) Survey was a CO Alarm Study. The primary goal of the CO Alarm Study is to evaluate whether CO alarms can be used as an alternate or supplement to combustion appliance testing in weatherized homes. To determine this, CO alarms were installed, studied, and monitored in 100 of the 850 homes included in the Natural Gas Appliance Testing Study (NGAT). This section addresses the results of the CO Alarm Study.

8.2 Methodology

To evaluate the use of CO alarms as an alternative or supplement to combustion appliance testing the CO Alarm Study 1) reviewed existing literature on the efficacy of CO alarms, 2) selected appropriate CO alarms and CO data loggers to use in this Study, 3) tested the sensitivity of the selected CO alarms, 4) identified and recruited participants for the Study, 5) developed an installation protocol and installed the alarms and data loggers in homes, 6) downloaded data on a periodic basis, 7) conducted the NGAT Survey, 8) removed all CO alarms and data loggers at the end of the study, and 9) analyzed the data collected.

8.3 Review of CO Alarm Literature

RHA reviewed information on CO alarms from a number of different sources including:

- Product literature from CO alarm manufacturers
- Evaluation reports from consumer organizations (i.e., Consumer Reports)
- California Air Resources Board (ARB)
- US Environmental Protection Agency (US EPA)
- Gas Technology Institute (GTI)
- Other published reports.

1997 LBNL CO Detector Study

The Lawrence Berkeley National Laboratory (LBNL) conducted a study of CO detectors (CO Detectors: How Selective Are They? An Independent Study by the Lawrence Berkeley National Laboratory) along with Quantum Group Inc., the manufacturers of a biomimetic sensor CO alarm (the CoStar CO Alarm). The study tested the resistance to interferent gases and CO selectivity with a variety of CO detectors. These detectors were subjected not only to CO gas, but also to other common gases found in households that might interfere with the detection of the CO by the sensor.[1]

Reliability Tests

According to the study, "typical reliability criteria used to analyze the effectiveness of any CO detector" is its:

- Sensitivity of concentrations of CO from 65 – 600 ppm
- Resistance to activation to low CO levels (15 – 30 ppm)

Table 8-1: LBNL CO Detector Reliability Testing Results

Sensor Technology	Premature Responses	Failure to Respond to CO
BIO*	2	0
MOS*	5	0
EC*	12	51

*BIO = biomimetic; MOS = metal oxide semiconductor; EC = electrochemical

LBNL's reliability testing of CO detectors utilizing three different sensor technologies show that EC (electrochemical) detector technology has the highest failure rates for premature responses and failure to respond (Table 8-1).

Selectivity Tests

Also important to any functional detector technology is its "selectivity," that is its ability to respond to a concentration of CO (it selects the CO molecule) while discriminating against other chemicals in the atmosphere. The Study found that approximately "70% of the common household gases presented were ignored by all detectors." Selectivity test results demonstrated that electrochemical (EC) and metal oxide semiconductor (MOS) CO detectors had trouble in distinguishing between a number of common household gasses (see Table 8-2).

[1] Helfman, Gundel, and Apte, 1997. CO Detectors: How Selective Are They? An Independent Study by the Lawrence Berkeley National Laboratory, LBNL.

Table 8-2: LBNL CO Detector Selectivity Testing Results

Sensor Technology	Type of Interferent Gases and Responses			
	Isopropanol	Ethanol	Ethylene	Nitrous Oxide
BIO	0	0	0	0
MOS	0	1	7	1
EC	4	4	2	0

The study of CO sensors concluded that:[2]

- A BIO (biomimetic) model was the only detector completely unaffected by all thirteen (13) interferent gases. This model showed no false alarms, premature responses, or failures.
- Nine (9) false alarms to ethylene in 30 tests were observed. Again, the BIO models performed best with no false alarms.
- Detectors with MOS (metal oxide semiconductor) sensors false alarmed in nearly half of the tests in which ethylene was present.
- An EC (electrochemical) model continuously failed CO selectivity tests. The same EC model failed to respond to CO alone following exposure to interferents.

GRI – Performance Testing of Residential CO Alarms

In a 1998 report entitled "Performance Testing of Residential CO Alarms" published by the Gas Research Institute (GRI-98/0284) and prepared by Mosaic Industries, nine commonly found, residential CO alarms were tested for reliability and sensitivity. They concluded that "while there was tremendous variability in performance among the brands, a majority of alarms of all brands suffered from one or another serious deficiencies in performance" (see Table 8-3).

Deficiencies included:

- Manufacturing defects
- Significant departures from the sensitivity specifications of UL 2034.
- A high rate of supervised failures in otherwise accurate alarms
- Poor accuracy of digital displays
- False alarms on exposure to common interference gases
- Late alarms and failures to alarm when tested at low relativity humidity.

The manufacturers of the models used in this study were not revealed by the study. This lack of information makes it hard to determine which models not to use.

[2] Ibid, page 9

Table 8-3: Performance Summary by Brand – GRI Performance Testing of Residential CO Alarms[3]

CO Alarms				Non-Compliance w/COHb Alarm Levels			Sensitivity to Interference Gasses	
Brand ID	Sensor Technology	Out-of-Box Failures	Supervised Failures	Initial	Final	Display Error +/-	UL Gasses	All Gasses
A1	BIO – color	0%	0%	20%	100%	--	0%	0%
A3	EC	20%	60%	0%	20%	17%	0%	100%
A5	EC	25%	0%	0%	0%	--	0%	100%
A8	EC	17%	17%	100%	100%	51%	0%	0%
A2	MOS	24%	0%	91%	100%	200%	45%	100%
A4	MOS	0%	0%	0%	80%	42%	0%	0%
A6	MOS	38%	0%	100%	--	--	--	--
A7	MOS	0%	0%	100%	100%	--	0%	0%
A9	MOS	0%	0%	25%	75%	--	0%	0%

Consumer Reports

Unlike the other testing labs, Consumers Union only conducted a response test in their October 2001 feature report on CO alarms. They subjected four different brands and a variety of models of CO alarms to two different concentrations of CO gas (150 and 400 ppm) and then timed each unit to determine how fast they responded. The results are listed in Table 8-4 below.

3 Mosaic Industries, Inc., 1998, Final Report: Performance Testing of Residential CO Alarms, Gas Research Institute, GRI-98/0284.

Table 8-4: Consumer Reports CO Alarm Ratings – October 2001

Brand & Model	Rank	Score	CO Sensing 150 ppm	CO Sensing 400 ppm
CO Alarms with Digital Displays				
Senco Model One	1	Excellent	Excellent	Excellent
Kidde Nighthawk Premium Plus KN-COPP-3	2	Excellent	Very Good	Excellent
American Sensors CO910	3	Very Good	Excellent	Excellent
American Sensors CO92	4	Very Good	Very Good	Excellent
Kidde Nighthawk Premium KN-COP-C	5	Very Good	Very Good	Very Good
Kidde Nighthawk KN-COP-DP	6	Very Good	Very Good	Very Good
First Alert FCD4 (CL)	7	Very Good	Very Good	Excellent
First Alert FCD2DDN (CL)	8	Very Good	Very Good	Excellent
CO Alarms without Digital Displays				
American Sensors CO800EL	1	Very Good	Excellent	Very Good
Senco 2002	2	Very Good	Excellent	Excellent
Senco 2003	3	Very Good	Excellent	Excellent
Kidde KN-COB-B	4	Very Good	Very Good	Very Good
Kidde KN-COB-DP	5	Very Good	Very Good	Very Good
First Alert FCD2N (CL)	6	Very Good	Very Good	Excellent
First Alert FCD3N (CL)	7	Very Good	Good	Good

Recall of CO Alarms

The only CO alarm recall to date was a 1999 recall by the CPSC of Nighthawk and Lifesaver CO Alarms manufactured by BRK Industries. In a recall announcement of March 19, 1999 (and updated on November 7, 2001) the CPSC announced the recall of "about 1 million carbon monoxide alarms, including 650,000 Nighthawks and 350,000 Lifesavers. The Lifesaver models could alarm late or not alarm at all, and the Nighthawk models could alarm late."[4]

The Nighthawk models included in this recall are all models manufactured between November 8, 1998, and March 9, 1999. While the Lifesaver models included in this recall are models 9CO-1 and 9CO-1C manufactured between June 1, 1997, and January 31, 1998.

UL 2034-98 CO Detector Standards

All CO alarms sold in the U.S. are UL listed under the UL 2034-98 Standard that requires CO alarms to meet the following criteria (summary).

4 CPSC, CPSC, Kidde Safety Announce Recall of Carbon Monoxide Alarms, Release # 99-082, November 7, 2001.

- Product markings and instruction booklets to advise residents how to respond to an alarm condition.
- The addition of a "reset button" capable of generation both a *warning* and an *alarm*. An initial *warning* that could be manually silenced allowing residents to ventilate and investigate the suspect area, and a *subsequent alarm* should elevated levels of CO (100 parts per million [ppm] or higher) exist after the first 5 minutes and 59 seconds.
- A sensitivity test, requiring CO detectors to <u>ignore low concentrations</u> (<30 ppm) of CO for at least 30 days. (Previously, detectors were only required to ignore 15 ppm for 8 hours.)
- A "rush hour" test, requiring that detectors <u>do not respond to a 35-ppm</u> CO concentration for one hour duration, twice a day for 30 days.
- Alarm threshold markings by which the manufacturers are required to indicate their products' alarm thresholds.

Types of Residential CO Sensors

The product literature review of residential CO alarms found the following types of CO sensors used in CO alarms:

- Biomimetic (BIO)
- Electrochemical (EC)
- Semiconductor (MOS)
- Infrared (IR)

<u>Biomimetic Detectors (BIO)</u>

Biomimetic (mimics body response) - usually battery operated, but sensitive to temperature and humidity fluctuations, last approximately six years. One technology uses gel-coated discs that darken in the presence of CO, tripping the alarm.[5]

According to the LBNL research: Biomimetic (BIO) sensors react to CO similar to the way hemoglobin in human blood reacts. The sensing elements undergo light transmission changes when exposed to CO. Put simply, the darker the sensor, the greater the CO exposure. The BIO sensor is designed with a specific threshold or "sensing window." If the CO concentration in the area is below this present threshold, then it will not respond. The rate at which the CO concentration changes, and the intensity of the change, is constantly monitored by a highly intelligent circuit.[6]

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5 Underwriters Laboratory of Canada, Carbon Monoxide Detectors – Information You Should Know, http://www.ulc.ca/consumer/carbon_monoxide_info.asp

6 1997 LBNL, page 4

Some biomimetic detectors utilize a color changing material that reacts with CO gas to let the alarm user known then CO levels are "low, medium, or high" by the color change on the detector. This type of biomimetic detector is not an alarm and is not UL listed. Manufacturers of these devices caution that customers should use a UL-approved CO detector for added assurance.

Electrochemical Cells (EC) Technology

Electrochemical sensors (least common, more accurate) - expensive, battery operated, short sensor life.[7]

Electrochemical (EC) sensors operate similar to a fuel cell, but in reverse. Three (3) platinum wire electrodes are placed in contact with an electrolyte to form an electrochemical sensor. The cell membrane allows gas to enter, and prevents the liquid electrolyte from leaking. The gas diffuses and reacts with the working electrode, changing its potential. This generates a voltage change in the monitoring circuit, proportional to the concentration of CO.[8]

Metal Oxide Semiconductor (MOS)

Metal Oxide Semi-conductor (most common) - usually plugged into wall, uses more power, sensitive to moisture, lasts approximately 5-7 years.[9] Metal oxide semiconductor (MOS) sensors consist of tin oxide. This is heated to cause oxidation of carbon monoxide to carbon dioxide. This chemical reaction donates electrons to the surface. Next, the surface of the tin oxide changes its resistance to the electric current. The corresponding decrease in resistance in the monitoring circuit is set proportional to the carbon monoxide concentration in the air.[10]

Infrared (IR)

Infrared detectors are new and not used typically for residential applications. One manufacturer utilizes IR detectors in a personal detector.

Residential CO Alarms

There are a variety of CO Alarms on the market today. There is no description of sensor technology listed on packaging on commercially available CO alarms. To determine the sensor technology available RHA had to access manufacturers' web pages on the Internet. This information is listed in Table 8-5. Prices range from a basic CO alarm at $30 to $70 for

[7] Op cit, Underwriters Laboratory of Canada
[8] 1997 LBNL, page 4
[9] Op cit, Underwriters Laboratory of Canada
[10] 1997 LBNL, page 4

the deluxe models. Basic CO alarms are not manufactured with digital readouts, whereas the deluxe units have a digital readout and some are even combined with smoke detectors to provide both types of safety alarms to the homeowner.

Most CO alarms companies manufacture units powered by batteries and/or line voltage. Line voltage units can be either

- Direct plug-in
- Line cord
- Hard-wired

Table 8-5: CO Alarm by Sensor Type

	Sensor Technology				
CO Alarm Manufacturer	**Model**	**BIO**	**MOS**	**EC**	**Proprietary or Decline to State**
AIM				X	
Atwood Mobile Products	Atwood CO Alarm			X	
Coleman Safety and Security Products Inc.				X	
BRK Brands Inc.	First Alert	X	X		
Kidde Safety	Nighthawk Lifesaver			X	
Maple Chase	Firex CO Alarm	X			
North American Detectors	American Sensor		X		X
Patrick Plastics, Inc.	S-Tech ProTech		X		
Quantum Group	CoStar	X			X
safeTalert					X
SENCO OR American Sensors Electronics Inc.	Model One			X	X

In addition to Underwriters Laboratories in the United States, Underwriters Laboratories Canada (ULC) certifies products from a number of American manufacturers.

Study Review Results

The results of the studies reviewed above indicate that the reliability of CO alarms appear to be less than adequate for alarms available in the consumer marketplace at the time of this Study.

- While the LBNL study found that biomimetic sensor technology had the best reliability and selectivity, electrochemical sensors had the worst reliability and selectivity and metal oxide semiconductors ranked in the middle, it should be noted that the LBNL study was actually conducted by a biomimetic-sensored alarm manufacturer, so the lack of bias in their study might be considered questionable.

- The GRI study found problems with all detector brands and sensor technologies. Electrochemical sensors had the worst out-of-box failure rates, while all had numerous test failures.
- The Consumer Reports study used a simplistic test protocol to rank a limited number of CO alarms (only five brands were tested). Their number one rated CO alarm (the Senco Model One) utilizes a proprietary electrochemical sensor. While the other studies found electrochemical sensors to be among the worst, Consumer Reports gave it the highest rating.

8.4 CO Alarm Selection and Testing

After reviewing the literature on CO alarms the Study Team agreed to select CO alarms based on the following criteria:

- Commercially available from local merchants
- Half of the alarms (75 alarms) to be the model used by the State's Weatherization programs.
- Battery-powered.

CO Alarms

The CO alarms used in this Study covered the three different types of sensor detector available. These included the ProTech 7030, the BRK First Alert, and Kidde Safety's Nighthawk. Two of the CO alarms listed above (First Alert and Knighthawk) represent those commonly found in hardware stores in California. The ProTech CO alarms were not found in stores, but ordered from a weatherization materials supplier. The Knighthawk CO alarms, in a variety of models, were the most common ones found in large hardware stores in northern California. After the alarms were purchased they were sent them to A.L. Wilson/SoCalGas for sensitivity testing.

Table 8-6: Types of CO Alarms Selected for CO Alarm Study

Manufacturer	Model	Sensor Type	# of Units
Patrick Plastics, Inc.	ProTech 7030	MOS	75
BRK Brands Inc.	First Alert FCD3N	EC	9
Kidde Safety	Knighthawk KN-COB-B	BIO	50

Battery-Powered CO Alarms

One of the selection criteria for the CO Alarm Study, as agreed on by the committee, was the use of battery-powered CO alarms. Battery-powered alarms utilize the same sensors as line-voltage alarms. The major difference between the two types of alarms is the availability of a "read-out" on the face of the alarm. The committee decided that this feature was unnecessary and might cause undue concern on the part of the participant if they read a CO level that was high but the alarm was not sounding. (A time factor is also involved before the alarm will sound which the read-out would not indicate.)

The CO alarms were to be installed for a short time (approximately six months) and then removed. The installation of line-voltage units requires a source of power to be found and wiring installed to bring it to where the CO alarm was to be installed either through the wall or ceiling. If a plug-in type was used the line cord would have to be encased in a protective conduit attached to the wall. To remove the CO alarm all the wiring and conduit would then have to be removed and holes in the wall or ceiling patched and repainted. The committee felt that if line-voltage CO alarms were installed and then removed six months later, the installation and removal process would take too much time, effort, and money to do properly.

The less expensive, quicker option was to install battery-powered CO alarms. These units were supposed to be able to operate for one year on a single battery, which would meet the needs of the program as the study was supposed to last about six months. Installation would only require the technicians to drill one or two small holes (depending on the unit) which could be easily patched when the units were removed.

Only nine battery-powered First Alert CO alarms were found in ten different hardware stores in northern California. As a result of the limited number of battery-powered CO alarms available in the consumer marketplace, only 134 alarms were acquired before the date agreed upon for sensitivity testing. However, not as many CO alarms failed the sensitivity testing as were expected so it was determined not to purchase the additional 16 CO alarms unless a high failure rate occurred in the field during the study period.

CO Alarm Sensitivity Testing Procedure

The CO alarms purchased by RHA were sent to Southern California Gas Company for sensitivity testing in a "CO Exposure Chamber" to determine if they operate properly. The CO alarms were tested as follows:

- All CO alarms were inspected upon unpacking and labeled with a unique number.
- Twenty (20) CO alarms were tested at a time in the CO exposure chamber.

- Concentrated CO gas was injected into the chamber and mixed with a fan to equalize the concentration of CO in the chamber. CO was added throughout the test period to maintain a 150 ppm CO concentration.
- The CO alarms were tested against the UL 2034-98 Standard that specifies that CO alarms exposed to 150 ppm CO must go into alarm:
  - no sooner than 10 minutes, and
  - no later than 50 minutes.
- A Dräger Pac III CO Monitor monitored CO concentrations and provided a continuous readout.
- When each unit sounded an alarm, the time taken was recorded by an observer watching from outside the exposure chamber.
- This procedure was repeated until all units were tested.
- The CO alarms that were not be used were stored in air-tight containers.
- Only CO alarms that passed this test were installed.
- If alarms fail in the field, they were replaced with one of the stored units that passed the initial sensitivity test.

Alarm Sensitivity Test Results

One hundred and thirty-four (134) CO alarms were sent to SoCalGas Company for testing to determine their sensitivity to a specific level of CO. According to the ASTM Standard 2-34-98, CO alarms should have a maximum response time of 10 to 50 minutes when exposed to CO at 150 ppm (+/- 5 ppm). In normal use, detectors should not alarm before 5% COHb (carboxyhemoglobin) is reached, but should alarm before 10% COHb is attained. The tests were conducted at room temperature and relative humidity with a CO concentration of 150 ppm.

Initial Sensitivity Testing

The results of the initial sensitivity testing listed in Table 8-7 show that only five alarms (3.7% of all units) failed the initial test (three additional alarms were marginal and were not used and are counted as “failed” in the table). That is, the alarm sounded late (when the percentage of CO exceeded 10% COHb) or sounded early (less than 5% COHb).

Table 8-7: CO Alarm Sensitivity Test Results (Initial and Post-Survey)

	% COHb at Alarm					
	Group I		Group II		Group III	
	Initial	Post	Initial	Post	Initial	Post
Average	5.9	6.3	7.0	7.0	7.3	8.2
Max	13.4	25.0	7.4	16.0	7.3	8.4
Median	5.8	6.0	7.0	7.1	0.5	0.7
Min	4.0	0.0	6.4	3.3	7.3	8.7
Mode	5.7	6.0	7.2	7.1	9.0	7.0
Standard Dev.	1.4	3.8	0.3	2.2	6.6	7.1
Number Tested	75	59	50	47	9	9
Failed Test	8	2	0	3	0	0

None of the alarms that failed the initial sensitivity are available in the marketplace. These alarms also had the greatest standard deviation and widest range in testing results.

Post-Study Sensitivity Testing

At the end of the NGAT Survey period (the first week in January) the CO alarms and data loggers used in the Study were removed from the residences and CO alarms shipped to A.L. Wilson/SoCalGas to be retested for sensitivity. Of these, five failed the Post-Survey test (see Table 8-7). In total, 13 out of 134 CO alarms (10%) failed the sensitivity testing procedure.

Selection and Procurement of CO Data Loggers

RHA was tasked with identifying and purchasing a data logging CO monitor for the Study. Sources, prices, and performance information were researched to find the best model of data logger and CO monitor to meet specific program needs (low cost, ease of use, and readily available). There are a limited number of low-cost data logging CO monitors available. Source information obtained from the Pacific Energy Center and A.L. Wilson along with internet research, were used to determine which data logger to utilize for the study.

After identifying a model of data logging CO monitor (Dräger PAC III) and getting approval from the committee, RHA purchased:

- 30 Dräger data loggers with CO sensors to be installed in residences.
- Five additional Drägers for use by the technicians in the field.
- A calibration kit and replacement batteries for each field monitoring technician.

8.5 CO Alarm Study Protocol

A CO Alarm Study protocol was developed that includes 1) installing and monitoring 100 of the CO alarms that passed the tests in homes, 2) a three-month pre-NGAT Survey monitoring period, 3) a three-month, post-NGAT Survey monitoring period, and 6) removal all of the CO alarms.

Installation and Monitoring

1. One CO alarm was installed in each of 100 homes.
2. Residents were instructed on how to respond when an alarm sounds.
3. Thirty (30) residences received CO data loggers in addition to CO alarms. These data loggers were located in close proximity to the CO alarms.
4. The CO data loggers were downloaded and inspected every three weeks.
5. Data from the CO data loggers was compared with client-reported CO incidences.
6. The CO data loggers were in place for three months before the NGAT testing procedure was conducted. They remained in place for three months after the NGAT testing procedure and downloaded regularly.
8. At the end of the study period the CO data loggers and alarms were removed.
9. The CO alarms were retested by Southern California Gas Company to determine if they were operational at the end of the study.

CO Participant Response Procedure

A procedure was developed to assist participants when their CO alarm sounded so that RHA could track each CO alarm incident by location, time, and date. Participants were asked to:

1. Follow the instructions on the card provided with the CO alarm if it sounded.
2. Call RHA's CO alarm hotline to report the incident. (A toll-free 800 number was provided on a card attached to the alarm).

If the manufacturer's procedure to reset the alarm failed, the participants were told to:

1. Call their local emergency number (the number was provided on a card attached to the alarm).
2. Call the RHA CO alarm hotline to report the incident and an RHA technician will visit the residence within 24 hours to determine if there is a problem with the alarm or the gas appliances.

Dwelling Unit Selection

1. CO Alarm Study participants were selected from a representative subsample of occupants and homes qualified to participate in the project.

2. CO data loggers were installed in 30 selected owner-occupied residences located in proximity to RHA technicians to enable a rapid response in case of alarm incidents and to facilitate the downloading of information from the data loggers in a timely manner.

8.6 CO Alarm/Data Logger Study Results

The Study design required 100 CO alarms to be installed on selected NGAT recipients. In addition, 30 data loggers to be installed along with CO alarms to determine if the CO alarms function properly.

CO Alarms

CO alarms were installed and monitored for alarm soundings. Only one actual CO alarm incident was reported during this Study, although there were numerous low-battery alarm soundings reported.

Problems

Overall, there were few problems with the installed CO alarms. Two alarms required replacement during the Study period because they would not stop chirping (low battery indicator) after receiving replacement batteries. One was in the CO-only study (BC-10224) and the other was one of the alarms in the data logger study (BC-10217). Both of these field-failed CO alarms passed both the initial and post sensitivity tests.

CO Alarms and High CO Readings

There were thirteen cases (eight CO alarm only and five CO alarm/CO data logger combination) in which room ambient, appliance ambient, and flue CO readings that were considered high (ambient readings >10 ppm and/or 35 ppm CO) for which no CO alarm incidents were recorded (see Table 8-8).

Table 8-8: CO Alarms and High CO Readings

Study		High Ambient CO			
	Customer ID	> 10 ppm	& Flue	>35	Alarm Sound
CO	RESD148906	X			No
CO	RESG311132	X	X		No
CO	RESG351034	X			No
CO	RESG366878	X	X		No
CO	RESG45800		X		No
CO	REPG99567	X			No
CO	RESG172081	X	X		No
CO	RESG211765		X		No
DL	RESG81766	X			No
DL	RESG98461	X			No
DL	RESD20790	X	X		No
DL	RESG438939		X		No
DL	RESG61355	X	X	X	No
	Totals	**10**	**8**	**1**	**13**

The CO levels were not high enough to cause the CO alarm to alert the occupants; therefore the CO alarms appear to operate as designed as far as not responding to low-levels of CO or random short-term CO events.

Data Logger/CO Alarm Events

Thirty data loggers were installed along with CO alarms to determine if the CO alarms would function properly. Due to a number of problems encountered with clients, only 29 data loggers remained in place long enough to be of use in this study (data loggers were actually installed in 32 homes).

Table 8-9: Data Logger and CO Alarm Incidents

Data Logger				CO Alarm Incidents			CO Alarm Sensitivity Post Test
ID #	Max ppm	# >10	# >30	Alarm Sounded	CO	Low Battery	
ERSD 0043	47	4	2	No	No	No	Pass
ERSD 0119	39	48	6	No	No	No	**Failed**
ERSD 0120	12	1	0	**Yes**	No	Low Battery	Pass
ERSD 0121	9	0	0	No	No	No	Pass
ERSD 0122	10	0	0	No	No	No	Pass
ERSD 0123	190	73	24	No	No	No	Pass
ERSD 0124	28	66	0	No	No	No	Pass
ERSD 0125	35	2	1	No	No	No	Pass
ERSD 0127	4	0	0	No	No	No	Pass
ERSD 0128	4	0	0	No	No	No	Pass
ERSD 0129	38	46	12	No	No	No	Pass
ERSD 0130	8	0	0	**Yes**	No	Low Battery	Pass
ERSD 0132	17	12	0	No	No	No	Pass
ERSD 0133	96	23	4	No	No	No	Pass
ERSD 0134	28	43	0	No	No	No	Pass
ERSD 0136	24	4	0	No	No	No	Pass
ERSD 0137	310	24	9	**Yes – 2 (8)***	**Yes**	Low Battery	Pass
ERSD 0138	9	0	0	No	No	No	Pass
ERSD 0139	41	63	2	No	No	No	Pass
ERSD 0140	89	47	1	**Yes**	No	Low Battery	Pass
ERSD 0141	18	19	0	No	No	No	Pass
ERSD 0143	20	20	0	No	No	No	Pass
ERSD 0144	10	0	0	No	No	No	Pass
ERSD 0145	15	15	0	No	No	No	Pass
ERSD 0146	0	0	0	**Yes**	No	Low Battery	Pass
ERSD 0148	14	4	0	**Yes**	No	Low Battery	Pass
ERSD 0149	19	34	0	No	No	No	Pass
ERSD 0150	17	3	0	No	No	No	Pass
ERSD 0333	13	1	0	No	No	No	**Failed**
		552	**61**	**Yes: 6**	**Yes: 6**	**Low Battery: 6**	**Failed: 2**

*2 alarm soundings reported, occupant reported when questioned, that the alarm went off 5 or 6 more times but didn't report them.

During the Study there were seven reported CO alarm soundings from six different participants (one participant reported a problem on two occasions). Six out of the seven alarm soundings were determined to be battery-related (the alarm chirps). Table 8-9 is a summary of CO alarm incidents on residences equipped with data loggers.

The only CO alarm sounding that was determined to be CO-related was the result of the occupant starting and running his car up directly outside of his open front door. He called RHA immediately and was told what to do to reset the alarm. During the review of the CO readings from the data logger for this participant, there were five or six addition possible high CO events that were not corroborated by CO alarm incident reports. After reviewing these potential events the participant was contacted and he reported that the CO alarm had sounded five or six other times but he had not reported these incidents to RHA (he had been instructed on how to reset the alarm after the first event).

CO Alarm Only Alarm Events

No CO alarm problems were reported by participants who received only the CO alarms. Considering the nuisance rate of the CO alarm/data logger participants (6 out of 30 or 20%) one would expect the same rate from the other alarms (14 reports), but there were none reported.

During the removal of the CO alarms, participants in this portion of the Study were asked if the alarm sounded and what type of alarm was it. Nine participants reported that the low-battery alarm sounded and one participant reported that the CO alarm sounded. Because they did not report these events when they happened, RHA could not investigate further.

Table 8-10: Follow-up Survey CO Alarm Incidents

Customer ID	CO Alarm Sounded	Low Battery	CO Alarm
REPG191840	YES	X	
REPG168870	YES	X	
REPG 213409	YES	X	
RESG109701	YES	X	
RESG460294	YES	X	
RESG351034	YES		X
RESG22692	YES	X	
RESG367105	YES	X	
RESG355942	YES	X	
RESG2054	YES	X	
Sum	**10**	**9**	**1**

Customer RESG351034, who reported that the CO alarm sounded, did not have any unusual CO readings during the NGAT Survey. The only gas appliances were the water heater and the stove/oven.

CO Data Loggers

The purpose for installing the data loggers was to monitor the CO alarms. According to the ASTM standard CO alarms are designed sound if CO concentrations exceed 30 ppm for 30 days or 70 ppm for one hour. The data loggers recorded ambient CO concentrations throughout the Study. Out of 29 data loggers, nine (31%) recorded 15-minute average CO concentrations in excess of 30 ppm (see Table 8-11); however, none of the readings exceeded 30 days required for a CO alarm to sound. Most CO concentration readings exceeding 10 ppm were occasional “spikes” and not consistent “high” CO readings.

Table 8-11: Data logger Readings by CO Concentration Levels

Data logger ID	Max CO	# of 15 min. Readings			CO Alarm ID #	Sensitivity Post-Test
		>10 ppm	>30 ppm	>70 ppm		
ERSD 0043	47	4	2	0	BC-10222	Pass
ERSD 0119	39	48	6	0	127	**Failed**
ERSD 0123	190	73	24	15	110	Pass
ERSD 0125	35	2	1	0	BC-10175	Pass
ERSD 0129	38	46	12	0	BC 10178	Pass
ERSD 0133	96	23	4	2	105	Pass
ERSD 0137	310	24	9	2	BC-10230	Pass
ERSD 0139	41	63	2	0	BC-10196	Pass
ERSD 0140	89	47	1	1	BC 10206	Pass

Four of the data loggers recorded CO concentration incidents exceeding 70 ppm (Table 8-11); however, three of the four high data loggers with high readings only recorded levels greater than 70 ppm once or twice (15 minute average per incident), the other recorded fifteen 15-minute periods of CO greater than 70 ppm.

The participant with the data logger (ERSD 0123) that exceeded the 1-hour alarm criteria (3.5 hours) did not report a CO alarm sounding during this high CO incident. These readings are suspect due to the nature of the CO readings (all of the high readings were multiples of 10 and during the time before and after the “incident” readings measuring down to -40 ppm CO were recorded) and this data is suspect and should not be considered. See the discussion below for more information on this data logger/household.

Data Logger ERSD 0137 (RESG 202471)

Data logger ERSD 0137 recorded the highest reading in the Study (310 ppm for a 15-minute period). The next 15-minute period was 160 ppm CO, but all other CO readings were below 60 ppm. This participant only reported his CO alarm sounding twice, once in the beginning of the Study (June 27) and the other towards the end of the Study (November 11) which turned out to be a low-batter alarm.

After reviewing the data logger data in light of the fact that this participant had reported a CO alarm incident (the only real CO alarm reported during the Study, all the others were low-battery alarms) it appeared that the six incidents of high CO levels did not trigger any more CO alarm soundings. However, in personal communication with participant, he reported that the CO alarm "went off five or six more times" that he failed to report to RHA. Unfortunately he did not report these incidents nor remembered the dates and times they may have occurred.

CO Alarm Incident #1 - Data Logger ERSD 0137 (RESG 202471)

On June 27, at 8:30 in the morning, the occupant reported that his CO alarm sounded. While talking to him on the phone it was determined that it was his car exhaust that triggered the alarm (he had started it and left it running next to an opened front door). He was told how to reset the alarm to turn the alarm off and to keep from running his car by the front door.

Figure 8-1: CO Alarm Incident #1 – ERSD 0137

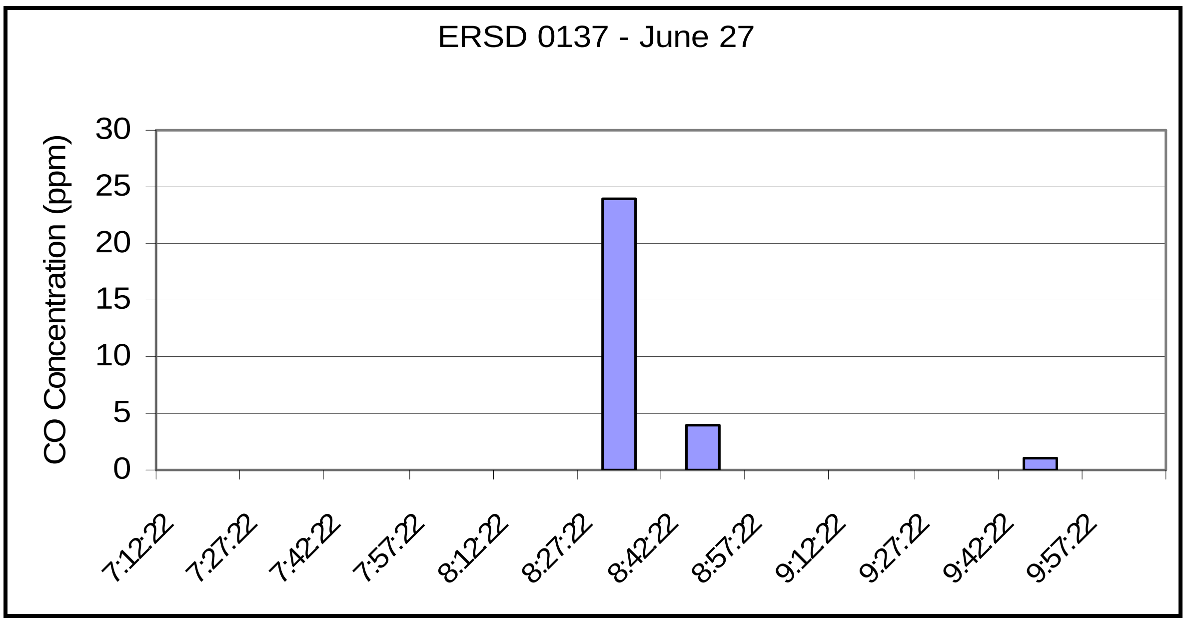


Figure 8-1 is a graph of CO concentration on the morning of the reported CO alarm incident. The data logger recorded an average CO concentration of 24 ppm for the initial 15-minute period when the CO alarm sounded. Based on the data logger readings, the CO alarm should not have sounded at this level of CO; however, it is likely that the actual CO level was much higher (the data logger averages the concentration for a 15 minute period) which caused it to alarm. The ASTM standard requires the CO alarm to sound within 4 – 15 minutes when CO concentrations are over 400 ppm. Within a half an hour the data show that the CO had been flushed from the house.

Non-Reported Incidents - Data Logger ERSD 0137 (RESG 202471)

This data logger recorded six "high" CO incidents through July and then they stopped (see Table 8-12). The CO concentrations are suspect in that they are all multiples of 10; however, given the initial incident reported on June 27 of the effect of the car exhaust, the readings follow a similar pattern of activity – no CO, then a high concentration and a gradual tail off. This appears to be consistent with the previous experience with starting and running the car next to the front door during summer months with the doors and windows open.

The data on the right side of Table 8-12 is not as clear as that on the left in terms of initial high spiking CO levels, while there is a steep and dramatic increase in CO concentration and a gradual tapering off, it appears to take much longer to develop and the CO concentrations lasted longer. This can probably be explained by the time of day and weather conditions. These occurred early in the morning when there is relatively little wind activity in southern California (the other readings were later in the morning when the off-shore breezes usually pick up in velocity). This would then mean that it took longer to flush the CO out of the house and that appears to be the case.

Table 8-12: ERSD 0137 High CO Incidents

Date	Time	CO (ppm)		Date	Time	CO (ppm)
7/19/2002	11:13:44 AM	0		7/23/2002	5:28:44 AM	0
7/19/2002	11:28:44 AM	310		7/23/2002	5:43:44 AM	30
7/19/2002	11:43:44 AM	160		7/23/2002	5:58:44 AM	60
7/19/2002	11:58:44 AM	30		7/23/2002	6:13:44 AM	50
7/19/2002	12:13:44 PM	0		7/23/2002	6:28:44 AM	40
				7/23/2002	6:43:44 AM	40
7/20/2002	9:28:44 AM	40		7/23/2002	6:58:44 AM	30
				7/23/2002	7:13:44 AM	10
7/21/2002	9:43:44 AM	40		7/23/2002	7:28:44 AM	0
7/21/2002	11:28:44 PM	20		7/25/2002	4:13:44 AM	0
				7/25/2002	4:28:44 AM	10
				7/25/2002	4:43:44 AM	30
				7/25/2002	4:58:44 AM	10
				7/25/2002	5:13:44 AM	0

Table 8-13 shows that before weatherization (during the summer months) this data logger recorded a number of “high” CO levels; however, after weatherization (and downloading and replacing the battery in the data logger) there were only six readings above 10 ppm, but below 25 ppm.

Table 8-13: ERSD 0137

	Pre-Wx	**Post-Wx**
Max	310	19
Min	0	0
Std Dev	4.17	0.73
Average	0.20	0.13
15-minute Readings		
Count	8477	8744
>50	4	0
>35	4	0
>25	14	0
>10	18	6
0 - 10	8459	8738
<0	0	0

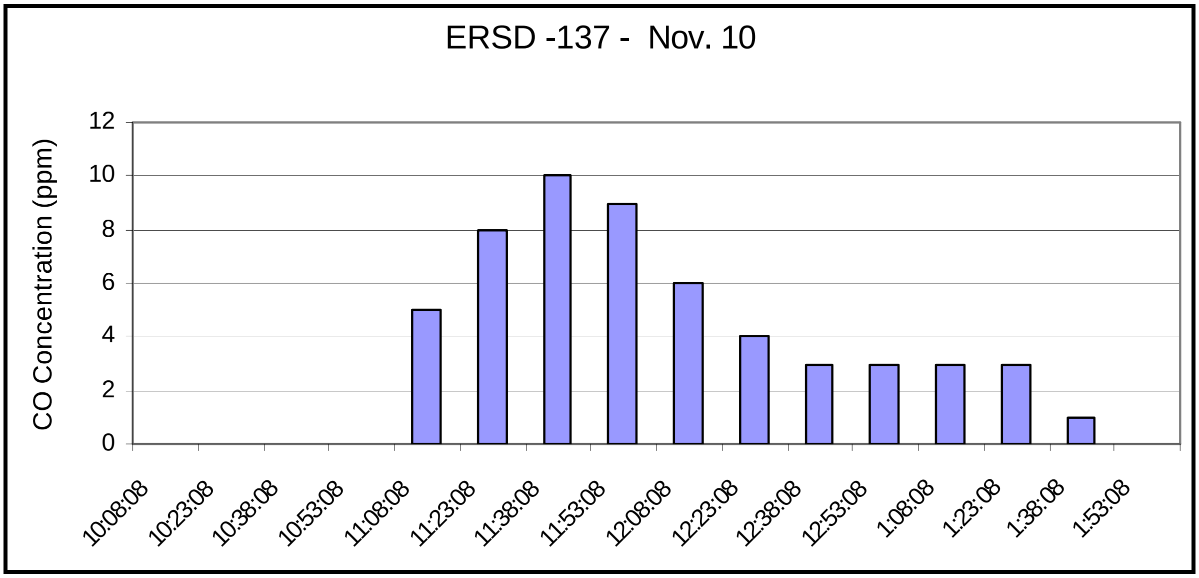
The NGAT Survey found little “wrong” with the gas appliances at this residence. The heater needed additional combustion ventilation air and the pilot needed to be repaired (constantly going out). The ambient CO and appliance CO levels were not of concern.

One of the concerns raised with this data logger readings were the number of readings that were a multiple of 10 with nothing in between. It is likely that because of the high concentrations of CO from the car exhaust these average values would calculate to an “easy” average number. As demonstrated in Table 8-13, the vast majority of readings with this data logger were between 0 – 10 ppm and not multiples of 10.

CO Alarm Incident #2- Data Logger ERSD 0137 (RESG 202471)

The occupant called and reported a problem with the CO alarm in November. He wasn’t sure if it was the CO alarm or the battery alarm. The technician who responded determined that it was a low-battery problem and replaced the battery. As shown in Figure 8-2, the recorded CO concentrations were not high enough to trigger a CO alarm incident.

Figure 8-2: CO Alarm Incident #2 – ERSD 0137



Data Logger ERSD 0123 (REPG 177444)

The data logger at this residence recorded the highest number of 15-minute average CO concentrations (73 readings) over 10, 30, and 70 ppm as well as the highest number of 15-minute reads under zero (603 readings). However, there were no reported CO alarm soundings for this household during the study and the ambient CO readings taken during the NGAT Survey were all below 10 ppm, which, along with the "abnormal" CO readings, may indicate that there wasn't a high CO problem at this residence. Most of the erratic CO concentration readings took place during the first two months and then stopped after the technician downloaded the data and replaced the battery.

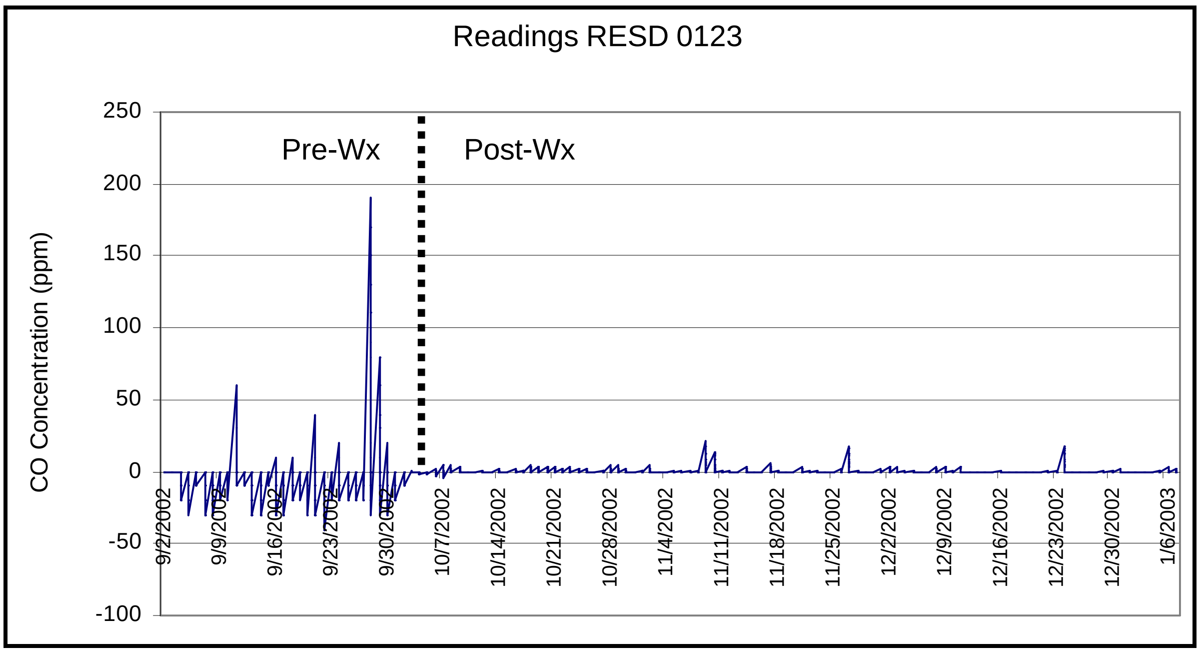
Table 8-14: ERSD 0123

	Pre-Wx	Post-Wx
Max	190	21
Min	-40	-4
Std Dev	11.75	1.23
Average	-2.03	0.23
15-minute Readings		
Count	3302	8850
>50	18	0
>35	18	0
>25	27	0
>10	30	43
0 - 10	2714	8762
<0	558	45

Figure 8-3 shows the erratic high and low data logger readings occurred prior to the NGAT Survey being conducted. They also stopped immediately after the third download and battery replacement by the technician. The technician reported that all he did was download the data and replace the battery and made no other changes to the data logger.

The number of "high" negative readings is suspect with this data logger. The Drägers can record negative readings but for the most part they are confined between 0 and -10. These readings were as low as -40 ppm which may indicate an internal problem with the data logger. The problem disappeared after the download and battery replacement and the data logger appears to have functioned properly afterward as most of the data logger readings were below 10 ppm and consistent with the ambient air readings (<10 ppm) found during the survey. In addition, the only problem found at this residence during the Survey was inadequate CVA and no problems with any of the appliances.

Figure 8-3: ERSD 0123 Data logger Readings



Data Reliability

Four of the Drägers produced suspicious readings. Two of the data loggers recorded extremely high incidents of ambient CO (ERSD 0123 – 190 ppm and ERSD 0137 – 310 ppm). When the data was analyzed the numbers were not consistent with other readings from the same data logger or with the other data loggers. The four data loggers had a number of readings that were multiples of 10 and one of them (RESD 0123) had low negative readings in multiples of 10, down to -40 ppm, which does not make sense. The Drägers often produced negative readings but the majority of them (85% of the negative reads and 19% of all reads) were from -1 to -5 (see Table 8-15).

Table 8-15 shows the distribution of data logger values for all readings. When values were greater than +20 or -10 the data logger recorded values in multiples of 10. These data loggers are designed for recording ambient CO in the workplace where OSHA Permissible Exposure Limits (PEL) of CO exposure is 50 ppm at which time they sound an alarm. The Drägers used in this study were not designed to be scientific instrument. They were designed to detect ambient CO levels that exceed 50 ppm and warn the wearer of the device. They were chosen to be used in this study because of their cost and ease of use.

The “high” readings of ERSD 0137 can be accounted for by the activity pattern of the occupant who would start and run his car in close proximity of his front door. These “high” incidents occurred early in the Study and no other “high” readings occurred after July.

The erratic readings of ERSD 0123 stopped after the technician downloaded the data and replaced the battery making it likely that something was “reset” internally when these devices were worked on. There are no settings on the data logger that would allow a technician to change values of readings from positive to negative or visa versa.

Table 8-15: Data Logger Value Distribution

PPM	# of Reads	% of Total
-40	11	0.02%
-30	134	0.21%
-20	301	0.47%
-6 to -10	1,667	2.61%
-1 to -5	12,206	19.14%
0	43,494	68.22%
1 to 5	2,869	4.50%
6 to 10	91	0.14%
11 to 20	54	0.08%
30	7	0.01%
40	7	0.01%
50	4	0.01%
60	4	0.01%
80	3	0.00%
90	1	0.00%
Sum	60,856	95.45%
Not Represented	2,900	4.55%
Total Reads	63,756	

Participant Survey

When the technicians removed the CO alarms they conducted the following "Exit Interview..

Customer Questionnaire/Exit Interview

1. **Did the customer experience any problems with the CO Alarm?** **yes** **no**

   If yes, what was the problem?

   ________ **chirping**
   ________ **low battery**
   ________ **CO alarm sounding**
   ________ **other** ________________

2. **Did the customer feel that the CO Alarm was useful, i.e., did they feel safer with the CO Alarm then before without one?** **yes** **no**

3. **Would the customer want one installed as a safety device?** **yes** **no**

The results of these interviews indicated:

- Question 1: Battery failure was the major problem with the 13% of the CO alarms. One CO alarm was reported after the fact in this survey.
- Question 2: 93% felt safer with the CO alarm than without one.
- Question 3: 89% wanted a CO alarm installed as a safety device.

8.7 Findings

The findings of the CO Alarm Study include the following:

- Ten percent (13 out of 134) CO alarms failed the sensitivity tests conducted by A.L. Wilson. This failure rate should be considered unacceptable as the sensitivity of a CO alarm is something that could not be determined by occupants.
- The nuisance rate of the alarms was high – 15%. Fifteen out of the 100 alarms reported low battery alarms during the six months the alarms were installed. This is not a CO alarm problem but a battery problem. Two alarms had to be replaced during the study because the low-battery alarm would not stop when the batteries were replaced.
- Only two CO alarm soundings were reported during the study (one at the end of the study). One of the CO alarm incidents was due to an external source of CO. The other was not reported until the alarm was removed so RHA could do not follow-up. This is consistent with the general findings of the NGAT Surveys –

there were no real cases of high CO producing appliances in the household that could produce enough CO to activate the alarms.

8.8 Conclusions and Recommendations

Conclusions

- The CO alarms appeared to operate as expected. There were very few incidents of high CO levels (>30 ppm CO) which would activate the alarms and there were many incidents of low CO levels (<30 ppm CO) which did not activate the alarms. The one household with high CO levels recorded reported that the CO alarm sounded in rough correlation to the recorded high CO events (because he did not report these incidents RHA could not actually correlate the data logger levels to the alarm soundings).
- Problems encountered in the field with the CO alarms were almost all battery-related. This limitation and nuisance alarming is easily overcome by using AC-powered CO alarms.
- The 10% failure rate of the CO alarms to sensitivity testing may be too high at this point in the current state of development of CO alarms to be reliable.
- The literature reviewed also indicated a number of reliability concerns about the state of the art in CO alarms that have yet to be overcome. While today's CO alarms are more reliable than they have been in the past there are still many concerns as to their current reliability to warrant their usage in lieu of combustion appliance testing.

Recommendations

- CO alarms should not be considered in lieu of combustion appliance testing in weatherization programs.

9

Summary and Recommendations

9.1 Introduction

This study has addressed a series of specific research questions associated with CO in low-income homes:

1. In low-income homes in California, what are the pre-existing levels of CO in the following locations: a) in indoor ambient air, b) in the proximity of specific appliances, c) in flue gases, and d) in the surrounding outdoor air?
2. What effect does the installation of infiltration-reduction measures have on CO levels within the home?
3. Do pre-existing or post-installation CO levels found in low-income homes represent a potential hazard to the occupants? What is the frequency and duration of elevated CO levels?
4. Are the existing policies and procedures and Minimum Standard for natural gas appliance testing previously recommended by the Team and adopted on an interim basis by the Commission necessary, and, if so, are they appropriate to identify high levels of CO and other combustion-related hazards in the homes of LIEE weatherization recipients?
5. To what extent would the detection of CO problems be affected by the elimination, reduction, expansion or modification of steps included in the Minimum Standard (including the installation of CO alarms as an alternative or supplement to gas appliance testing)?
6. What modifications, if any, to the current natural gas appliance CO testing policies and procedures should be adopted for the LIEE Program?
7. How should the measure approval process be standardized across utilities?[1]

This section responds to these questions on the basis of the analysis discussed in Sections 4 through 8.

[1] While this was not listed as a specific research question in the Phase 4 work plan, it clearly flows from the study objectives cited above.

9.2 Pre-Existing Ambient CO Findings and Conclusions

9.2.1. Summary of Pre-Existing CO Levels

Section 4 focused on pre-existing levels of ambient CO. Table 9-1 summarizes the results of the analysis of ambient CO levels. Note that the last column of the table summarizes the distribution of the maximum of all readings. This is based upon the highest reading from all ambient tests, regardless of the room and the type of test.

Table 9-1: Distribution of Highest Net Reads for Ambient Tests

CO Read in PPM	Test #1 Room Ambient	Test #2 Room Ambient	Appliance Ambient	Maximum Across All Tests
Percent with Ambient CO at or above the action level of 10 ppm	0.16%	6.30%	3.22%	**7.1%**
90% confidence interval on Percent with Ambient CO at or above the action level of 10 ppm	-0.07% to 0.39%	4.87% to 7.73%	2.15% to 4.29%	**5.59% to 8.61%**
Percent with Ambient CO at or above The threshold level of 35 ppm	0.00%	0.33%	0.19%	**0.50%**
90% confidence interval on Percent with Ambient CO at or above the threshold level of 35 ppm		0.00% to 0.66%	0.03% to 0.35%	0.09% to 0.91%
Arithmetic Average CO (ppm)	0.38	3.239	1.90	3.51
90% confidence interval on arithmetic average CO (ppm)	0.31 to 0.46	2.89 to 3.59	1.69 to 2.11	3.14 to 3.87
Geometric Average CO (ppm)	0.08	0.83	0.39	0.96
90% confidence interval on geometric average CO (ppm)	0.07 to 0.09	0.73 to 0.94	0.34 to 0.45	0.85 to 1.08
Number of Homes w CO Reads	786	785	730	786

Two conclusions may be drawn from the summary statistics shown in the final column.

- First, as shown, 7.1% (weighted to represent the overall population) of all homes had one or more reading at or above the action level of 10 ppm. That is, in a population of 1,000 homes, 71 (on average) would have at least one ambient reading at or above 10 ppm and would require further investigation of CO sources in the home. There were 55 such homes in the statewide NGAT sample.
- Second, 0.50% of all homes had one or more reading at or above the threshold level of 35 ppm. That is, in a population of 1,000 homes, five homes (on average) would have an ambient reading of 35 ppm or greater. In the statewide NGAT sample, there were four such homes.

9.2.2. The Need for Assessment of Combustion Appliances

Given the results summarized in Table 9-1, the Standardization Team confronted a key policy question: Are the levels of CO found in NGAT survey homes high enough to warrant conducting any tests for CO or CO-related problems as part of the LIEE Program? Answering this question is complicated by two issues:

- First, there is considerable disagreement about the level at which CO presents a potential hazard. Health effects depend partly on the characteristics of the parties subject to exposure. Moreover, the relationship between health effects and CO levels is more or less continuous, and characterizing a specific level at which CO becomes hazardous is an inherently judgmental process.
- Second, the results discussed in this section do not directly deal with the issue of duration of CO exposure and the cumulative effects of multiple exposures during a 24 hour period. Both are strong determinants of health effects. This issue cannot be addressed as rigorously as would be desirable because of the necessity of relying on short-term readings in the NGAT survey. Section 6 considered the sources of high CO and concluded that many of the high readings were associated with kitchen appliances. Unfortunately, the nature of the data collected in this survey make it difficult to generalize with any certainty about the duration of high CO levels and the potential of multiple episodes during a 24-hour period.

At least partly because of these and other issues, the Team disagreed upon the need to conduct CO assessments as part of the LIEE program. Nonetheless, a compromise was reached after some debate. The Team agreed that some level of CO assessment should be implemented under the LIEE Program, due at least partly to the following considerations:

- First, some homes covered by the survey were measured to have ambient CO levels above at least some of the standards and thresholds discussed in Section 3.3. Just over 7% of these homes had ambient CO levels at or above 10 ppm, which corresponds roughly to the 8-hour standards/guidelines of USEPA, WHO and CARB. Moreover, 0.5% of these homes had ambient CO above 35 ppm, which coincides roughly with the one-hour standard of USEPA. While not all members of the Team agree that these levels are hazardous, all Team members agreed to implement some level of testing.
- Second, some Team members argued that the LIEE Program is unique, in that it entails the provision of a comprehensive set of energy-efficiency measures spanning both building envelope infiltration reduction and appliance repair and replacement. Given this comprehensive treatment, the potential for adversely affecting CO levels is greater than in other programs.
- Third, some Team members suggested that low-income households are generally less financially capable of maintaining their natural appliances. Some members of the Team also assumed that low income households may be less likely to know

that gas appliance testing and services are available at no cost from their local gas utility, although no direct evidence to this effect was collected in the course of the study. Given this, the assessment of appliance performance is appropriate for this specific Program.

9.3 Pre-Existing Exhaust/Flue CO Level Findings

Section 5 examined the levels of CO found in appliance exhausts/flues. Table 5-11, which is reproduced below as Table 9-2, summarizes the frequency with which flue CO levels exceeded either ANSI air-free standards (as interpreted for this study) or as-measured standards used by the utilities.

Table 9-2: Summary of Exhaust/Flue CO Levels

Appliance	% of appliances for which Flue CO is above ANSI Standard (Open or No Door Test)	% of appliances for which Flue CO is above Utility Standard (Open or No Door Test)
Natural Draft Furnaces/Heaters	4.44%	3.70% – 4.79%
Induced Draft Furnaces/Heaters	1.69%	1.69%
Direct Vent heaters	0.00%	0.00% - 3.12%
Water Heaters	2.31%	1.83% - 1.94%
Ovens	26.36%	9.93% - 26.58%
Broilers	28.05%	12.04% - 26.78%
Cook Tops	NA	1.06% - 25.18%
Dryers	NA	0.00%
Gas Logs	NA	3.11% -24.12%

The relevance of flue CO levels was debated at some length by the Team. Some members of the Team believe that flue CO, in itself, is not relevant to health and safety insofar as it is normally contained in the flue and does not affect the air the customer breathes. Others believe that flue CO should be assessed even in the absence of high ambient CO levels because it could constitute a potential future problem should drafting become impaired. The Team agreed that natural gas appliance inspections and CO tests cannot guarantee long-term safety for LIEE participants.

9.4 The Impact of Infiltration Reduction Measures on Ambient CO Levels

Section 7 examined the potential impact of infiltration reduction on ambient CO levels. On average, no significant change in ambient CO was found for homes receiving infiltration-reduction measures. Blower door tests indicated that while some homes did experience significant reductions in air changes, no systematic pattern of changes in ambient CO accompanied these changes. As noted in Section 7, two caveats must be offered with respect to the analysis of weatherization-induced changes in ambient CO. First, confounding factors like the influence of dust buildup in seldom-used appliances may have affected the results. And second, it is possible that the effect of building infiltration reduction on ambient CO levels may take a considerable amount of time to take effect and may be missed by spot tests like the ones used in this study. In summary, the analysis reveals no clear evidence that weatherizing LIEE Program homes significantly impacts the overall level of ambient CO. However, in view of the above caveats, the Team does not consider the analysis of the impacts of infiltration reduction on ambient CO levels to be conclusive.

The effect of infiltration reduction on drafting was also investigated in Section 7. Two appliances were identified for which all pre-weatherization draft tests were passed but all post-weatherization draft tests were failed. In all other cases, there was no change in draft performance between the pre- and post-weatherization periods.

The absence of any evidence to the effect that infiltration reduction has a significant impact on ambient CO levels or drafting leaves little basis for choosing between pre-weatherization and post-weatherization tests. The fact that drafting was affected in two cases offers some weak support for post-weatherization testing. Additionally, conducting post-weatherization CO tests would guard against any risk associated with weatherization crews inadvertently interfering with appliance operation. The evidence compiled in this study offers no support for conducting these tests both before and after weatherization.

9.5 Appropriateness of the Minimum Standard

Section 6 discussed the methods used to detect ambient CO. One area examined was the effectiveness of the current Minimum Standard to discern problems leading to ambient CO above the action level of 10 ppm. The 55 cases with ambient CO above the 10 ppm action level were analyzed to determine the appliance(s) generating the CO, and the results of the tests covered under the Minimum Standard were summarized for these appliances. The following conclusions were reached in Section 6:

Space Heating. In seven of the 718 homes with combustion space heating, the presence of ambient CO levels at or above the action level appears to have been attributable to the space heating system. As shown in Section 6, the differences in visual examination results between space heating action level and non-action level homes were minimal.

The combination of visual and combustion air tests identified three of the seven space heating action level homes. The inclusion of ambient tests is required to identify all of these homes. This should not be particularly surprising given that ambient tests were used to define the set of 55 homes from which these were drawn, and given that this element of the Minimum Standard was included for this purpose. One other result that should be noted is that draft tests identified only one (14.29%) of the seven space heating action level homes. While the Minimum Standard does not involve the use of instruments, it was indicated elsewhere in this report that tactile and smoke tests gave virtually identical results to those yielded by instruments.

As shown in Section 6, the flue tests on space heating systems did discriminate between homes under and over the action level, but identified only 86% (six of the seven) of the appliances responsible for CO over the action level. However, the combination of the flue test and the draft test identified all seven space heating action homes. On the other hand, the flue test was also failed in 19 homes where ambient CO was below 10 ppm.

In one home, ambient CO above 35 ppm was found to be traceable to the space heater. Both room and appliance ambient tests conducted under the Minimum Standard detected this case, as did a flue test on the space heating unit.

Water Heating. There were 3 homes for which water heating appeared to be responsible for CO at or above the 10 ppm action level and 373 for which this was not the case (the others did not have combustion water heating in a space subject to ambient tests). As shown in Section 6, visual examinations and combustion air evaluations did not differ appreciably between these two groups. It appears that these tests—while valuable in their own rights—did not act as indicators of high ambient CO associated with water heaters.

The indoor ambient CO results derived from the Minimum Standard did not provide any additional information on the contribution of water heating to action levels of ambient CO, because none of the Minimum Standard tests is designed to be taken with the water heater operating. If water heating appliance ambient readings were added to the protocol, all three homes would have been identified. The use of room ambient tests would have identified one of three cases where the water heater was responsible for ambient CO levels at or above 10 ppm. The use of flue CO readings above the ANSI standard would have identified two of three (67%) of these homes. However, water heater flue CO reads were also above the ANSI standard for four homes where water heaters did not cause ambient CO levels to exceed the action level.

In one home, ambient CO above 35 ppm was found to be traceable to the water heater. While the Minimum Standard would not have detected this case, it was detected by the relevant room ambient test, the appliance ambient test, and the flue CO test.

Kitchen Appliances. The current Minimum CO Testing Standard used by the utilities does not explicitly conduct visual examinations, combustion air evaluations, or CO tests for kitchen appliances. As a result, the Minimum Standard is not designed to assess the performance of these appliances. The relatively common incidence of ambient readings at or above 10 ppm in kitchens, as found in the more comprehensive NGAT tests, would seem to warrant some kinds of tests. As shown in Section 6, visual and "appliance on" tests of burners and pilots would reveal some problems, as would kitchen appliance flue tests. Flue tests revealed air-free CO above the ANSI standard (as interpreted in this study) in 35 (74.47%) of the 47 cases where kitchen appliances were responsible for high ambient readings. However, flue tests were also failed in 124 (22.63%) of the 548 cases where kitchen appliances did not yield ambient CO levels above the 10 ppm action level.

In two homes, ambient CO above the threshold of 35 ppm traceable to kitchen appliances was found. The Minimum Standard would have detected only one case. Either a room ambient CO test conducted in the kitchen, or an exhaust/flue CO test on kitchen appliances would have detected both cases.

Other Appliances. Only 26 homes out of the 815 homes surveyed had gas logs. One of these homes was found to have ambient CO above the action level of 10 ppm in the room containing the gas logs. Again, however, the Minimum Standard does not explicitly apply to gas logs, so it is not capable of discerning such cases. No instances of ambient CO at or above 35 ppm were found to be attributable to gas logs.

The NGAT survey found no evidence of any ambient CO associated with natural gas dryers. Moreover, as seen in Section 5, no natural gas dryers tested in this study exceeded the utility standards for as-measured flue CO.

9.6 *Recommended Combustion Appliance Protocols*

9.6.1. Overview

The Standardization Team offers several recommendations for a set of combustion appliance assessment protocols for the LIEE Program.[2] These recommendations relate to three general issues:

- In which LIEE homes should combustion appliance assessments be conducted?
- What protocols should be used in the course of combustion appliance assessments?
- When should combustion appliance assessments be conducted?
- What should be done when a combustion appliance in an LIEE Program participant's home fails a test?

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2 It should be noted again that, while CPUC staff did take part in the Team meetings, these staff do not necessarily endorse any of the recommendations contained in this report.

- What role (if any) should CO alarms play in the LIEE Program?
- Who should conduct the combustion appliance assessments?

These issues are addressed below.

9.6.2. Applicability of Combustion Appliance Assessments

Applicability to Combustion Fuels other than IOU Natural Gas

There are two key questions relating to the applicability of combustion appliance assessments. The first question relates to the fuel used by the appliances in question: Should assessments be done only on natural gas appliances using IOU natural gas, or on all combustion appliances (e.g., propane and wood)? The Standardization Team considered four program options in this regard:

- First, assessments could be restricted to IOU natural gas appliances, but infiltration reduction measures could still be installed in homes with other combustion appliances. This option was rejected because it would violate one of the rationales for conducting appliance tests, namely the potential for affecting ambient CO levels through weatherization.
- Second, assessments could be conducted for other combustion appliances prior to weatherization, and infiltration reduction measures could be deemed non-feasible for homes with CO levels above some threshold (say, the ambient action level of 10 ppm). Under this option, homeowners and/or tenants would be advised when appliances exceeded the threshold. This option would avoid the aggravation of CO in homes with pre-weatherization readings that were above the threshold, but would not provide a safeguard against the creation of CO problems through major infiltration reductions. Further, this option would entail the expenditure of IOU ratepayer funds for testing appliances that do not use IOU natural gas.
- Third, assessments could be conducted for other combustion appliances prior to or after weatherization, and appliances with CO related problems could be repaired or replaced. This would provide the same level of service to these homes as for homes with IOU natural gas, but would use IOU ratepayer funds for both assessment and appliance repair and replacement.
- Fourth, assessments could be restricted to IOU natural gas appliances, and LIEE Program infiltration reduction measures could be deemed non-feasible for all homes using other combustion fuels (e.g., kerosene or propane). This would avoid situations in which major reductions in infiltration could affect ambient CO levels. It is true that it would prohibit homes with other combustion appliances from receiving a full range of LIEE measures, and that many of these homes (those in IOU electric service areas) would be contributing to the funding of the LIEE Program through their electricity bills.

The Standardization Team recommends that this fourth option be adopted by the Commission. The Team also proposes that homes for which infiltration reduction measures are deemed non-feasible under this provision be referred to the State's Low Income Home Energy Assistance Program (LIHEAP), or, in the case of homes with non-IOU natural gas appliances, the relevant natural gas utility for full treatment. The Team also proposes to request that LIHEAP contractors and non-IOU natural gas utilities report back to the involved IOU to verify that service was provided.

PG&E concurs with the Standardization Team recommendation on natural gas appliance testing in the interest of reaching a Team consensus. The Standardization Team recommends that electricity customers should be deemed to be ineligible for infiltration reduction weatherization measures, which would otherwise reduce the amount of electricity consumed for heating and air conditioning, if they have a non-natural gas combustion appliance. However, PG&E wishes to make it clear that implementation of this recommendation will have an adverse effect on its ability to serve its rural customers.

PG&E contractors have set goals in all counties in an effort to reach equitable penetration levels for both rural and urban customers. Rural and urban statistics are supplied quarterly in the utilities' Rapid Deployment Reports. PG&E's service territory is large and geographically diverse, and consequently PG&E serves many homes in rural communities where natural gas is not available. For example, over fifty percent of PG&E's customers in Alpine, Amador, Calaveras, El Dorado, Lake, Lassen, Mariposa, Plumas, Sierra, Trinity and Tuolumne Counties are on an electric heat rate. Many of these electric customers use propane and other non-natural gas equipment. Based on its LIEE program field experience in these counties over the last several years, PG&E estimates that approximately fifty percent of these customers have propane or other non-natural gas appliances in addition to electric heat. This totals over 20,000 low income rural PG&E customers in just these eleven counties who would not be eligible for full program participation, but who are nevertheless included in PG&E's demographic estimate of customers who are eligible for the program.

Currently, PG&E performs CO tests on propane and other non-natural gas combustion appliances in these customer homes that qualify for non-infiltration measures (i.e., that utilize electric heat) so that these customers can receive all of the weatherization measures for which they qualify. These appliances are not adjusted, repaired or replaced. If a CO-problem associated with a non-natural gas appliance is identified, the customer is referred to their supplier and receives only non-infiltration LIEE Program measures until the problem is corrected.

Applicability to Homes Revisited under Rapid Deployment

A second issue relating to the application of appliance assessments is the treatment of homes scheduled to receive only electric measures. As part of rapid deployment, utilities are permitted to go back to homes that have already been weatherized in order to install additional electric measures like energy efficient replacement refrigerators. The Team recommends that natural gas appliance assessments not be required in such cases where weatherization is not provided.

9.6.3. Combustion Appliance Assessment Protocols

The Standardization Team's recommendations for combustion appliance assessment protocols are presented below. In the one case in which there is still some disagreement among the members of the Team, both majority and minority opinions are presented.

Visual Examinations

The Team recommends that the visual examination steps currently taken under the Minimum Standard should be retained. These steps include flue and vent system checks as well as appliance component checks.

Combustion Air Evaluations

The Team recommends that the combustion air evaluation steps currently taken under the Minimum Standard should be retained.

CO Testing

The choice of a specific type of CO test for each appliance was the subject of considerable discussion within the Team. Three tests were considered in the course of the study: room ambient CO tests, appliance ambient CO tests, and exhaust/flue CO tests. These tests were described in Sections 4 and 5. In order to provide further input to the Commission, we review the arguments for and against each type of test below.

- ***Room Ambient Tests***. The room ambient tests recommended as an option for the combustion appliance assessment are conducted in the rooms containing combustion appliances, with all appliances operating.[3] These tests are conducted in the middle of the respective rooms, and are relatively easy to administer. They do discern the presence of CO in the ambient air at the time of testing, but, as discussed in Section 6, may not always identify the offending appliance because of air mixing. As indicated in Section 6, for instance, room ambient CO readings above the action level of 10 ppm in rooms with space heating and/or water heating was often attributable to kitchen appliances in another room.

3 Using the terminology developed in Section 2, these would be Room Ambient Tests #2.

- ***Appliance Ambient Tests.*** Appliance ambient tests are similar to room ambient tests, in the sense that they focus on ambient CO. However, they differ in that they are administered close to the combustion appliance, and, as indicated in Section 6, were found to be more effective than room ambient tests in discerning potential CO problems associated with space heating and water heating appliances.
- ***Exhaust/Flue CO Tests***. As explained in Section 5, exhaust/flue tests are conducted in the exhaust streams of the combustion appliances in question.[4] A high exhaust/flue CO reading indicates that the appliances is emitting high **CO** into the exhaust stream, but this may or may not affect ambient CO in the living space at the time of the test. The effect of exhaust/flue CO on ambient CO in the home depends upon the effectiveness with which the exhaust stream is being vented. Proponents of flue CO testing argue that without flue CO testing, appliance wit high flue CO but venting properly at the time of the test may not be discovered, and that these appliances may present a problem at a later date if venting problems occur. Opponents of exhaust/flue CO testing argue that flue CO, in itself, is not a hazard to occupants, and that potential problems occur only if problems in drafting occur and ambient CO is elevated some time in the future after weatherization has been completed.

Assuming that potential CO problems found by the chosen test are mitigated as part of the LIEE Program, the choice between exhaust/flue CO tests and ambient CO tests involves a very simple tradeoff between stringency and cost. Ambient tests will reveal potential problems given the conditions experienced during the on-site tests. On the basis of the results of this study, ambient CO at or above the action level of 10 ppm will be found in roughly 7% of the homes tested, and will require some sort of mitigation in these cases. Exhaust/flue CO tests will reveal a wider range of potential problems (both those that exist under test conditions and those that could occur should inadequate venting occur at a later date), and the cost of mitigation will be higher. The choice between these two options is a policy question, rather than a technical issue.

The Team recommends that the following protocols should be adopted for CO testing of various natural gas appliances:

- ***Heating Appliances.*** Room ambient CO testing or flue CO testing of heating appliances should be maintained as a standard step in the overall testing protocol.
- ***Water Heaters.*** Room ambient or flue testing of water heaters should be conducted if the water heater is in the home's envelope or in a closet abutting conditioned space.

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[4] As also indicated in Section 5, it was generally not possible to conduct exhaust tests on some appliances (e.g., gas logs and most kitchen appliances) before dilution air enters the exhaust stream. As a result, what we refer to as exhaust/flue tests for these appliances are more akin to appliance ambient tests.

- ***Kitchen Appliances.*** Room Ambient tests should be taken in the kitchen while kitchen appliances are operating.
- ***Gas Logs.*** Exhaust/flue tests[5] should be conducted on gas logs.
- ***Dryers.*** No ambient or flue tests should be conducted on dryers. None of the dryers in the sample were found to have flue CO above the standard, or to lead to ambient CO above the action level. However, visual inspections of dryers will be conducted to ensure that they are properly exhausted to the outdoors.

If a problem is identified through the application of the overall natural gas appliance testing protocol, the Team recommends that the case be referred to qualified utility-trained personnel for resolution.

Draft Tests

As indicated in Section 6, the study found that over 3% of space heaters and 5% of water heaters had inadequate draft, and consequently recommends that draft tests be conducted as part of the combustion appliance protocol. The Team recommends that smoke tests should be used to test for proper drafting of appliances for which these tests are applicable. This recommendation is based on the results of the analysis presented in Section 6.4, which indicated that the smoke test gives virtually identical results to the instrument test, and the fact that smoke tests are considerably easier to implement.

9.6.4. Timing of Combustion Appliance Testing

The members of the Team currently differ with respect to the timing of combustion appliance testing. PG&E conducts testing on all homes prior to weatherization and on a 20% sample of homes after weatherization; SoCalGas and SDG&E conduct testing after weatherization. All of the utility members of the Team have designed their respective protocols to reflect their judgment on the best way of serving the interests of their customers. Evidence collected on the influence of weatherization on CO levels was deemed inconclusive, thereby providing little guidance for the choice of timing. However, in the interest of moving toward the goal of standardization, all members of the Team recommend that testing be conducted after weatherization. This would guard against the possibility that weatherization does have some influence on drafting and/or long-term concentrations of CO.

Since the team recommends post-weatherization combustion appliance testing, it is possible that the test would discover inadequate combustion ventilation air, and that this would require additional combustion air vents to be installed. This is normally not a problem, but

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[5] In this context, the recommended test is the one discussed in Section 5. It is conducted inside the top edge of the fireplace opening. As indicated earlier, it may be more appropriate to refer to it as an appliance ambient test, but we will retain the terminology adopted in Section 5 and refer to it as an exhaust/flue test.

on a rare occasions the installation of additional venting may require a major and costly retrofit for the unit to pass inspection. Therefore, the Team recommends that preliminary combustion air ventilation evaluations be conducted as part of the initial home assessments.

9.6.5. Actions to be Taken When Appliances Fail Tests

The Team recommends the following actions when appliances are found to have problems:

- In owner-occupied homes, natural gas space heaters failing one or more of the tests covered by the new protocol should be repaired or replaced.
- In owner-occupied homes, natural gas water heaters failing one or more of the tests should be repaired or replaced.
- In owner-occupied homes, non-program appliances failing one or more of the tests covered under the new protocol should be serviced.[6] If these repairs do not correct the problem in question, the appliances in question should be capped and reported to the owner.
- In renter-occupied homes, appliances failing one or more of the tests covered by the new protocol should be serviced.[7] If servicing an appliance does not correct the problem in question, the appliance be should be tagged, shut off, capped and reported to the tenant and the landlord.

This policy would expand the types of appliances repaired or replaced under the Program to include water heaters that are found to have CO-related problems. (Under rapid deployment, water heaters ten years old or older are replaced with high-efficiency units. The current recommendation would not be limited to water heaters at least ten years old.) The associated costs of repairs and replacements are summarized in Table 9-3 and Table 9-4. Table 9-3 summarizes the repair and replacement costs incurred as part of the NGAT study. As indicated there, all types of appliances were repaired or replaced as necessary. As shown, the costs of repairing and replacing appliances were predominantly associated with space heating and water heating. Relatively little was spent on dryers or kitchen appliances, even though they were also eligible for repair or replacement under the NGAT study protocols. The total cost of all repairs was roughly $292,000. The cost of water heater repairs and replacements was just over $87,000. However, only $46,642 of the cost of repairing or replacing water heaters was associated with CO-related problems as defined above. The average cost of all water heater repairs (averaged over all 815 NGAT homes) was $119.69; however, the average cost of CO-related repairs was $57.23 per home.

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[6] In this context, servicing an appliance entails providing services that are within the scope of the gas service department for customers in general.

[7] See footnote 6.

Table 9-4 uses the average cost per home for water heating appliances, coupled with an estimate of the number of owner-occupied homes projected to be treated by each of the natural gas utilities in 2003, to develop a rough estimate of the total cost associated with repairs or replacements of water heaters in accordance with the Team's recommendation. As shown in Table 9-3, the cost of this expansion of repairs and replacements to cover water heaters for the three natural gas utilities would be approximately $1.9 million in 2003. (Again, this incremental cost is relative to the base LIEE Program without replacement of water heaters older than ten years old; the incremental cost relative to the current program including water heater replacements would be far smaller.)

Table 9-3: Cost of Repairs and Replacements of Combustion Appliances (NGAT Project)

	Furnace		Water Heater		Dryer		Oven/Stove/Cooktop		
	Repair	**Replace**	**Repair**	**Replace**	**Repair**	**Replace**	**Repair**	**Replace**	**Totals**
Total R&R Costs	$30,319.60	$145,281.65	$15,481.59	$82,059.92	$4,733.01	$1,137.32	$15,924.71	$7,070.48	$292,135.59
Number of Appliances	125	104	109	134	16	2	89	11	408
Average Costs per Appliance	$242.56	$1,396.94	$142.03	$612.39	$295.81	$568.66	$178.93	$642.77	$716.02
Maximum Cost	$1,791.05	$3,500.00	$1,312.95	$3,028.35	$1,361.32	$568.66	$758.04	$1,034.12	$6,179.60
Minimum Cost	$20.00	$350.00	$8.80	$400.00	$27.50	$568.66	$20.00	$432.39	$8.80
RnR Costs	**Number of Appliances Repaired or Replaced**								**Households**
<$100	53	-	66	-	7	-	40	-	91
>$99 and <$200	14	-	22	-	3	-	17	-	34
>$199 and <$300	17	-	14	-	1	-	22	-	31
>$299 and <$400	21	1	1	-	-	-	-	-	13
>$399 and <$500	5	-	-	43	1	-	4	3	36
>$499 and <$1,000	13	1	5	84	3	2	6	7	88
>$999	2	102	1	7	1	-	-	1	115
Total	**125**	**104**	**109**	**134**	**16**	**2**	**89**	**11**	**408**
# of Households Less than $500	110	1	**78**	43	12	-	83	3	205
# of Households More than $500	12	103	**31**	91	4	2	6	8	203
Overall Average Cost per Home	**$37.20**	**$178.26**	**$19.00**	**$100.69**	**$5.81**	**$1.40**	**$19.54**	**$8.68**	**$358.45**

Table 9-4: Projected Cost of Repair/Replacement of Water Heaters for 2003 Program

	Number of Owner-Occupied Weatherized Homes		
	PG&E	SoCalGas	SDG&E
Owner Occupied %	44.00%	41.00%	36.00%
Total Homes Weath.	21,562	49,020	7,890
Owner-Occupied Homes	9,487	20,098	2,840
Cost per Owner-Occupied Weatherized Home	$57.23	$57.23	$57.23
Total Cost of Repairing/Replacing Water Heaters	542,941	1,150,209	162,533

9.6.6. Role of CO Alarms

The Standardization Team recommends against the use of CO alarms as either a substitute for or a supplement of the testing procedures specified above. This position is based on the high failure rate during the sensitivity tests, the number of nuisance alarms (e.g., battery-related chirping), and the negative information gathered in the literature review about the state of the art in CO alarms.

9.6.7. Assessment Personnel

The Team recommends that the utilities be permitted to retain their current option of conducting appliance assessments using in-house staff or contracting with third parties to provide these services.

PG&E uses a lower-paid inspector to perform combustion appliance safety (CAS) tests rather than a gas service representative (GSR) because a GSR isn't required in the vast majority of cases. GSRs are called in response to CAS fails only about 15% of the time. CAS failures are always immediate response jobs for the GSR, so in many cases the inspector waits for the GSR to complete the adjustment so the impact to the customer is lessened. Additionally, due to PG&E's union rules, only PG&E GSRs are allowed to perform minor repairs and disconnections on gas appliances.

9.6.8. Pre-Approvals and Inspections

One of the objectives of this study was to support the standardization of pre-approvals of the installation of LIEE Program measures. The Team's recommendations on natural gas appliance testing essentially decouple measure pre-approvals from CO testing, and this is a major step in the direction of standardization. The Team is not yet prepared to make a recommendation with respect any other changes to the utilities' pre-approval procedures. However, it should be noted that PG&E's support of the recommendation to conduct post-weatherization CO testing rather than pre-weatherization testing is contingent upon the retention of its current pre-approval and inspections procedures.

For the purposes of this report, each of the utility members of the Team provided a description of and rationale for its current pre-approval policies. These descriptions and rationales are presented below. It should be noted that any evaluative statements contained in these rationales reflect the judgment of the utility in question, but not necessarily the opinion of the Team as a whole.

PG&E Procedures

PG&E pre-approval is used for several purposes: to prevent any contractor from over-assessment of measure feasibility, to protect the contractor from post-inspection disputes regarding what measures were or were not feasible, to forecast costs and measure commitments at an early stage, and to screen out non-qualifying home situations before costly measures are installed. In addition, if the Commission adopts the policy of denying infiltration reduction measures to electric heat rate customers who have propane and other non-natural gas appliances, PG&E will use pre-approvals to identify these appliances in the home to avoid installation of the measures by mistake.

PG&E uses the measure pre approval inspection to ensure program compliance by the contractors. Before the pre approval inspections were instituted, PG&E discovered that some contractors were removing functional measures in order to install new measures. The measure pre approval inspection has greatly limited that practice, and has actually helped contractors treat each home comprehensively. The contractor Energy Specialist (ES) is the first out to a home, conducting energy education and installing CFLs in that initial visit. The ES spends more time educating the customer for long-term energy savings than identifying potential measures. The PG&E pre-weatherization inspector's only focus is to identify feasible measures. Because PG&E accurately reports all necessary measures to the contractor, the contractor is able to bring the correct material and labor to the job site on the first visit. Pre-inspections protect the contractor as well, from disputes during post inspections about what measures were eligible for installation. Additionally, pre-inspections allow PG&E to forecast what the estimated program measure commitments are at an early stage, before receiving contractor invoices.

In addition, the pre approval inspection will be used to address a concern brought on by eliminating propane customers and pre CAS tests. In the course of verifying whether or not Combustion Ventilation Air (CVA, a minor home repair measure in the LIEE program) is needed, our inspectors will verify that any homes an Energy Specialist has identified as All Electric don't have propane appliances in them. If infiltration measures are accidentally installed in these homes, there isn't any recourse but to perform a CAS test and correct any problems. (Failing to properly identify appliance fuel was common when PG&E was allowing the contractors to identify All Electric homes and skip calling in for a CAS test in 1999. Energy Specialists do not have the expertise to identify appliance fuel type.)

Since 1998, 10% of our homes failed the CAS test. The most common reason was a malfunctioning or inoperative primary appliance. However, there are some fails that would have been very costly to correct after measures were installed. While performing the pre approval inspection, our inspectors will note any unusual situations or structural problems that just can't be reasonably corrected. These situations include the homes with a flat roof and a slab floor that need CVA in an interior closet, requiring an entire ducting system routed through the home; the town homes with inadequate CVA in the garage where the homeowner association refuses to allow CVA openings to be cut into the garage door; the homes with the furnace cold air return located too close to the furnace closet; and the mobile home without a kitchen exhaust fan. Disconnection of a properly operating appliance because of a structural defect like the examples above is not a reasonable option. Once infiltration-reducing measures are installed in these homes, repairing the fail can be extremely costly, thus PG&E uses pre-approval to screen out these costly situations before they occur.

SCE Procedures

SCE's Home Assessment Service (HAS) is designed to assess each potentially eligible electric measure found in an income-eligible customer home. Through this process, the Assessment Agency will pre-inspect the customer's entire home for eligibility and feasibility of LIEE services. Upon completion of a pre-inspection, agencies will return the information to SCE for verification and referral to agencies and contractors for installation of measures.

The feasibility questions determine if the appliance(s) or service(s) meet the requirements of the LIEE Statewide Policies and Procedures Manual, and the California Weatherization Installation Standards (WIS) Manuals (Conventional Home & Mobile Home).

LIHEAP contractors, CBOs and private contractors will all be involved in HAS. After an entity verifies customer eligibility, the pre-inspection process begins by pre-screening existing electric measures appliances and completing the questions on the Home Assessment Form. Some of the answers to the Pre-Screening questions determine whether the assessment representative will move forward with the actual assessment of each electric measure. *For example:* It might be feasible to replace a customer's existing refrigerator, because the customer has available space, a grounded outlet, good flooring, and a clear route to the location (these are sample feasibility evaluation questions). However, through the pre-screen questions it was determined that the refrigerator is only 5 years old. In this case, the agency would not go on to evaluate feasibility, because the existing refrigerator does not meet the requirements for replacement service.

Once an assessment has been completed the form will be returned to SCE and information will be verified and input into SCE's database. Referrals will then be forwarded to licensed contractors for installation of electric measures

SDG&E Procedures

The order in which SDG&E's customers are served by the prime contractor and its subcontractors is as follows: outreach and education, home assessment identifying measures which need to be installed, weatherization and appliance measures installed by the prime's subcontractors, and the natural gas furnace CO inspection by the prime contractor's gas services staff. Initial home assessments are conducted during the same visit as the initial customer outreach contact and energy education whenever possible.

SDG&E Gas Furnace Inspection and Repair Procedures. SDG&E's HVAC licensed prime contractor's staff performs an initial natural gas furnace inspection for both homeowners and renters in single-family homes, multi-family units and mobile homes after the home has been weatherized. The natural gas furnace inspection provided to all LIEE customers includes cleaning the furnace, turning it on, adjusting if necessary and verifying that the furnace is operating and drafting correctly. For each furnace inspection, the prime contractor's staff completes a check off list, including a room ambient carbon monoxide (CO) test and appliance ambient CO test, to insure consistency. Whenever a defective natural gas appliance is found, the prime contractor staff will do furnace repairs or replacement, and/or notify SDG&E gas services staff to verify any problems, and shut off, tag, and cap faulty appliances if necessary.

The prime contractor's staff does minor furnace repairs if needed, and can replace furnace parts for single family residential homeowners and renters if the cost is less than $120.00. The prime's staff will replace furnace parts as necessary in multifamily units, if the property owner provides the parts at the time of the furnace inspection.

An SDG&E gas service technician inspects and provides prior approval for natural gas furnace replacements for homeowners. These are inspected and pre-approved to eliminate any possibility of self-serving by the prime contractor or it's HVAC subcontractors who install of new furnaces or do major repairs. The SDG&E gas service technician also verifies the furnace thermostat is located in a proper location, or designates a new thermostat location, where appropriate, prior to installation of a replacement furnace.

SDG&E Weatherization Measure Pre-approvals and Inspections. SDG&E's prime field services contractor conducts DAP customer outreach, energy education, and initial home assessments. SDG&E checks its DAP database to make sure a customer has not participated in its program within the last ten years before referring the customer back to its prime contractor for service. The prime contractor also maintains a current version of the DAP dbase and makes sure a customer has not participated in the program before offering them DAP services (other than in RD appliance replacement “go back” situations).

DAP energy efficiency measures are installed by subcontractors working directly for the prime. After SDG&E receives an invoice from the prime contractor for a completed job, SDG&E DAP inspectors verify up to 100% of the all weatherization jobs. This allows SDG&E inspectors to verify that all feasible measures were installed for each customer, the program measure installation standards were met, consistency workmanship of the crews, confirm measure performance, and provide feedback to the DAP manager on any problems identified, or suggest ways to enhance the program.

During the inspection process the inspectors will look for signs of removal of pre-existing energy efficiency or weatherization measures. If they see any consistent signs of this, or hear negative feedback from customers, the inspector will report back any concerns to their supervisor and the DAP manager. If it is determined that there are problems, the prime contractor has the responsibility to take any and all necessary steps to ensure corrective action with their subcontractors.

In addition to the above services, SDG&E also sends out a Gas Service Representative on the request of either a customer or an LIEE contractor.

<u>SoCalGas Procedures</u>

SCG Gas Furnace Inspection and Repair Procedures. There are two processes in the SoCalGas furnace inspection and repair procedures:

- The majority of Furnace Repair/Replacement customers are referred to the DAP program by SoCalGas’ energy service technicians. When a customer calls SoCalGas’ service department to have their furnaces serviced, and it is deemed inoperative, the technician refers the customer to DAP. The service technician will document, in detail, the problem with the furnace and whether it should be repaired or replaced. When the customer calls DAP for assistance, program staff already have the service technician’s report in SoCalGas’s database system. The customer is then qualified, based on program guidelines, and the work is assigned to one of SoCalGas’s HVAC contractors for action.
- DAP weatherization contractors, who also hold HVAC licenses, and participate as furnace program contractors, are authorize to qualify and recommend repairs/replacement of furnaces to the DAP office. The DAP office receives the customer agreements from the contractor with all qualifying information and contractor’s recommendations for verification. Once DAP verifies the

information, contractor is allowed to provide furnace repair or replacement services to that customer.

All furnace-related work is inspected for compliance with local building codes and ordinances, manufacturer specifications, workmanship, and Weatherization Installation Standards. In addition, all homes are tested for ambient CO.

SCG Weatherization Measure Pre-approval and Inspections. SoCalGas' program contractors conduct customer outreach and home assessments, and determine which weatherization or appliance measures are needed for each home served under the DAP program. All homes must be checked by the contractors against the DAP database to ensure they have not been previously weatherized under SoCalGas's program before a customer is promised any services. If contractor does not check against the DAP database, and a home is later found to have been previously weatherized under SoCalGas' program, the contractor is denied payment for that home.

SoCalGas inspects up to 100% of DAP home receiving attic insulation as a measure. All other homes are inspected at a minimum rate of 20%. SoCalGas's policy is to conduct room ambient appliance CO tests on up to 100% of the homes weatherized under its LIEE program . During the inspection process, the inspectors look for installation of inappropriate measures by contractors, or any signs of removal and replacement of pre-existing weatherization measures. If they see any signs of this, or hear negative feedback from customers, the inspector will report back any concerns to their supervisor and the DAP manager. If the manager determined that there are concerns, the contractor is held responsible for taking any and all necessary actions to correct the situation.

Appendix A

Summary of Interviews of Independent Contractors

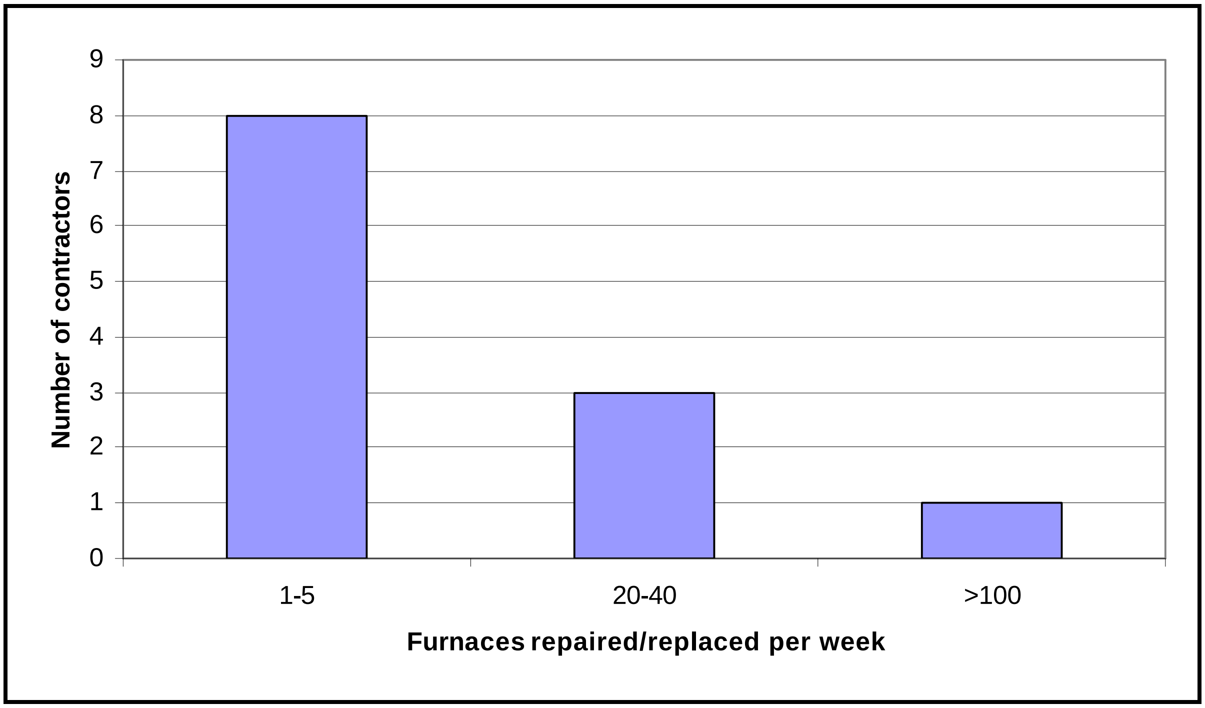
In March and April 2002, RER interviewed a number of independent contractors in California to understand industry practices regarding CO testing outside of utility-associated programs. A total of 34 interviews were conducted. 12 of these interviews were with contractors who did furnace repair and furnace replacement work. RER found that many of these contractors did only furnace-associated work or did furnace work along with some plumbing work. In addition, RER also spoke with 22 contractors who did caulking and weatherstripping work. RER found that few contractors did ***only*** caulking and weatherstripping work and that most contractors who did this type of work also did waterproofing, painting and general handyman type activities.

The results of these interviews show that furnace repair and replacement contractors are more likely to check for high levels of CO then are their weatherstripping and caulking counterparts. These results are discussed in more detail below:

Interviews with furnace repair and replacement contractors

A total of 12 interviews were conducted with furnace repair and replacement contractors in California. Of these contractors, three repaired or replaced 1-2 furnaces per week, five repaired or replaced 4-5 furnaces per week, three repaired or replaced 20-35 furnaces per week and the largest contractor repaired or replaced about 125 furnaces per week. The size distribution of these contractors is shown in Figure A-1:

Figure A-1: Size Distribution of Furnace Repair and Replacement Contractors



Of the 12 contractors interviewed, a majority (9) did not do any work that was associated with any utility programs. Of the three contractors whose work was associated with utility programs, one contractor said 20% of the work he did was associated with a utility program (he repaired or replaced about 35 furnaces per week), and two more contractors said about 50% of the work they did was associated with a utility program (one of these contractors repaired or replaced 2 furnaces per week and the other repaired or replaced 22 furnaces per week).

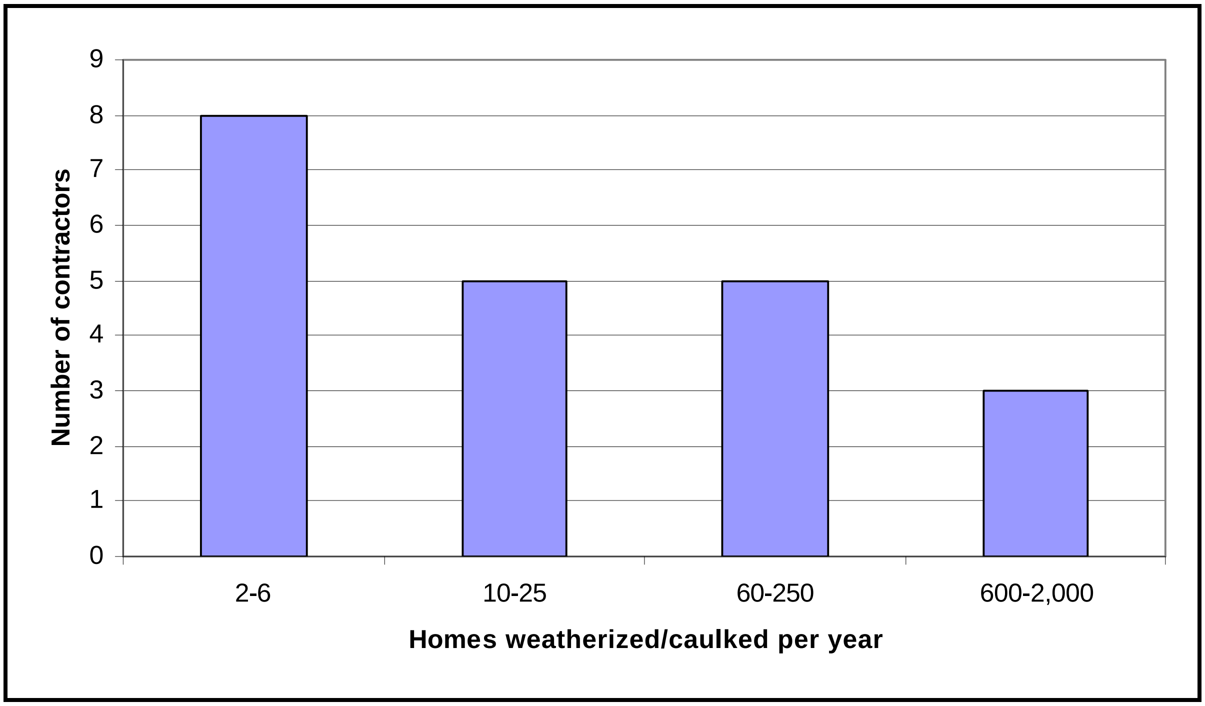
With regards to CO testing, 11 out of the 12 contractors interviewed checked for CO in one way or another (as shown in Figure A-3). Of these 11 contractors, two contractors reported they tested for CO by only doing a visual check for cracked heat exchangers, one contractor reported that he only tested for CO if requested by the customer, seven contractors contractors indicated that they used CO detection equipment to measure CO levels before conducting repair or replacement work and one contractor indicated that he used CO detection equipment to measure CO levels both before and after conducting repair or replacement work. Interviews with contractors show that the majority of contractors only checked for CO levels before beginning repair or replacement work. When asked why they did not check for CO levels after the repair or replacement work had been completed, contractors indicated that they simply assumed that the work they did fixed the problem (in the case of repairs) or that the new furnace was not faulty, and therefore, CO emissions need not be checked (in the case of replacements).

The CO detection equipment was used to measure appliance specific (i.e. furnace) flue levels. Finally, the customer was never charged extra for the CO check and none of the contractors who checked for CO levels charged their customers extra for doing the CO check and many educated the customer if levels of CO were unusually high.

Interviews with weather stripping and caulking contractors

A total of 22 interviews were conducted with contractors who did weather stripping and caulking work. Of these 22 contractors, eight contractors repaired 2-6 homes in a year, five contractors repaired 7-50 homes in a year, five contractors repaired 51-250 homes in a year, and three contractors repaired 600 – 2000 homes in a year. The size distribution of these contractors is shown in Figure A-2:

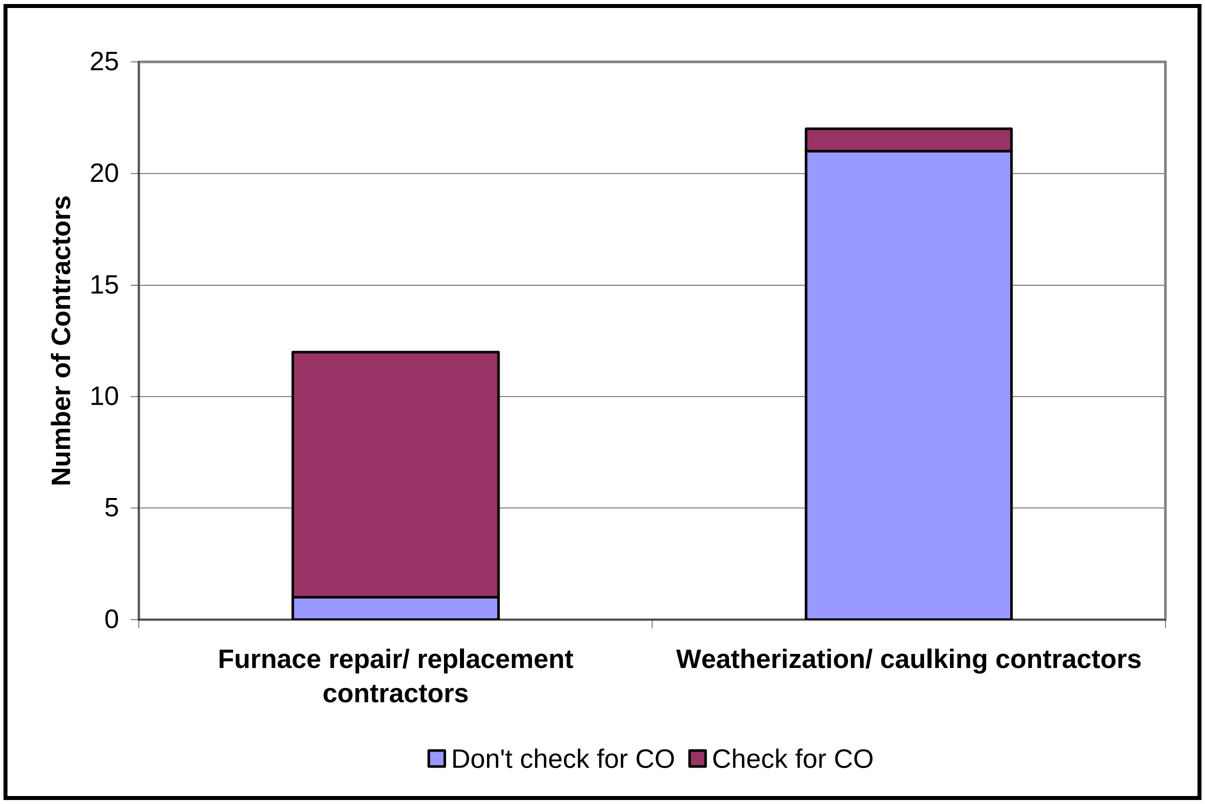
Figure A-2: Size Distribution of Weather Stripping and Caulking Contractors



Of the 22 contractors interviewed, a majority (19) did not do any work that was associated with a utility program. Of the three contractors that did do work that was associated with a utility program reported that about 20-50% of their work was associated with a utility program. One of these contractors repaired 35-50 homes in a week, the next contractor repaired five homes in a week and the last contractor repaired two homes in a week.

With regards to CO testing, only one contractor systematically checked for CO levels. Incidentally, about 50% of this contractor's work was associated with a utility program and he checked for CO before starting his caulking and weatherstripping work and used CO detection equipment. These results are shown in Figure A-3. One more contractor (who repaired 12 homes in a week) reported that if the customer asked for a check of CO levels, then he would call in another contractor to come into the home and measure CO levels. Another contractor reported that he did not check for CO levels but if it needed to be done, the testing would be done or arranged by the general contractor. Finally, one more contractor (who repaired five homes in a week) reported that he did not usually check for CO levels but did carry CO detection equipment with him and would use this equipment if doing any work around a furnace.

Figure A-3: CO Checks by Type of Contractor



APPENDIX B

NGAT SURVEY PROTOCOL

PART 1—ON-SITE SURVEY PROTOCOL

A. THE NATURAL GAS APPLIANCE TESTING (NGAT) STUDY

The NGAT Study On-Site Survey Protocol was developed to study the following six procedures and meet the requirements of each:

1. Ambient CO Alarms as an Alternate or Supplement to Testing
2. Visual and Olfactory Checks and Self Reports
3. Room Ambient Test
4. Appliance Ambient CO Test and Staging in Winter Condition
5. Flue Gas CO Test and Staging in Winter Condition with Fans
6. Complete Testing Procedure in Worst Case Condition

B. BACKGROUND INFORMATION TO BE COLLECTED

The demographic and structural data from the utility outreach and Wx assessment will be included in the participant database. Much of the participant demographic information has already been collected during the outreach and assessment process.

- Data from the intake forms will be entered and provided to the technician before starting, so that this information will not have to be collected again.
- Technicians will be required to collect any uncollected client data information. See the Data Collection Form.

C. NATURAL GAS APPLIANCES TO BE TESTED

1. All operating gas appliances within the living space will be tested, and all forced-air heating systems regardless of location.
2. Appliances located within ten (10) feet of the living space will be tested.
   - Within the home, attic, basement, utility or appliance room, attached garage, or a room/enclosure with a wall common to the living space (e.g., a water heater closet built into the structure but accessed from outdoors).
   - Outside the house:
     - All roof-mount and slab-mount furnaces.
     - Any water heater, clothes dryer, etc. located (or having an exhaust termination) within 10' of a door or window leading into the living space.
3. Abandoned Appliances
   a. An abandoned appliance does not require testing.
   b. An appliance is considered abandoned <u>only if</u>:
      - the gas line valve is capped, <u>or</u>
      - the valve is removed and the gas line is capped.
   c. Primary appliances must <u>not</u> be abandoned without prior approval of the Project Manager and consent of the client. They are the heating system, cooking appliance, and water heater, when only one of each is present.
   d. Secondary appliances may be abandoned with the client's permission. They include a second heater, cooking appliance, or water heater, and the clothes dryer.

e. When a cook top or oven burner is abandoned, the burner valve must be properly capped.

f. Any appliance or burner, either abandoned or found abandoned, must be recorded on the client's Data Collection Form.

D. HEALTH & SAFETY INSTRUCTIONS

D.1 Gas Appliance Defects

Any and all defects and problems with any gas appliance will be identified and recorded, but not remedied until after weatherization measures are installed and the Post-Wx NGAT Testing procedures are completed.

Exception: Testing stops and immediate action is required for the following:

- Unstoppable gas leak(s)—see D.7.
- Room Ambient CO in excess of 35 ppm

D.2 AMBIENT CO LEVELS

a. If Room Ambient CO exceeds the outdoor ambient reading by 10 ppm, record finding in the Data Collection Form (Sections D and F). Indicate the appliance(s) operating in the room and the date and time of the reading.

b. Room Ambient CO **35 ppm or less**: Conduct NGAT testing.

c. Room Ambient CO **36 – 199 ppm**:
   - Ventilate the home, and advise occupants to evacuate until Room Ambient CO is reduced to 35 ppm or less.
   - Conduct NGAT testing, but do not stay in an atmosphere with 36 – 199 ppm CO for more than fifteen (15) minutes.

d. Room Ambient CO **200 ppm or higher**:
   - Advise occupants to immediately evacuate the home.
   - Ventilate the home until Room Ambient CO is reduced to 199 ppm or less.
   - Conduct NGAT testing, but do not stay in an atmosphere with 36 – 199 ppm CO for more than fifteen (15) minutes.

D.3 Gas Appliance Problems

Gas appliance problems such as the following require repair after Wx and Post-Wx NGAT Testing, but the appliance can still operate:

- Continuous roll-out with flue-gas CO below the Action Level and Room Ambient CO of 35 ppm or less.
- Delayed ignition.
- Inadequate or improper combustion air venting.
- CO above Action Level (without continuous spillage).
- Dryer not exhausted to the outdoors (or otherwise substandard).
- Water heater without combustion chamber inner shield or outer door.
- Furnace without roll-out shield (when unit was manufactured with one).
- Floor furnace is present and the clothes dryer is exhausted under the house.

D.4 Drafting and Spillage Problems

If a vent does not draft (see Table H-2) and/or is spilling combustion gases into the living space, the following shall be conducted:

a. Shut down and "Service Tag" the appliance (follow procedures in D.6) after the Post-Test (after the Pre-Test, if the Post-Test will not be conducted the same day).

b. Thoroughly inspect flue/vent for blockages or other problems.

c. Repair vent problems after weatherization and Post-Wx NGAT Test are completed.

D.5 Combustible/flammable Materials in Unsafe Locations

Combustible/flammable materials located in, on, or near enough to be considered unsafe shall be removed or relocated before proceeding. If those materials cannot be removed, further testing of the affected appliance will not be conducted.

D.6 CO Levels After Post-Wx Tests

If in In-Flue levels of CO of a gas appliance is above the "In-Flue CO Action Level" (Table D-1) the following shall occur:

a. Turn appliance off at the gas control valve and line valve and "Service Tag" the appliance.

b. Instruct client to not use that appliance until the corrections have been made.

c. Repair/replacement will occur after weatherization and the Post-Wx NGAT Test are completed.

d. Provide a substitute appliance (only if appliance is critical to the health and well being of household) until the appliance can be repaired or replaced.

e. Document client notification:

- Complete "Combustion Appliance Action Form," obtain client's signature, and give a copy to the client.
- Record in Data Collection Form.

Table D-1: In-Flue CO Action Levels

Appliance	CO PPM "AS MEASURED"		
	PG&E	SoCalGas	SDG&E
• Forced Air Unit (FAU)	100	275*	275*
• Gravity Furnace	100	275*	275*
• Floor Furnace	100	275	275
• Wall Furnace (Natural Draft)	100	125*	125*
• Wall Heater (Direct Vent)	100	275	275
• Water Heater	100	125	125
• Oven/Broiler	100 (225 after service)	225	225
• Cook-Top Burners	100	25	25
• Clothes Dryer	100	275	275
• Gas Log	100	25	25
• Pool/Spa Heater	100	275	275
• Refrigerator	100	25	25

*Average of all firebox chambers; however, corrective action is required when any one chamber of a multi-burner/chamber equals or exceeds the listed action level.

D.7 Gas Leaks

Gas leaks require immediate attention. NGAT Technicians may stop leaks when tightening a fitting will remedy the leak. When that is not possible/feasible, the RHA Technician will:

a. Warn client to not use appliances that could ignite leaking gas.

b. Postpone remaining NGAT tests that could ignite leaking gas until after the leak is repaired.
   - Note: Electric sparks can ignite leaking gas. Avoid using a telephone or flashlight (3-cell or larger) in the presence of strong odors of leaking gas.

c. Ask the client to call their gas utility's service department (or LP gas dealer) immediately to fix the leak.
   - If odors of leaking gas are strong inside the house, telephone from outside the house (e.g., on a cell phone or at a neighbor's house).
   - If the leak cannot be located or fixed, go outside to wait for repair service (but do not turn off gas at the meter).

d. Document client notification:
   - Complete "Combustion Appliance Action Form," obtain client's signature, and give a copy to the client.
   - Record in Data Collection Form, Section E.

D.8 Customer Cancels Procedures

If testing (or weatherization) is stopped by the customer (e.g., because they have an emergency and/or must leave), the Technician (or crew) is to notify RHA in Chico.

E. VISUAL AND OLFACTORY CHECKS AND SELF REPORTS

This minimal procedure includes a Customer Interview to ascertain their knowledge of the state of their gas appliances, an Olfactory Check for odors of gas leaks and of combustion byproducts (aldehydes), and a visual inspection of gas appliances and ducts. The technician will conduct this procedure during a walk-through survey of the residence.

E.1 CUSTOMER INTERVIEW

1. Conduct Customer Interview.
2. Walk through the residence with the customer or contact person and identify all combustion appliances.

E.2 OLFACTORY CHECK OF BUILDING

During the walk-through, sample the air by smelling for odors. Record if any of the following can be detected by smell and where they were detected (location):

1. Aldehyde odors—Check:
2. Gas odors—Check:
3. Masking odors (cigarette smoke, VOCs, noxious odors, etc.)

E.3 WALK-THROUGH INSPECTION OF GAS APPLIANCES

During the walk-through conduct a cursory visual inspection of each combustion appliance.

1. Sketch a floor plan of the residence while conducting the walk-through inspection of the structure.
2. Identify and locate each combustion appliance on the floor plan.
3. Check for the following and record findings:
   - Gas water heaters in bedrooms or bathrooms.
   - Unvented room heater or cooking appliance used for space heating.
   - Mobile Home with gas cooking—mechanical or gravity kitchen ventilation defects/malfunction.
4. Inspect for health and safety issues around appliances:
   - Combustible and/or flammable items stored on or near appliances.
5. Check for the type of combustion air venting.
   - Combustion air vents to outdoors (or to adjacent interior volume).
   - Combustion air vent openings dirty, or obstructed by stored household items.
6. [FAUs] Check at furnace location for duct disconnections and plenum leaks near open combustion appliances and sources of pollution (e.g., chemicals in a garage) that can draw in noxious products.

E.4 CUSTOMER ASSISTANCE

When Pre- and Post- NGAT Testing is scheduled, each participant will be asked to <u>not</u> be (a) cooking in the oven, drying clothes, or smoking during the test periods, nor (b) operating the wood stove/fireplace prior to testing.

F. ROOM AMBIENT TESTS

This procedure will measure CO in each room with a combustion appliance. *<u>Exclude</u>* Cook Top Burners, Gas Log, and Clothes Dryer.

F.1 PREPARE CO MONITORS/COMBUSTION ANALYZER

1. With the combustion analyzer outside or per manufacturer's instructions, turn on the analyzer and record the *Initial* Outdoor CO reading on the Data Collection Form.
2. Record outside air temperature on the Data Collection Form.

F.2 LEAVE HOUSE IN "AS-FOUND" CONDITIONS.

F.3 PERFORM "ROOM AMBIENT CO" TEST #1

1. Measure CO in each room/area containing a gas appliance (including utility room or service porch) or in the case of a forced air unit, CO is measured in the center of the living space.
   - Take each reading holding the CO analyzer probe vertically (with the inlet pointing upward) at approximately chest level, in between chest level and the ceiling, and as close to the ceiling as possible.
   - Testo: (a) Hold the probe straight out at chest level, within 1 foot of the ceiling, and half way between chest and ceiling locations, and (d) record the highest reading.

- Sample the air in each room containing a combustion appliance. Stand in the physical center of the room when feasible, but attempt to stay 10 feet away from supply registers and gas appliances. (Indicate on the floor plan the location of each sample point.)
- When there is an appliance enclosure, check two feet outside the door of the enclosure. Applies to all appliance enclosures, regardless of combustion air source (indoors, outdoors, or combination).

2. Record each Room Ambient CO reading and temperature by room tested.
   - Include attached, enclosed garages if gas appliances are present.
   - Do not operate nor include Gas Log or Clothes Dryer.
3. See D.4 of Health & Safety Instructions for the action to be taken when the First Room Ambient CO Test reading:
   - Exceeds the Outdoor Reading by 10 ppm or more at any location, or
   - Exceeds 35 ppm.

F.4 PREPARE FOR "ROOM AMBIENT CO" TEST #2

F.4.1 Simulate winter conditions by doing the following:

1. Close all exterior doors and windows.
2. Keep fireplace damper closed.
3. Keep interior doors open, except to appliance enclosure.
4. Keep exhaust fans/devices and air handler off.

APPLIANCE ARE NOT OPERATING FOR THE FOLLOWING CHECKS.

F.4.2 Conduct individual appliance Gas Leak tests.

- First, smell/sniff around the gas lines, valves, and controls. Record findings on data collection sheet.
- Second, test valves, line connectors, and controls for gas leaks with a bubble test solution. Record findings on data collection sheet.

IF GAS LEAKS CAN BE EASILY REPAIRED, THE TECHNICIAN SHOULD FIX THE LEAK. IF THE TECHNICIAN CANNOT FIX THE LEAK(S), STOP TEST AND ALLOW CUSTOMER TO CALL THEIR GAS COMPANY. SEE HEALTH & SAFETY INSTRUCTIONS (SECTION D).

F.4.3 Individual Visual Inspection of Gas Appliances

For this inspection, use a mirror and flashlight as needed. Some tools may be required to remove a roll-out shield in order to view the combustion chamber. For each appliance, check for the following conditions, and record findings on the Data Collection Form for that appliance.

- Condition/appearance of appliance (dilapidated, intact, dirty, old, worn, etc.)
- Visual evidence of improper combustion (excessive soot, charring from rollout, scorching, corrosion, etc.).
- Burner defects (clogging, soot, rust, damage, misalignment, etc.) and air shutters and venturies for obstructions and abnormalities.
- Heating system heat exchanger defects (cracks, holes, warping, metal fatigue, etc.).

- Missing or defective parts, such as the following:
  - Combustion chamber door.
  - Roll-out shield (if unit was manufactured with one).
  - Air handler door defective or missing.
  - Gas clothes dryer not properly exhausted outdoors

F.4.4 Inspect each combustion appliance Flue/Vent System for:

- Missing or damaged vent pipe(s) or sections
- Flue/vent pipe disconnections, leaks, obstructions, etc.
- Improper flue pipe type, slope, termination, and clearance from combustibles.
- Draft hood defects (missing, double, misaligned, etc.).

IF PROBLEMS ARE IDENTIFIED, RECORD REPAIRS NEEDED (DATA FORM SECTION B) AND CONTINUE TESTING.

F.4.5 Check Pilot (light pilot if necessary)

- Identify the type of pilot (standing or electronic)
- Check pilot operation (Is pilot working properly?)
- Check flame characteristic (good flame, floating, weak, etc.)

IF PILOT IS FAULTY, RECORD REPAIRS NEEDED (DATA FORM SECTION B) AND CONTINUE TESTING.

F.4.6 Check Gas Control Valves

Visually check external condition of gas control valves and limit controls and record findings. Look for:

- Damaged valve.
- Missing parts.
- Faulty or missing wiring.
- Bypassed safety (locked-open ASO, etc.).

IF VALVES OR CONTROLS ARE DAMAGED OR MISSING, RECORD REPAIRS NEEDED (DATA FORM SECTION B) AND CONTINUE TESTING.

APPLIANCES MUST BE OPERATING FOR THE FOLLOWING CHECKS.

F.4.7 Check Burners and Plenums

Turn on appliance and check the following:

- Operation (Is burner working properly?)
- Ignition timing (how long does it take to ignite burners?)
- Flame characteristic (good flame, floating, weak, yellow, etc.)
- If an FAU, check for:
  - Evidence of flame interference by the air handler (e.g., flames lift off the burner when fan starts up).
  - Plenum leaks in rooms containing appliances.

IF BURNER(S) IS(ARE) FAULTY, RECORD REPAIRS NEEDED (DATA FORM SECTION B) AND CONTINUE TESTING. IF THE MAIN BURNER SAFETY DEVICE HAS FAILED AND GAS IS FLOWING WITH NO IGNITION, “SERVICE TAG” THE APPLIANCE (SEE D.8).

F.4.8 Tactile Spillage Test

Operate appliance at least 5 minutes prior to performing this test.

1. Perform the "Tactile" Spillage Test along the draft hood opening (or the lintel of a fireplace).
2. Move the back (or palm) of your hand along the entire opening of the draft hood or along lintel.
3. If combustion byproducts are spilling, they will feel warm and moist on your skin.
4. If the spillage is continuous (not caused momentarily by gusts of wind), corrective action is required (see the Health and Safety section).

F.4.9 Visual Draft Test

1. Operate appliance at least 5 minutes prior to performing this test.
2. Perform "Visual" Draft Test using "smoke" to test for drafting along the draft hood opening (or the lintel of a fireplace).
3. Use a chemical smoke "puffer".
4. Puff smoke along the entire leading (top) edge of the draft hood opening and watch to determine if it is pulled into the draft hood. If not, draft is inadequate and corrective action is required (see item D.6 of the Health and Safety Instructions).

F.5 PERFORM "ROOM AMBIENT CO" TEST #2

1. After appliances have operated at least 5 minutes, sample room air for CO from the same location used for the first sample (Room Ambient CO Test #1).
2. Follow measurement procedures prescribed in Step F.3.
3. Record each Room Ambient CO reading by room tested.
4. See Protocol Section D.2 for the action to be taken when the Room Ambient CO Test reading:
   - Exceeds the Outdoor Reading by 10 ppm or more at any location, <u>or</u>
   - Exceeds 35 ppm.

G. <u>PROCEDURE #4</u>: APPLIANCE AMBIENT CO TEST AND STAGING IN WINTER CONDITION

This section applies *only* to operating **furnaces, space heaters, and water heaters**.

- The residence is setup in winter conditions.
- Exhaust fans are <u>off</u>.

G.1 PERFORM APPLIANCE AMBIENT CO TESTS ON FURNACES AND/OR SPACE HEATERS AND WATER HEATERS

1. Perform <u>Appliance</u> Ambient CO Tests after the *Second* Room Ambient CO Test.
2. Operate each appliance for at least 5 minutes before conducting the Appliance Ambient CO Test.
3. Perform Appliance Ambient Appliance CO Tests only on Forced-air Furnaces, Space Heaters, and Water Heaters at the following locations:
   - <u>FAU</u>: Inside the supply register nearest the furnace.

- Others: Immediately above heat exchanger.

4. Watch for a *change* in CO reading from *Second* Room Ambient CO Test.
   - An increase in CO reading is a condition requiring investigation into the reason for the increase (e.g., cracked heat exchanger).
   - Record increase in Data Collection Form Section F (see Health & Safety Instructions, D.2).

G.2 OLFACTORY CHECK

After the gas appliance has warmed, up repeat the Olfactory Check for evidence of aldehydes in each room where an appliance has been operating, and record findings in the Data Collection Form.

G.3 PREPARATION FOR PROCEDURE 5

Appliances may be left on at the conclusion of Appliance Ambient CO testing, because Procedure 5 requires the minimum warm-up times specified in Table H-1.

H. PROCEDURE #5: FLUE GAS CO TEST AND STAGING IN WINTER CONDITION WITH FANS

H.1 ESTABLISH *DEFAULT* WORST CASE CONDITION OF THE RESIDENCE

1. Keep the residence in winter conditions (exterior doors and windows closed, fireplace damper closed when possible).
2. Close the following interior doors:
   - Doors to appliance enclosures (except during open-door test).
   - Doors that separate a room with supply register(s) from a central return (only if a FAU is present)
     - For example, doors to bedrooms and bathrooms that contain a supply register when the return grille is in the hallway.
     - This includes bathrooms and utility rooms containing an exhaust fan. The fan will be turned on, but the door will be closed. (For a utility room with clothes dryer, see next step.)
3. Open the following interior doors:
   - Door to laundry/utility room with a functional clothes dryer that is vented outdoors.
   - Doors to a kitchen with a functional range hood that is vented outdoors.
   - All other interior doors.
4. Fans and exhaust devices to be turned on:
   - Air handler (operated with burners off when possible, except when testing the furnace).
   - All exhaust fans/devices vented outdoors (e.g., bathroom and utility exhaust fans, kitchen or range hood fan, and clothes dryer).
   - *Exclude*: whole-house fan and window-mount ventilation fans.
5. In addition to operating the appliance being tested, operate other appliance(s) in the CAZ that can affect operation of the appliance being tested (e.g., open combustion furnace and water heater sharing an enclosure).

H.2 WARM UP APPLIANCES BEFORE TAKING DRAFT AND CO MEASUREMENTS.

Appliances must be warmed up adequately before instrumented Draft and CO measurements are made (see Table D-1).

- In the Data Collection Form, note the time each appliance is turned on and the time of each test.
- Table H-1 shows “minimum” and “additional” warm-up times. Instrumented tests may be performed only after the appliance has warmed up for the minimum time.
- If CO is below the Action Level (Table D-1) after the minimum warm-up period, that concludes the CO Test.
- If CO is at or above the Action Level after the minimum warm-up, the appliance must be allowed “additional” warm-up time before testing again.
- If CO is *still* above the Action Level after the “additional” warm-up time specified in Table D-1, the appliance must be serviced after the Post-Wx Test. Record that as a required repair in Data Collection Form, Section E.

Table H-1

Unit Tested	Minimum (and Additional) Warm-Up Times
Furnace/Heater and Water Heater	5 min. (to 15 min. max if CO is above action level*)
Cook-top Burners	20 sec. (up to 1 minute if above action level*)
Griddle	5 minute (up to 15 minutes if above action level*)
Oven/Broiler**	15 minutes (up to 30 minutes if above action level*)
Clothes Dryer**	1-2 minutes
Gas Log and Gas Fireplace Unit	5 minutes (up to 15 minutes if above action level*)

*Action Level for each appliance is defined in the Health & Safety Instructions, Table D-1.

**Because Oven and Dryer cycle on and off frequently, make sure burner is operating during CO measurement. (A wet towel in the dryer will keep the burner on longer.)

H.3 PERFORM "INSTRUMENTED" DRAFT TESTS.

1. Test with enclosure door <u>open</u> *and* with door <u>closed</u>, when possible.
2. Use the Combustion Analyzer in Draft mode to measure draft in the vent pipe of a natural draft appliance or flue pipe of an induced draft unit.
3. Drill a 3/8" diameter sampling hole the pipe, 12" to 24" (inches) above the draft hood on natural-draft units (outlet thimble on induced-draft furnaces).
   - Drill sampling hole in a straight section of single-wall rigid metal vent pipe (avoid elbows and wyes).
   - Drill double-wall pipe only when it is not part of a listed vent/flue system and drilling it is not prohibited by the local jurisdiction.
   - Drill the ribbed portion of flexible pipes with caution to avoid separating the pipe at a seam. If the plug button does not seal the hole completely, see 4.b. below.
   - Do <u>not</u> drill:
     - Pipes containing asbestos.
     - Pipes with decorative covering in a visible location, unless client gives permission.
4. Seal holes drilled for Draft Test.
   a. After each Draft Test, seal the hole with a tight-fitting "plug button".
   b. After Draft is checked for the last time, the plug button may be additionally secured as needed with Metallic Tape or High-Temp Caulk (e.g., 450 °F RTV red silicone).
   c. Seal test hole in a Double-Wall pipe with a tight-fitting Lag Bolt and High-Temp Caulk. Put caulk on the threads as needed to seal the inner hole.
5. Performing the "Instrumented" Draft Test
   a. Insert the sampling probe to the center of the vent pipe, obtain a draft measurement, and record the reading in the appliance's page of the Data Collection Form.
   b. If the reading is less then the values in Table H-2, see item Protocol Section D.4 in the Health & Safety Instructions.

Table H-2

Outdoor Temperature	Minimum Negative Pressure	
Below 30°F	- 0.02 iwc	- 5.0 Pa
30 to 80°F	- 0.01 iwc	- 2.5 Pa
Over 80°F	- 0.005 iwc	- 1.25 Pa

H.4 REPEAT TACTILE AND VISUAL TEST

With the appliances fully warmed up:

1. Following the instrumented draft test, repeat the following tests
   a. Tactile Test for Spillage (see F.4.8).
   b. Visual Draft Test with smoke (see F.4.9).
2. Perform visual examination of the heating system heat exchanger.

H.5 MEASURE APPLIANCE CO.

1. Test with enclosure door open *and* with door closed, when possible.
2. Measure Appliance CO with appliances adequately warmed-up and operating (per Table H-1).
3. For each appliance tested, record both "as measured" and "air-free" readings on applicable page in the Data Collection Form.
4. Locations for measuring:
   - Natural-Draft Furnace/Heater: Inside each exhaust port before dilution air. When there is a baffle present (e.g., in a Wall Furnace), check CO on both sides of the baffle.
   - Induced-Draft Open Combustion units: Use the hole drilled for the draft test in flue/vent pipe or inside flue/vent termination on roof. (See Instructional Supplement regarding access.)
   - Closed-Combustion units: Inside flue termination, e.g., on mobile home and direct vent furnaces. (See Instructional Supplement below regarding access.)
   - Water Heater: Inside the center tube on both sides of the baffle.
   - Clothes Dryer: Inside vent termination, or by placing the probe down into the lint screen cavity if located on top of dryer.
   - Gas Log: Inside the top edge of the fireplace opening.
   - Gas Fireplace Unit: Place probe extension into dilution air intake and point end down into the flue below the dilution air inlet.
   - Cook Top Burners: 12" (inches) above the open flame with grate in place (do not point end of probe into the flame).
   - Griddle: Inside the port opening with the griddle in place.
   - Oven or Broiler: Inside oven exhaust termination on top of the stove. On built-in ovens, extend probe inward as far as possible. When the oven is vented outdoors, sample ahead of where dilution air is added.
5. Common Vent: Operate both appliances simultaneously during Draft and CO tests, unless CO is measured beyond the wye (See Supplemental Instructions, Section K).

H.6 INSPECT DUCTS AND VENTS IN THE ATTIC AND/OR CRAWL SPACE

1. Inspect the following:
   - Duct system for catastrophic supply/return leaks and disconnections.
   - Flue/vent system for leaks, disconnections, improper slope, improper pipe type, pipe terminating in the attic, etc.
2. Record adverse findings in Data Collection Form, Section E., and follow Health & Safety Instructions if problems exist.

H.7 MEASURE AND EVALUATE COMBUSTION AIR FOR FURNACE/HEATER AND WATER HEATER

1. Evaluate combustion air source (see Supplemental Instructions, Section P).
   - Identify and measure vents/ducts to the outdoors; or
   - Measure room volume, and vents to adjacent space when applicable.
   - Take into consideration blocking effect of mesh and louvers on vents/ducts.
2. Determine whether combustion air is adequate:
   - Calculate the NFVA of the vents/ducts to outdoors; or
   - Calculate room volume, and NFVA to adjacent space when applicable.

I. PROCEDURE #6: COMPLETE TESTING PROCEDURE IN WORST CASE CONDITION

This procedure applies only to homes with a forced-air heating system.

I.1 IDENTIFY COMBUSTION APPLIANCE ZONES

1. Identify each CAZ, and determine if it is inside or outside the main body of the house.
2. Record zone setup on the floor plan.

I.2 PERFORM CAZ TESTS TO DETERMINE *ACTUAL* "WORST CASE" SET-UP OF THE HOME

1. Utilizing Attachment A or Attachment B, as applicable, determine which of the following conditions constitute *Actual* Worst Case conditions:
   - Air handler operating or off; Exhaust fans operating or off.
   - Arrangement of interior doors: open or closed.
2. Record Actual Worst Case condition at the bottom of the Attachment used.

I.3 *ACTUAL* "WORST CASE" CONDITION

1. Based on CAZ Test findings:
   - Set residence in Actual Worst Case condition, and
   - Repeat the appliance testing prescribed below in steps I.4, I.5, and I.6.
   - Record findings in the Data Collection Form.
2. If *Actual* Worst Case set-up is the same as the *Default* Worst Case (see H.1):
   - Record this fact in the Data Collection Form, Section L, and
   - Do not perform Procedure 6 testing.

I.4 PROCEDURE 3 RETESTING

1. *Final* Outdoor CO reading.
2. Observation for the following conditions:
   - Delayed Ignition
   - Roll-out Ignition
   - Improper flame characteristics.
   - Flame Interference
3. Olfactory check for aldehydes.
4. Second Room Ambient CO Tests.
5. Smoke Test for Draft.
6. Tactile Test for Spillage.

I.5 PROCEDURE 4 RETESTING

- Appliance Ambient CO Tests

I.6 PROCEDURE 5 RETESTING

1. Instrumented Draft measurements.
2. Instrumented CO measurements.
3. Visual check of heating system heat exchanger during operation.

PART 2—SUPPLEMENTAL INSTRUCTIONS

J. OPEN-DOOR & CLOSED-DOOR TESTS

1. General: When possible, CO and Draft Tests must be performed with the doors to the room or space containing appliances both open and closed, and the results of both tests are recorded separately.
   - When the enclosure too small for a person to fit into with the door closed, it is OK to do only the "Open Door" Test and circle "N/A" in the "Closed Door" box.
   - It is sometimes possible to get Closed-Door readings in a small enclosure.
     - Use the Draft Gauge with long tubing, and a CO Analyzer probe extension with plastic tubing.
     - Run the tubing under the door and close it if gap is large enough (or close door as much as possible around the hose).
2. Confined Area/Hallway: For an appliance in a confined area that can be closed off completely with doors (e.g., Wall Furnace in a hallway):
   1. Perform "Open Door" Test with one or more doors to a common area (Kitchen, Living Room) open.
   2. Perform "Closed Door" Test with all doors closed. (Note: If volume of the area is insufficient to provide adequate combustion air, keep access door(s) open except briefly during the Closed Door test.)
3. Garage:

   a. For all tests:
      - Keep drive-through garage door closed.
      - Keep all exhaust devices in the garage operating, such as:
        - Clothes dryer vented outdoors.
        - The air handler when the FAU and/or any part of the return system is located in the garage.

   b. For "Closed Door" Test, close all doors and windows.

   c. For "Open Door" Test:
      - Open door into the house (with all Exhaust Devices operating in the house).
      - If there is a window into the house but no door, open the window.
      - If there is no opening into the house, only the "Closed Door" Tests are required.
4. Attic: Perform only a "Closed Door" test, with the attic access in the normal, closed position.

K. TESTING APPLIANCES WITH A COMMON VENT

- When two appliances share a Common Vent, operate both simultaneously during tests.
- *Exception*: When CO in either appliance is sampled beyond the Vent Wye (e.g., an Induced Draft Furnace checked at the Vent Termination), turn off the other appliance during that CO Test.

L. FLUE AND VENT SYSTEM DEFECTS

1. General: A Flue/Vent System with a disconnected joint, improperly positioned Draft Hood, two Draft Hoods, obstruction, or any other condition which could adversely affect draft or cause combustion products to enter the home is an Action Condition.
2. Improper Terminations—Conventional Homes:
   - Flue/vent pipes must not terminate below or within 10' laterally of an opening into the living space.
     - *Exception*: Flue termination of a properly-installed direct vent furnace or slab-mount package system.
   - A flue/vent must terminate at least 1' above the roof it penetrates.
   - A flue/vent located within 8' of a wall must terminate at least 2' above the wall.
   - Water heater vent pipes within 10' of an evaporative cooler must terminate at least 3' above the cooler intake.
   - When a furnace flue/vent pipe located within 10' of an evaporative cooler is not 3' above the cooler intake:
     - A cooler cover must be in place (existing or newly installed).
     - The client must be informed of the non-conforming flue/vent and advised to keep cover in place during heating season.
3. Improper Terminations—Mobile Homes:
   - Termination of a water heater vent pipe shall not be within 3' of the air intake of an evaporative cooler.
   - When the termination of a furnace flue/vent pipe is within 3' a an evaporative cooler:
     - A cooler cover shall be in place (existing or newly installed).
     - The client shall be informed of the non-conforming flue/vent and advised to keep cover in place during the heating season.
4. Masonry Fireplace with Gas Log: UMC Section 901.2 states that, when a gas log is installed, the fireplace damper must be "permanently blocked open to a sufficient amount to prevent spillage of combustion products into the room."
   - A Damper that is not blocked open (e.g., with a permanently-installed damper clip) is a Required Repair.
   - A gas log with a damper clip in place that does not pass the Visual Draft test is also a Required Repair.
5. Unvented Appliances
   - When the primary heat source is an unvented appliance, the house is not feasible for inclusion in the study.
   - If the oven is used for room heat because the primary heating system is defective, the heating system is a Required Repair.

M. BURNER ABNORMALITIES

M.1 FORCED AIR UNITS:

a. A change in flame pattern and/or color when blower comes on ("flame interference") usually indicates a cracked heat exchanger. If detected, see Section D.

b. Delayed Ignition (e.g., with a bang or whoosh) and/or Roll-Out, Large Yellow Flames (more than 50% yellow), Soft Lazy Flames, etc., must be repaired by a qualified technician. If there is also high flue or ambient CO, see Section D, Health and Safety Instructions.

(Note that a decorative fireplace or gas log may be designed to burn with a yellow flame, and would not be considered abnormal if CO and Draft Test results are satisfactory.)

M.2 COOK STOVE/OVEN:

a. If a Gas Leak or other Hazard is not present, the following problems may be recorded as Recommended Repairs:
    - A pilot does not work, but the burner can be lit with a match, it burns properly, and CO is OK.
    - A burner knob is frozen or for some other reason 1 or 2 burners will not light, even with a match.

b. The following are required repairs:
    - Three or more top burners do not operate.
    - The oven does not work (cannot be lit with a match).
    - The oven door is broken or does not close.

c. A broiler with separate burner that does not operate is <u>not</u> a required repair.

M.3 RECALLED APPLIANCES

When a horizontal "NOx rod furnace" described in Attachment F is identified, it must be recorded as a Required Repair.

N. PILOT AND THERMOCOUPLE OR PILOT GENERATOR

- Thermocouple or pilot generator must be correctly positioned in pilot flame.
- Pilot flame must be properly adjusted (i.e., a soft, steady pilot flame heating the top half-inch of the thermocouple or pilot generator).
- An IID must be checked to determine whether the pilot is properly ignited by it.

O. ALTERNATIVE CO TESTING—FLUE TERMINATION INACCESSIBLE

1. This provision applies only when the prescribed CO measurement location is inside the flue termination *and* access is <u>not</u> feasible, even with a "probe extension."
2. Examples include the following types of heating units:
    - Roof-mount
    - Induced Draft with pipe that cannot be drilled.
    - Closed Combustion (including Direct Vent wall units)
3. When the flue termination on a roof is within 10' of the roof edge and it is safe to use a ladder, an attempt shall be made to reach the flue termination with a CO probe extension (made of 1/4" aluminum tubing) up to 10' long.
4. When CO sampling cannot be achieved with a probe extension, CO testing will be limited to the Appliance Ambient Test.
5. Conditions which justify Alternative CO Testing include the following:
    - Roof height or location prevents use of standard ladders.

- Roof slope is greater than 4/12.
- Roof is substandard, or roofing material is in poor condition.
- Roofing is tile or metal.
- Mobile Home has awnings along both sides.
- Direct Vent termination cannot be safely accessed.

P. COMBUSTION AIR FOR OPEN COMBUSTION APPLIANCES

P.1 OVERVIEW

1. Open-combustion appliances are appliances that draw combustion air from the room/space in which they are located.
   - The appliances can be "Natural Draft" (with a Draft Hood) or "Induced Draft" (with an inducer fan and no draft hood).
   - Combustion air can be drawn from outdoors (through vents or ducts), or from indoors (utilizing room volume).
2. These Combustion Air requirements apply only to the Furnace/Heater and Water Heater (Cooking Appliances and Clothes Dryers are excluded).
3. The required amount of combustion air is a function of the Btu/hour Input rating of the appliance, as stated on the manufacturer's nameplate. When the nameplate is missing or illegible, the default Btu/hr values (see P.5 below).
4. Also refer to Protocol Attachment E*, "Combustion Air Requirements for Gas Furnaces/Heaters and Water Heaters"* for a summary of code requirements, definitions, and a matrix of vent and duct sizes and room volumes required for several common Btu/hour Input ratings.

P.2 COMBUSTION AIR FROM OUTDOORS

P.2.1 Vent Size

1. Combustion air from outdoors is conveyed to the appliance enclosure through vents and/or ducts leading out of the envelope.
2. The required size of a vent is expressed as "net free venting area" (NFVA) in square inches. However, all vents and ducts are required to be screened (except ducts terminating in the attic), and the blocking effect of screens and louvers must be taken into account.
3. Because of that blocking effect, the "gross area" of a vent's screened opening (the actual size in sq. in.) is larger than the NFVA ("net free" area in sq. in). When an NFVA rating is not stamped on the vent, it can be estimated by multiplying the gross opening area by the "Reduction Factors" shown in the following table.

SCREEN AND LOUVER "REDUCTION FACTORS" FOR COMBUSTION AIR VENTS

1/4" Screen (Hardware Cloth)	1/4 Screen with Metal Louvers	1/4 Screen with Wood Louvers	Insect Screen* (Mesh under 1/4")	Insect Screen* with Metal Louvers	Insect Screen* with Wood Louvers
0.90 (90%)	0.75 (75%)	0.25 (25%)	0.50 (50%)	0.50 (50%)	0.25 (25%)

*Note: 1/4" Screen is mesh with wires spaced 1/4" apart ("quarter-inch hardware cloth"), which is specified in the 1998 CMC (Article 702.3). Mesh with a weave tighter than 1/4" (referred to in the table as "insect screen") can have wires 1/8" apart, or it can be 1/16" mesh (the insect screen used on doors and windows).

Examples:

- Assume a vent with a 5"x10" opening covered with 1/4" screen (no louvers). 5" x 10" = 50 sq. in. gross opening. 50 sq. in. x 0.90 = 45 sq. in. NFVA.
- With metal louvers: 50 sq. in. x 0.75 = 37.5 sq. in NFVA.

When the NFVA requirement is known, *divide* it by the applicable "Reduction Factor" to determine the gross vent size required. Using the first example in reverse: to provide 45 sq. in of NFVA, a 1/4" screen-only vent must have a gross size of 50 sq. in. (45 sq. in. NFVA ÷ 0.90 = 50 sq. in gross area).

P.2.2 Number, Location, and NFVA of Vents

Usually two vents to outdoors are used, although a provision was added to the CMC in the '90s allowing for just one combustion air vent under specific conditions (which may be encountered in newer homes). Following are the code requirements for vent location and size. Also see Appendix E, "Combustion Air Requirements for Gas Furnaces/Heaters and Water Heaters.

1. Two Vents:
   - Locations: One vent located within 12" of the floor, and one within 12" of the ceiling (vertical and horizontal ducts may also be used).

     Exception: A pre-existing Upper vent located at any height above the Draft Hood opening is acceptable; however, a new Upper vent installed in this project must be located within 12" of the ceiling.
   - NFVA:
     - Each vent or vertical duct must provide **1 sq. in.** NFVA for each **4,000 Btu/hr** of combined Input ratings for all applicable appliances drawing combustion air from that room/space (e.g., Furnace and Water Heater).
     - When 2 horizontal ducts are used, they must each provide **1 sq. in.** NFVA for each **2,000 Btu/hr** of combined Input ratings.

     Note: The lower vent may be a vertical duct from the attic (starting 6" above insulation) that terminates within 12" of the floor. The ends must not be screened, and the duct must comply with UMC Chapter 7 and local code.
2. One Vent:
   - Location: One vent (or one vertical or horizontal duct) located within 12" of the ceiling.
   - NFVA: The vent/duct must provide **1 sq. in.** NFVA for each **3,000 Btu/hr** of combined Input ratings for all applicable appliances drawing combustion air from that room/space. The following conditions must also be met:
     - All air is taken from outdoors, and appliance clearances are at least 6 inches on the front and 1 inch on the sides and back, and
     - NFVA of opening/duct is no smaller than the cross-sectional area of the vent pipe.

P.3 COMBUSTION AIR FROM INDOORS

Combustion air may also be obtained from the room or space in which the appliance is located. The volume of air required (in cubic feet) is a function of the total of Btu/hr Input rating(s).

P.3.1 Room Volume

Room Volume must be at least **50 cu. ft** for each **1,000 Btu/hr** of combined Input ratings for all applicable appliances drawing combustion air from that room (e.g., Furnace and Water Heater).

P.3.2 Vents to an Adjacent Space

1. If volume is not adequate, and outside air vents are not appropriate, vents in the wall and/or door may be installed to bring air in from adjacent rooms.
2. Vents must be **1 sq. in.** for each **1,000 Btu/hr** Input (minimum 100 sq. in.) and positioned within 12" of the ceiling and within 12" of the floor.

P.4 MOBILE HOME WATER HEATER UPPER COMBUSTION AIR VENT

When the Upper vent is created by passing the appliance vent pipe through the center of a larger pipe, adequacy of the area (space) between the outer and inner pipes may be verified by doing the following:

1. Measure the diameter of each pipe.
2. Obtain the "Pipe Area (sq. in.)" for each pipe from the chart below.
3. Subtract the smaller pipe area from the larger one to determine the NFVA between the pipes.

Pipe Diameter (in.)	3"	4"	5"	6"	7"	8"	9"	10"
Pipe Area (sq. in.)	7.0	12.6	19.6	28.3	38.5	50.3	63.6	78.5
Pipe Circumference (in.)	9.4	12.6	15.7	18.8	22.0	25.1	28.3	31.4

P.5 DEFAULT BTU/HOUR INPUT RATINGS

When the Btu/hr Input Rating cannot be obtained from the ID label, the following "default" values may be used:

P.5.1 For Combustion Air (CVA) calculations:

1. Wall Furnaces
   - Single Sided: 35,000 Btu/hr.
   - Double Sided with Two Burners: 60,000 Btu/hr.
2. Floor Furnaces
   - Standard: 30,000 Btu/hr (usually 22" wide).
   - Large: 60,000 Btu/hr (usually wider than a single floor-joist bay).
3. Free-Standing Heaters
   - Small: 25,000 Btu/hr…
   - Standard: 50,000 (over 24" wide & 12" deep).
4. Forced Air Furnaces
   - 25,000 Btu/hr per burner.
5. Water Heaters
   - 1000 Btu/hr per gallon.

P.5.2 For Minimum Ventilation Requirement (MVR) calculations:

1. Cook Top Burners:
   - 10,000 Btu/hr per burner.
2. Ovens:
   - 10,000 Btu/hr per burner.
3. Clothes Dryers
   - 10,000 Btu/hr per burner.

Q. COMBUSTION APPLIANCE ZONE (CAZ) TESTING

Q.1 PURPOSE

1. Combustion Appliance Zone (CAZ) testing is performed in per Protocol Section I (Procedure #6) to determine "*actual* worst case" set-up of the house when:
   - The home is heated with a forced-air unit (FAU), and
   - Vented open combustion gas appliance(s) are present.
2. Pressure tests are conducted under three different modes of air handler and exhaust fan operation to identify which house set-up (i.e., air handler on/off, exhaust devices on/off, interior doors open/closed) creates the greatest negative pressure (worst case) in each CAZ.

Q.2 PROCEDURE

1. CAZ testing is guided by the step-by-step field form: *NGAT Protocol Attachment A—CAZ "Worst Case" Worksheet*
2. When there are more than one CAZ present, perform CAZ testing for each CAZ, using a separate Worksheet for each. (See Sections Q.3 and Q.4.).
3. Digital Manometer Operation:
   a. Place the Manometer within 5 feet of the vented appliance(s) in the CAZ being tested. Avoid placing the manometer on the floor, and *do not move it* while readings are being taken.
   b. Use Channel A. Leave the *Input* tap open. Attach the hose going outdoors to the *Reference* tap.
   c. With *Mode* control on *Time Select*, toggle downward until "L" appears (Long Term Average).
   d. Set the *Range* in the low position (200.0 Pa).
4. Hose Routing and Manometer Placement
   a. The hose to outdoors can be routed through a cracked door, a window, an access cover/door to a vented attic or crawlspace, etc. Seal the gap caused by the hose (e.g., with masking tape).
   b. When the CAZ is an enclosure too small for the Technician to be in with the door closed: (1) place the Manometer outside the enclosure, (2) route the hose from the *Reference* tap to outdoors as usual, and (3) route a second hose from the *Input* tap to the enclosure interior.
   c. When the main body of the house contains a vented open combustion appliance (e.g., space heater or water heater), the main body is a CAZ—and the Manometer is placed near the applicable appliance(s). If two appliances are not close to each other, the Manometer is placed approximately halfway between the two.
5. Fans and exhaust devices
   a. Fans and exhaust devices operated for the test are those which exhaust air from the building.
   b. They include:
      - Bathroom and utility room fans.
      - Ducted kitchen range hood.
      - Clothes dryer exhausted outdoors (clean the lint filter prior to operating).

- Central vacuum system.
- Attic vent fan (if manually controlled).

c. *Exclude* whole house fans.

6. Air Handler

a. Operate the air handler on high speed, without the burner operating when possible.

b. When there is a Fan switch with "Auto" and "On" positions, the "On" position will usually operate the fan at high speed.

c. If there is a fan speed control on the furnace, select the highest speed available.

7. Smoking Interior Doors

a. See Step C of the CAZ "Worst Case" Worksheet (Attachment A).

b. When the main body of the house is the *only* CAZ:

- Smoke is applied to all interior doors except storage closets.
- Smoke is not applied to entrance doors nor the attached garage door.
- *Exception*: Smoke is applied to the door into the garage if the garage contains a clothes dryer exhausted outdoors (the dryer fan will be running during "fan-on" tests).

c. When a CAZ is outside the main body of the house—in a room (e.g., utility room), an attached garage, a basement, or an enclosure—the door to that CAZ is smoked *after* other doors are smoked and set closed/open (Attachment A, Step C.2.b).

d. When the door to the CAZ is weatherstripped, crack the door enough to allow airflow, and apply smoke on the latch side.

8. Do not perform CAZ testing under the following conditions:

a. The home does not have an FAU.

b. The FAU is outdoors (slab/roof-mount), *and* there is not a vented natural draft appliance present in:
(1) the living space, or
(2) an attached room/enclosure which opens into the living space, or
(3) a room/enclosure which draws combustion air from the living space.

c. The dwelling is a mobile home with closed combustion FAU, *and* there is not a vented natural draft appliance present in:
(1) the living space, or
(2) an attached room/enclosure which opens into the living space, or
(3) a room/enclosure which draws combustion air from the living space.

Q.3 CAZ AND "APPLICABLE" APPLIANCES

1. A combustion appliance zone (CAZ) is a room or space containing one or more "applicable" appliance listed below. It must be a natural draft open combustion gas appliance that is vented outdoors.

2. Applicable Appliances

a. Space Heater (FAU, Wall Furnace, Free-standing Heater).

b. Water Heater.

c. Older-style gas Oven that is vented outdoors.

d. Floor Furnace that is located in, or accessed from, a finished basement that connects by doorway to the living space—if operation of the Floor Furnace is likely to be influenced by: (1) basement depressurization caused by the FAU or exhaust devices in the home, or (2) by the operation of other appliances in the basement.

3. Appliances Excluded
   a. Clothes Dryer.
   b. Gas Oven that is not vented outdoors.
   c. Water Heater located in a screened porch.
   d. Floor Furnace that draws combustion air from, and is accessed from, the crawl space.

Q.4 CAZ EXAMPLES

There are too many possibilities to list; however, some situations likely to be encountered are included in this section. For an unusual situation, apply Section Q procedures to determine how to handle it. The following are examples of Combustion Appliance Zones:

1. A room or space containing an "applicable" appliance (Q.3.2) which draws combustion air from the room or space. The CAZ includes all areas communicating with each other, such as:
   a. Downstairs and upstairs open areas not separated by a door.
   b. A converted garage and the main body of the house not separated by a door.
   c. The main body of the house and a utility room open to the main body (no door or a vented/louvered door).
2. An appliance room/enclosure that is accessed from indoors and draws combustion air from the living space. (The room/enclosure may have combustion air vents to indoors only, or one to indoors and one to outdoors.)
   a. The enclosure is considered to be in the main body of the house if all combustion air comes from the living space, and combustion air is adequate.
   b. The enclosure is considered to be not in the main body of the house if: (1) any combustion air comes from outdoors, or (2) combustion air is not adequate. (In this case, the enclosure would be tested as a separate CAZ.)
3. An appliance enclosure that is accessed from indoors but draws combustion air from outdoors.
   a. The enclosure is one CAZ.
   b. The indoor space is another CAZ, if it contains an "applicable" appliance (Q.3.2).
4. An attached garage, a utility room, a basement, or similar room/space that contains an "applicable" appliance and is separated from the main body of the house by a door.
   a. The room/space is a CAZ which is not in the main body and is tested separately.
   b. If the room/space communicates with the living space (e.g., the door is vented to the living space, louvered door, etc.), the room/space and the living space are effectively one CAZ. Place the Manometer in the more restricted area (typically the room/space), and leave the door closed.

Appendix C

Natural Gas Appliance Testing Survey Data Collection Forms

Natural Gas Appliance Testing Survey
Cover Page

Client Name:	
Address:	
Study Group	[ ] Basic NGAT Survey [ ] CO Alarm [ ] CO Alarm/Data Logger

This Report Includes the following forms:

FORM	TITLE	NAT. GAS	PRO.	ELE.	IN REPORT	N/A	NUMBER OF FORMS
A	Basic Information				REQ.		
B	Client and Building Information				REQ.		
C	Walk-Through Olfactory Test				REQ.		
D	Floor Plan				REQ.		
E	Repairs				REQ.		
F	Ambient Conditions				REQ.		
G	Space Heater						
H	Water Heater						
I	Cook Top/Stove/Oven						
J	Dryer						
K	Gas Log						
L	CAZ Test*						
M	Other						
	WORKSHEETS TITLE						
	CAZ Attachment A Worksheet						
	CVA Worksheet						

***The CAZ Worst Case Condition Testing procedure was not performed for the following reason:**

[ ] A Forced Air Unit (FAU) is not present in the residence.
[ ] "Actual" and "Default" Worst Case conditions are the same.
[ ] Natural draft appliance that requires CAZ Test not present.

A. BASIC INFORMATION

A.1 TYPE OF SURVEY

[ ] **Basic NGAT Survey**		
[ ] **CO Alarm**	Control Number:	
	Install Date:	
	Remove Date:	
[ ] **Data Logger**	Control Number:	
	Install Date:	
	Remove Date:	

A.2 NGAT SURVEYOR INFO

Pre-Wx Survey

Technician ____________________

Date / /2002

Post-Wx Survey

Technician ____________________

Date / /2002

Post-Repair Survey

Technician ____________________

Date / /2002

Notes:

B. CLIENT AND BUILDING INFORMATION

B.1 OCCUPANCY

Occupants	Age	Number	
	<5 years (Pre-school)		
	5 – 18 (School-age)		
	18 – 65 (Adults)		
	>65 (Seniors)		

B.2 BUILDING INFORMATION

Garage [ ] Attached [ ] Detached [ ] No Garage/Carport	
Carport [ ] Open [ ] Enclosed (3 sides)	
Converted to living space?	[ ] Yes [ ] No
Foundation Type:	Slab / Raised Floor / Basement
Wall Type:	Stucco / Panel Siding / Ship Lap / Masonry / other
Other Info:	

B.3 INITIAL CLIENT INTERVIEW (ONLY FOR FIRST VISIT)

1. Have you noticed any gas odors or leaks? N **Y** → ______________________________
2. What do you usually use to heat your home? ____________________________________
3. Have you had problems with any gas appliance? N **Y** → _________________________
4. Do you ever use your fireplace? N/A N **Y** → How often? _________
5. Do you ever use a portable kerosene or gas heater to warm any part of the house? N **Y**
   If Yes, how long ago was is used? [ ] Earlier today [ ] Yesterday [ ] More than one day ago.
6. [Gas Oven **Y** N] When was your oven used last? __________________
   For how long? ______
7. [Gas Oven **Y** N] Do you ever use your oven to take the chill off? N Y
8. Do you park car(s) in the garage? N/A N **Y** → ___ # of cars.
   If Yes: Do you warm up your car(s) in the garage? N Y
9. Does anyone smoke indoors? N **Y** → ______ (#). If Yes, how recently? ___________
10. How often do you open a window for fresh air in winter time? ____ days/wk, ___ hrs/day
11. Are any rooms colder or warmer than the rest of the house? Y N
12. Where are your gas appliances located?

Notes:

C. WALK THROUGH OLFACTORY TEST

C.1 GAS ODORS

Are gas odors present? [ ] Yes [ ] No

C.2 ALDEHYDES

Are aldehyde odors present? [ ] Yes [ ] No

C.3 CIGARETTE SMOKE

Do occupants smoke indoors? [ ] Yes [ ] No

C.4 OTHER ODORS

Are any strong, obnoxious odors present inside? [ ] Yes [ ] No

Are any strong, obnoxious odors present outside? [ ] Yes [ ] No

C.5 PROXIMITY TO EXTERNAL SOURCES OF CO

Source		Distance Away	#
Car(s) in attached garage	[ ] Yes [ ] No		
Car(s) in attached carport	[ ] Yes [ ] No		
Near freeway/major arterial	[ ] Yes [ ] No	(If less than .25 miles)	
Near factory/other (explain)	[ ] Yes [ ] No	(If less than .25 miles)	

Notes:

D. FLOOR PLAN

- Draw a floor plan of each floor of the residence. *Letter* exterior doors (A, B). *Number* windows (1, 2).
- Estimated square footage of residence:_______________sq.ft. Number of stories:_____
- Show locations of: (a) appliances, and (b) Ambient CO measurements.

- **Pre-Wx** "as found": .... Doors ____________________*open*. Windows ______________________*open*.
- **Post-Wx** "as found": .... Doors ____________________*open*. Windows ______________________*open*.
- **Post-Repair** "as found": .... Doors ____________________*open*. Windows ______________________*open*.

Abbreviations:
BA = Bathroom; **BR** = Bedroom; **DR** = Dining Room; **FR** = Family Room; **LR** = Living Room; **LAN** = Laundry; **POR** = Porch;
E-POR = Enclosed Porch; **CP** = Carport; **GAR** = Garage;
CTP = Cook Top; **OVN** = Oven; **RNG** = Range; **DRY** = Clothes Dryer; **WH** = Water Heater;
DVW = Direct Vent Wall Furnace; **FAU** = Forced Air Unit; **FLF** = Floor Furnace; **FSH** = Free-Standing Heater;
PKG = Packaged Unit; **WLF** = Wall Furnace; **FP** = Fireplace; **GLG** = Gas Log; **GL** = Gas Lighter;
RA = Room Ambient test location

E. REPAIRS

E.1 REPAIR ACTIVITY

APPLIANCE	DESCRIPTION OF REPAIR(S) NEEDED	REPAIRED (If not repaired explain why in E.2.)
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No
		[ ] Yes [ ] No

E.2 NOT REPAIRED

APPLIANCE	REASON FOR NOT REPAIRING APPLIANCE

E.3 ABANDONED APPLIANCE

APPLIANCE	REASON FOR ABANDONMENT

F. AMBIENT CONDITIONS

F.1 OUTDOOR AMBIENT CO (PPM)

	Pre-Wx				Post-Wx			
	Start		Finish		Start		Finish	
	Testo	Draeger	Testo	Draeger	Testo	Draeger	Testo	Draeger
Outdoor Ambient CO:								
Outdoor Temperature:	°F		°F		°F		°F	
Wind Speed (No, Low, Moderate, High):								
Time:								

F.2 ROOM AMBIENT CO*(PPM)

F.2.1 Pre-Wx

				Room Ambient #1 "As Found"		Room Ambient #2		Appliance Ambient	
Starting Pre-Wx Outdoor Ambient CO Level =									
	Location	Appliance(s)	Start time	Testo	Drgr	Testo	Drgr	Testo	Drgr
1-1									
1-2									
1-3									
1-4									
1-5									
Indoor Temperature (deg. F)				**°F**		**°F**		**°F**	

F.2.2 Post-Wx

				Room Ambient #1 "As Found"		Room Ambient #2		Appliance Ambient	
Starting Post-Wx Outdoor Ambient CO Level =									
	Location	Appliance(s)	Start time	Testo	Drgr	Testo	Drgr	Testo	Drgr
1-1									
1-2									
1-3									
1-4									
1-5									
Indoor Temperature (deg. F)				**°F**		**°F**		**°F**	

***Triggers/Action Levels**: *If the Room Ambient reading is greater than 35 ppm, follow the Health & Safety Protocol D.2.*

G. HEATING SYSTEM

ONE FORM PER HEATING SYSTEM

[ ] Primary Heating System [ ] Secondary Heating System Heating System [ ] of [ ]

G.1 FUEL TYPE

Gas: [ ] *Natural* [ ] *Propane* [ ] **Fuel Oil**

G.2 HEATING SYSTEM TYPE

[ ] **Ducted:** [ ] *Forced Air* [ ] *Gravity*
[ ] **Wall Furnace**: [ ] *Interior Wall* [ ] *Exterior Wall* [ ] *Double Sided*
[ ] **Floor** [ ] **Free-standing** [ ] **Fireplace Gas Heating Unit**
[ ] **Hydronic** [ ] **Other:**

G.3 LOCATION OF HEATING UNIT

[ ] **Inside Conditioned Space** [ ] *Enclosed (closet opens to interior)* [ ] *Open*
[ ] **Outside Conditioned Space** [ ] *Enclosed (closet opens to exterior)*
[ ] *Roof* [ ] *Attic* [ ] *Garage*
[ ] *Slab/Ground* [ ] *Basement* [ ] *Crawlspace*

G.4 PILOT

[ ] **Standing**: [ ] *On* [ ] *Off*
[ ] **Luminous / Resistance** [ ] **Electronic IID**

G.5 COMBUSTION TYPE

[ ] **Open:** [ ] *Natural Draft* [ ] *Induced Draft*
[ ] **Closed:** [ ] *Vertical Flue* [ ] *Horizontal Direct Vent*
[ ] **Unvented** [ ] **Other – list:**

G.6 NAME PLATE DATA

Manufacturer:	Input Rating (KBTUH) =
Model:	**Or** Default Rating (KBTUH) =

G.7 COMBUSTION VENTILATION

Other appliance(s) in room:	Total Appliance KBTUH: =
Combustion Air Source(s)	**Total KBTUH Input (sum)=**

[ ] Outdoors Only
[ ] Indoors Only, from: [ ] *Conditioned Space* [ ] *Unconditioned Space*
[ ] Indoors and Outdoors

Combustion Air Vent(s)*

Upper: [ ] Vent [ ] Duct [ ] None **Condition:** [ ] Clear [ ] Blocked
Lower: [ ] Vent [ ] Duct [ ] None **Condition:** [ ] Clear [ ] Blocked
Volume: [ ] Room/Enclosure only [ ] Vent(s) to adjacent space present

CVA Calculation(s)

	Existing	Required	
Upper* Openings NFV area =			sq. inches
Lower Openings NFV area=			sq. inches
Room Volume =			cu. feet

Is existing CVA acceptable? Yes [ ] **No** [ ] If "No", note repairs in Sec. E.1.

*Use Upper vent lines for a unit located in an attic, basement, or crawlspace.

G.8 HEATING SYSTEM - SAFETY

G.8.1 Combustibles

	Pre-Wx	Post-Wx
Are any combustible products located near gas appliance?	**[ ] Yes** [ ] No	**[ ] Yes** [ ] No
If Yes, where materials removed?	[ ] Yes **[ ] No**	[ ] Yes **[ ] No**

G.8.2 Gas Leaks

G.8.2.1 Olfactory Tests	Pre-Wx	Post-Wx
Are gas odors present:	[ ] No **[ ] R/R**	
• Near or around appliance?	[ ]	
• Around valves or fittings?	[ ]	
• Other locations	[ ]	

G.8.2.2 Soap/Bubble Test	Pre-Wx	Post-Wx
Were gas leaks detected by bubbles?	[ ] No **[ ] R/R**	
Where?		
• First fitting/Shut-off valve	[ ]	
• Gas Flex	[ ]	
• Appliance fitting	[ ]	
• Appliance regulator/control	[ ]	
• On appliance	[ ]	
• Other:	[ ]	

G.8.2.3 Gas Leak Repair	Pre-Wx	Post-Wx
Fixed by:		
• RHA Technician:	[ ]	
• Gas Service Technician	[ ]	
• Other:	[ ]	

G.8.3 Aldehyde Olfactory Tests

Are aldehyde odors present:	Pre-Wx	Post-Wx
• In the room or space?	**[ ] Yes** [ ] No	
• Near or around appliance?	**[ ] Yes** [ ] No	

Safety Notes:

G.9 VISUAL INSPECTIONS

G.9.1 Visual Check of Heater Flue/Vent System

Location	Inspection	Pre-Wx	Post-Wx
	Disconnections	[ ] OK **[ ] R/R**	
	Leaks	[ ] OK **[ ] R/R**	
	Obstructions	[ ] OK **[ ] R/R**	
	Improper pipe type	[ ] OK **[ ] R/R**	
	Slope	[ ] OK **[ ] R/R**	
	Termination	[ ] OK **[ ] R/R**	
	Draft hood	[ ] N/A	
	misaligned	[ ] OK **[ ] R/R**	
	missing	[ ] OK **[ ] R/R**	
	double	[ ] OK **[ ] R/R**	
	Other	[ ] OK **[ ] R/R**	
		List repairs needed in Sec. E.1.	

G.9.2 Visual Check of Combustion System

Inspection	Pre-Wx	Post-Wx
Heat exchanger defects (cracks, holes, warping, metal fatigue, etc.).	[ ] OK **[ ] R/R**	
Excessive soot	[ ] OK **[ ] R/R**	
Scorching	[ ] OK **[ ] R/R**	
Corrosion	[ ] OK **[ ] R/R**	
Burners clogged (soot, rust, etc.)	[ ] OK **[ ] R/R**	
Burners damaged	[ ] OK **[ ] R/R**	
Burners misaligned	[ ] OK **[ ] R/R**	
Pilot properly aligned with pilot generator	[ ] OK **[ ] R/R**	
Air shutters obstructed or abnormal	[ ] OK **[ ] R/R**	
Venturies obstructed or abnormal	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
	[ ] OK **[ ] R/R**	
	List repairs needed in Sec. E.1.	

G.9.3 Gas Control Valve

Inspection	Pre-Wx	Post-Wx
Damaged valve or missing parts	[ ] OK **[ ] R/R**	
Damaged wires and/or burned insulation	[ ] OK **[ ] R/R**	
Bypassed safety/locked-open ASO	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
	List repairs needed in Sec. E.1.	

G.9.4 Visible Duct System

[ ] No duct system present (not FAU)		
Problem(s)	**Pre-Wx**	**Post-Wx**
Disconnects		
Supply	[ ] OK **[ ] R/R**	
Return	[ ] OK **[ ] R/R**	
Gaps or other holes in duct work or connections		
Supply	[ ] OK **[ ] R/R**	
Return	[ ] OK **[ ] R/R**	
Missing air handler cover	[ ] OK **[ ] R/R**	
Air handler cover not sealed	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
List repairs needed in Sec. E.1.		

G.9.5 Ducts in Attic or Crawl Space

[ ] No duct system present (not FAU)		
Problem(s)	**Pre-Wx**	**Post-Wx**
Disconnects		
Supply	[ ] OK **[ ] R/R**	
Return	[ ] OK **[ ] R/R**	
Gaps or other holes in duct work or connections		
Supply	[ ] OK **[ ] R/R**	
Return	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
List repairs needed in Sec. E.1.		

G.10 HEATING SYSTEM APPLIANCE TESTING

G.10.1 "Appliance On" Tests	Pre-Wx	Post-Wx
G.10.1.1 Pilot	[ ] N/A	
Standing Pilot operating properly? [ ] N/A	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
Electronic Pilot ignites properly? [ ] N/A	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
Pilot in proper position	[ ] Yes **[ ] R/R**	
G.10.1.2 Burner Ignition		
Start-up Time		
Burners operate properly?	[ ] Yes [ ] **No**	[ ] Yes [ ] **No**
If **"No"**, what is the problem?		
Rollout	[ ] No **[ ] R/R**	
Delayed ignition	[ ] No **[ ] R/R**	
Short cycling	[ ] No **[ ] R/R**	
Other	[ ] No **[ ] R/R**	
G.10.1.3 Burner Flame Characteristics		
Color — Normal	[ ] Yes [ ] **No**	[ ]Yes [ ]**No**
>50% Yellow	[ ] OK **[ ] R/R**	
Strength		
Normal / Adequate	[ ] Yes [ ] **No**	[ ]Yes [ ] **No**
Soft, lazy	[ ] No **[ ] R/R**	
Under-gassed	[ ] No **[ ] R/R**	
Over-gassed	[ ] No **[ ] R/R**	
Other	[ ] No **[ ] R/R**	
Interference from air handler? [ ] N/A	[ ] No **[ ] R/R**	
G.10.1.4 Visual Check of Heat Exchanger - Burners On		
Heat exchanger defects (cracks, holes, warping, metal fatigue, etc.). [ ] Not Visible	[ ] OK **[ ] R/R**	

G.10.2 OPEN DOOR Draft & Spillage Tests

[ ] Not feasible (attic unit or crawl space)	Pre-Wx	Post-Wx
G.10.2.1 Tactile Test for Spillage		
Evidence of spillage?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**
G.10.2.2 Smoke Draft Test		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
G.10.2.3 Instrumented Draft Test		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**

G.10.3 OPEN DOOR In-Flue CO Test

[ ] Not feasible – attic, crawlspace		Pre-Wx		Post-Wx	
CO in flue before dilution air.		As-Measured	Air-Free	As-Measured	Air-Free
Location (circle one choice)		ppm	ppm	ppm	ppm
Flue/Port #1	Side 1 Baffle A				
Flue/Port #2	Side 1 Baffle B				
Flue/Port #3	Side 2 Baffle A				
Flue/Port #4	Side 2 Baffle B				
Flue/Port #5					

G.10.4 CLOSED DOOR Draft & Spillage Tests

[ ] Not feasible	Pre-Wx	Post-Wx
G.10.4.1 Tactile Test for Spillage		
Evidence of spillage?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**
G.10.4.2 Smoke Draft Test		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
G.10.4.3 Instrumented Draft Test		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**

G.10.5 CLOSED DOOR In-Flue CO Test

[ ] Not feasible		Pre-Wx		Post-Wx	
CO in flue before dilution air.		As-Measured	Air-Free	As-Measured	Air-Free
Location		ppm	ppm	ppm	ppm
Flue/Port #1	Side 1 Baffle A				
Flue/Port #2	Side 1 Baffle B				
Flue/Port #3	Side 2 Baffle A				
Flue/Port #4	Side 2 Baffle B				
Flue/Port #5					

H. WATER HEATER

H.1 FUEL TYPE

Gas: [ ] *Natural* [ ] *Propane*

H.2 SYSTEM TYPE

[ ] Storage Size: [ ] 30 gal. [ ] 40 gal. [ ] 50 gal. [ ] Other: _____gal.

[ ] Central Storage Water Heater – **Don't fill out this form** – unless water heater is located in the unit to be weatherized.

[ ] Instantaneous

H.3 LOCATION OF WATER HEATER

[ ] **Inside Conditioned Space** [ ] *Enclosed (closet opens to interior)* [ ] *Open*

[ ] **Outside Conditioned Space** [ ] *Enclosed (closet opens to exterior)*

[ ] *Slab/Ground* [ ] *Attic* [ ] *Garage*

[ ] *Basement*

H.4 COMBUSTION

[ ] Natural Draft

[ ] Induced Draft

H.5 NAME PLATE DATA

Manufacturer:	Input Rating (KBTUH) =
Model:	Or Default Rating (KBTUH) =

H.6 COMBUSTION VENTILATION

Other appliance(s) in room:	Total Appliance KBTUH: =
Combustion Air Source(s)	**Total KBTUH Input =**

[ ] Outdoors Only

[ ] Indoors Only, from: [ ] *Conditioned Space* [ ] *Unconditioned Space*

[ ] Indoors and Outdoors

Combustion Air Vent(s)*

Upper: [ ] Vent [ ] Duct [ ] None **Condition:** [ ] Clear [ ] Blocked

Lower: [ ] Vent [ ] Duct [ ] None **Condition:** [ ] Clear [ ] Blocked

Volume: [ ] Room/Enclosure only [ ] Vent(s) to adjacent space present

CVA Calculation(s)	**Existing**	**Required**	
Upper* Openings NFV area =			sq. inches
Lower Openings NFV area=			sq. inches
Room Volume =			cu. feet

Is existing CVA acceptable? Yes [ ] **No** [ ] If "No", note repairs in Sec. E.1.

*Use Upper vent lines for a unit located in an attic, basement, or crawlspace.

H.7 WATER HEATER - SAFETY

H.7.1 Combustibles

	Pre-Wx	Post-Wx
Where any combustible products placed or stored near gas appliance?	**[ ] Yes** [ ] No	**[ ] Yes** [ ] No
If Yes, where materials removed?	[ ] Yes **[ ] No**	[ ] Yes **[ ] No**

H.7.2 Gas Leaks

H.7.2.1 Olfactory Tests	Pre-Wx	Post-Wx
Are gas odors present:	[ ] No **[ ] R/R**	
• Near or around appliance?	[ ]	
• Around valves or fittings?	[ ]	
• Other locations	[ ]	

H.7.2.2 Soap/Bubble Test	Pre-Wx	Post-Wx
Were gas leaks detected by bubbles?	[ ] No **[ ] R/R**	
If "Yes" where?		
• First fitting/Shut-off valve	[ ]	
• Gas Flex	[ ]	
• Appliance fitting	[ ]	
• Appliance regulator/control	[ ]	
• On appliance	[ ]	
• Other:	[ ]	

H.7.2.3 Gas Leak Repair	Pre-Wx	Post-Wx
Fixed by:		
• RHA Technician:	[ ]	
• Gas Service Technician	[ ]	
• Other:	[ ]	

H.7.3 Aldehyde Olfactory Tests

Are aldehyde odors present:	Pre-Wx	Post-Wx
• In the room or space?	**[ ] Yes** [ ] No	
• Near or around appliance?	**[ ] Yes** [ ] No	

Safety Notes:

H.8 VISUAL INSPECTIONS – WATER HEATER

H.8.1 Visual Check of Heater Flue/Vent System

Location	Inspection	Pre-Wx	Post-Wx
	Disconnections	[ ] OK **[ ] R/R**	
	Leaks	[ ] OK **[ ] R/R**	
	Obstructions	[ ] OK **[ ] R/R**	
	Improper pipe type	[ ] OK **[ ] R/R**	
	Slope	[ ] OK **[ ] R/R**	
	Termination	[ ] OK **[ ] R/R**	
	Draft hood	[ ] N/A	
	misaligned	[ ] OK **[ ] R/R**	
	missing	[ ] OK **[ ] R/R**	
	double	[ ] OK **[ ] R/R**	
	Other	[ ] OK **[ ] R/R**	
List repairs needed in Sec. E.1.			

H.8.2 Visual Check of Combustion System

Inspection	Pre-Wx	Post-Wx
Heat exchanger defects (cracks, holes, warping, metal fatigue, etc.).	[ ] OK **[ ] R/R**	
Excessive soot	[ ] OK **[ ] R/R**	
Scorching	[ ] OK **[ ] R/R**	
Corrosion	[ ] OK **[ ] R/R**	
Burners clogged (soot, rust, etc.)	[ ] OK **[ ] R/R**	
Burners damaged	[ ] OK **[ ] R/R**	
Burners misaligned	[ ] OK **[ ] R/R**	
Pilot properly aligned with pilot generator	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
	[ ] OK **[ ] R/R**	
List repairs needed in Sec. E.1.		

H.8.3 Gas Control Valve

Inspection	Pre-Wx	Post-Wx
Damaged valve or missing parts	[ ] OK **[ ] R/R**	
Bypassed safety/locked-open ASO	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
List repairs needed in Sec. E.1.		

Notes:

H.9 WATER HEATER APPLIANCE TESTING

H.9.1 "Appliance On" Tests	Pre-Wx	Post-Wx
H.9.1.1 Pilot		
Standing Pilot operating properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
Pilot in proper position	[ ] Yes **[ ] R/R**	
H.9.1.2 Burner Ignition		
Start-up Time		
Burner operates properly?	[ ] Yes [ ] **No**	[ ] Yes [ ] **No**
If **"No"**, what is the problem?		
Rollout	[ ] No **[ ] R/R**	
Delayed ignition	[ ] No **[ ] R/R**	
Other	[ ] No **[ ] R/R**	
H.9.1.3 Burner Flame Characteristics		
Color — Normal	[ ] Yes [ ] **No**	[ ]Yes [ ] **No**
>50% Yellow	[ ] OK **[ ] R/R**	
Strength		
Normal / Adequate	[ ] Yes [ ] **No**	[ ]Yes [ ] **No**
Soft, lazy	[ ] No **[ ] R/R**	
Under-gassed	[ ] No **[ ] R/R**	
Over-gassed	[ ] No **[ ] R/R**	
Other	[ ] No **[ ] R/R**	
H.9.1.4 Visual Check of Heat Exchanger - Burners On		
Heat exchanger defects (cracks, holes, warping, metal fatigue, etc.).	[ ] OK **[ ] R/R**	

H.9.2 OPEN DOOR Draft & Spillage Tests

	Pre-Wx	Post-Wx
[ ] Not feasible (attic unit or crawl space)		
H.9.2.1 Tactile Test for Spillage		
Evidence of spillage?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**
H.9.2.2 Smoke Draft Test		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
H.9.2.3 Instrumented Draft Test		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**

H.9.3 OPEN DOOR - In-Flue CO Test

[ ] Not Feasible (attic or cs)	**Pre-Wx**		**Post-Wx**	
Start Time of Test:				
CO in flue before dilution air	As-Measured	Air-Free	As-Measured	Air-Free
Location	ppm	ppm	ppm	ppm
• Baffle left / front side				
• Baffle right / back side				

H.9.4 CLOSED DOOR Draft & Spillage Tests

	Pre-Wx	Post-Wx
[ ] Not feasible		
H.9.4.1 Tactile Test for Spillage		
Evidence of spillage?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**
H.9.4.2 Smoke Draft Test		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
H.9.4.3 Instrumented Draft Test		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**

H.9.5 CLOSED DOOR - In-Flue CO Test

[ ] Not Feasible	**Pre-Wx**		**Post-Wx**	
Start Time of Test:				
CO in flue before dilution air	As-Measured	Air-Free	As-Measured	Air-Free
Location	ppm	ppm	ppm	ppm
• Baffle left / front side				
• Baffle right / back side				

I. COOK TOP / STOVE / OVEN

I.1 FUEL TYPE

Cook top [ ] Natural Gas [ ] Propane [ ] Electric If electric, don't fill out cook top section.
Oven [ ] Natural Gas [ ] Propane [ ] Electric If electric, don't fill out oven section.
Broiler [ ] Natural Gas [ ] Propane [ ] Electric If electric, don't fill out broiler section.

I.2 SYSTEM TYPE

[ ] **Range** with: [ ] *Oven/Broiler combination* [ ] *Oven with broiler top burner*
[ ] **Cook Top**
[ ] **Separate Oven** with: [ ] *Oven/Broiler combination* [ ] *Oven with broiler top burner*
[ ] **Other:**

I.3 COOK TOP

Number of burners =
Number of operating burners =

I.4 OVEN

Number of burners =
Number of operating burners =

I.5 COOKING APPLIANCE - SAFETY

I.5.1 Combustibles

	Pre-Wx	Post-Wx
Where any combustible products placed or stored near gas appliance?	**[ ] Yes** [ ] No	**[ ] Yes** [ ] No
If Yes, where materials removed?	[ ] Yes **[ ] No**	[ ] Yes **[ ] No**

I.5.2 Gas Leaks

I.5.2.1 Olfactory Tests	Pre-Wx	Post-Wx
Are gas odors present:	[ ] No **[ ] R/R**	
• Near or around appliance?	[ ]	
• Around valves or fittings?	[ ]	
• Other locations	[ ]	

I.5.2.2 Soap/Bubble Test	Pre-Wx	Post-Wx
[ ] Not feasible.		
Were gas leaks detected by bubbles?	[ ] No **[ ] R/R**	
Where?		
• First fitting/Shut-off valve	[ ]	
• Gas Flex	[ ]	
• Appliance fitting	[ ]	
• Appliance regulator/control	[ ]	
• On appliance	[ ]	
• Other:	[ ]	

I.5.2.3 Gas Leak Repair	Pre-Wx	Post-Wx
Fixed by:		
• RHA Technician:	[ ]	
• Gas Service Technician	[ ]	
• Other:	[ ]	

I.5.3 Aldehyde Olfactory Tests

Are aldehyde odors present:	Pre-Wx	Post-Wx
• In the room or space?	[ ] **Yes** [ ] No	
• Near or around appliance?	[ ] **Yes** [ ] No	

Safety Notes:

I.6 VISUAL CHECK OF COMBUSTION SYSTEM – COOK TOP/OVEN/BROILER

Problem(s)	Pre-Wx	Post-Wx
Cook Top		
Burners:		
• damaged	[ ] OK **[ ] R/R**	
• misaligned	[ ] OK **[ ] R/R**	
Cook top pilot(s) malfunctioning	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
	[ ] OK **[ ] R/R**	
Oven		
Spreader plate:		
• damaged	[ ] OK **[ ] R/R**	
• improperly positioned	[ ] OK **[ ] R/R**	
Oven burner:		
• damaged	[ ] OK **[ ] R/R**	
• misaligned	[ ] OK **[ ] R/R**	
• dirty/clogged	[ ] OK **[ ] R/R**	
Oven/broiler pilot(s) malfunctioning	[ ] OK **[ ] R/R**	
List repairs needed in Sec. E.1.		

I.7 "APPLIANCE ON" TESTS – COOK TOPS

I.7.1.1 Burner ignition		Pre-Wx	Post-Wx
Ignites properly?		[ ] Yes **[ ] No**	
Burns properly?		[ ] Yes **[ ] No**	
If no, what is the problem?			
• Delayed ignition		[ ] OK **[ ] R/R**	
• Pilot size		[ ] OK **[ ] R/R**	
• Other		[ ] OK **[ ] R/R**	
I.7.1.2 Flame characteristics			
Color	Normal	[ ] OK **[ ] R/R**	
	>50% Yellow	[ ] OK **[ ] R/R**	
	Over-gassed	[ ] OK **[ ] R/R**	
	Under-gassed	[ ] OK **[ ] R/R**	
	Other	[ ] OK **[ ] R/R**	

I.8 "APPLIANCE ON" TESTS – OVENS

I.8.1.1 Burner Ignition		Pre-Wx	Post-Wx
	Ignites properly?	[ ] Yes **[ ] No**	
	Burns properly?	[ ] Yes **[ ] No**	
If no, what is the problem?			
	Delayed ignition	[ ] OK **[ ] R/R**	
	Pilot size	[ ] OK **[ ] R/R**	
	Other	[ ] OK **[ ] R/R**	
I.8.1.2 Flame characteristics			
Color	Normal	[ ] OK **[ ] R/R**	
	>50% Yellow	[ ] OK **[ ] R/R**	
	Over-gassed	[ ] OK **[ ] R/R**	
	Under-gassed	[ ] OK **[ ] R/R**	
	Other	[ ] OK **[ ] R/R**	

I.8.2 Instrumented CO Test				
	Pre-Wx		**Post-Wx**	
CO in flue before dilution air.	**As-Measured**	**Air-Free**	**As-Measured**	**Air-Free**
Location	**ppm**	**ppm**	**ppm**	**ppm**
Oven #1				
Oven #2				
Broiler #1				
Broiler #2				
LF Burner				
LR Burner				
RF Burner				
RR Burner				
Griddle				
Other Burner				

J. CLOTHES DRYER

J.1 FUEL TYPE

Gas: [ ] *Natural* [ ] *Propane*

J.2 APPLIANCE LOCATION

Indoors: [ ] *Laundry room* [ ] *Closet* [ ] *Room separated by door*

Outdoors: [ ] *Garage/carport Attached* [ ] *Service Porch*

[ ] *Garage Detached* [ ] *Basement*

J.3 EXHAUST VENTING

Exhausting to: [ ] Indoors, [ ] Outdoors

[ ] Basement/crawlspace under house

Garage: [ ] Attached, [ ] Detached

J.4 APPLIANCE SAFETY

J.4.1 Combustibles

	Pre-Wx	Post-Wx
Where any combustible products placed or stored near gas appliance?	**[ ] Yes** [ ] No	**[ ] Yes** [ ] No
If Yes, where materials removed?	[ ] Yes **[ ] No**	[ ] Yes **[ ] No**

J.4.2 Gas Leaks

J.4.2.1 Olfactory Tests	**Pre-Wx**	**Post-Wx**
Are gas odors present:	[ ] No **[ ] R/R**	
• Near or around appliance?	[ ]	
• Around valves or fittings?	[ ]	
• Other locations	[ ]	
J.4.2.2 Soap/Bubble Test	**Pre-Wx**	**Post-Wx**
[ ] Not feasible.		
Were gas leaks detected by bubbles?	[ ] No **[ ] R/R**	
Where?		
• First fitting/Shut-off valve	[ ]	
• Gas Flex	[ ]	
• Appliance fitting	[ ]	
• Appliance regulator/control	[ ]	
• On appliance	[ ]	
• Other:	[ ]	
J.4.2.3 Gas Leak Repair	**Pre-Wx**	**Post-Wx**
Fixed by:		
• RHA Technician:	[ ]	
• Gas Service Technician	[ ]	
• Other:	[ ]	

J.4.3 Aldehyde Olfactory Tests

Are aldehyde odors present:	Pre-Wx	Post-Wx
• In the room or space?	[ ] **Yes** [ ] No	
• Near or around appliance?	[ ] **Yes** [ ] No	

Safety Notes:

J.5 VISUAL CHECK OF CLOTHES DRYER

J.5.1 General Condition	Pre-Wx	Post-Wx
Is lint filter clean/removed?	[ ] Yes **[ ] No**	[ ] Yes **[ ] No**
Visual evidence of burner problems		
Scorching	[ ] OK **[ ] R/R**	[ ] OK **[ ] R/R**
Missing access panel	[ ] OK **[ ] R/R**	[ ] OK **[ ] R/R**
Other Problems	[ ] OK **[ ] R/R**	[ ] OK **[ ] R/R**

J.6 APPLIANCE TESTING

J.6.1 "Appliance On" Tests	Pre-Wx	Post-Wx
Burner Ignition		
Ignites properly?	[ ] Yes **[ ] No**	[ ] Yes **[ ] No**

J.6.2 Instrumented CO Test		
	Pre-Wx	**Post-Wx**
	As-Measured	**As-Measured**
Test Location	ppm	ppm
[ ] Inside moisture exhaust or [ ] Inside lint screen port		

Notes:

K. GAS LOG

K.1 FUEL TYPE

Gas: [ ] Natural [ ] Propane

K.2 COMBUSTION AIR SOURCE

[ ] Outdoor
[ ] Indoor
[ ] Both – Outdoor and Indoor

K.3 APPLIANCE SAFETY

K.3.1 Gas Leaks

K.3.1.1 Olfactory Tests	Pre-Wx	Post-Wx
Are gas odors present:	[ ] No **[ ] R/R**	
K.3.1.2 Soap/Bubble Test		
Were gas leaks detected by bubbles?	[ ] No **[ ] R/R**	

K.3.1.3 Gas Leak Repair	Pre-Wx	Post-Wx
Fixed by:		
• RHA Technician:	[ ]	
• Gas Service Technician	[ ]	
• Other:	[ ]	

Safety Notes:

K.4 GAS LOG TESTING

	Pre-Wx		Post-Wx	
Startup Time:				
Test Time:				
Location	**As-Measured ppm**	**Air-Free ppm**	**As-Measured ppm**	**Air-Free ppm**
At top of fireplace opening				

L. COMBUSTION APPLIANCE ZONE (CAZ) TEST

Heating System __ of __

L.1 "APPLIANCE ON" TESTS – HEATING SYSTEM

Location:				
	Pre-Wx		Post-Wx	
Time appliance is turned "ON":				
L.1.1 Room Ambient CO #3 (Worst Case)	Pre-Wx		Post-Wx	
(Locations same as F.2)	Testo	Drgr	Testo	Drgr
Start or Finish Outdoor Ambient CO Level =				
Room Ambient CO Level =				
Indoor Temperature	°F		°F	
Time				
L.1.2 Appliance Ambient CO				
Heater CO Level =				

L.2 OPEN-DOOR TESTS

[ ] Not feasible (attic unit or crawl space)

L.2.1 Heating System: Instrumented Draft Test

	Pre-Wx	Post-Wx
Test Start Time:		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] No [ ] R/R	[ ] No [ ] R/R

L.2.2 Heating System: In-Flue CO Tests

		Pre-Wx		Post-Wx	
Test Start Time:					
CO in flue before dilution air. Location		As-Measured ppm	Air-Free ppm	As-Measured ppm	Air-Free ppm
Flue/Port #1	Side 1 Baffle A				
Flue/Port #2	Side 1 Baffle B				
Flue/Port #3	Side 2 Baffle A				
Flue/Port #4	Side 2 Baffle B				
Flue/Port #5					

L.3 CLOSED-DOOR TESTS

[ ] Not feasible (attic unit or crawl

L.3.1 Heating System: Instrumented Draft Test

[ ] Not feasible	**Pre-Wx**	**Post-Wx**
Test Start Time:		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**

L.3.2 Heating System: In-Flue CO Tests

		Pre-Wx		**Post-Wx**	
Test Start Time:					
CO in flue before dilution air.		As-Measured ppm	Air-Free ppm	As-Measured ppm	Air-Free ppm
Location					
Flue/Port #1	Side 1 Baffle A				
Flue/Port #2	Side 1 Baffle B				
Flue/Port #3	Side 2 Baffle A				
Flue/Port #4	Side 2 Baffle B				
Flue/Port #5					

L. COMBUSTION APPLIANCE ZONE (CAZ) TEST

Water Heater __ of __

L.1 "APPLIANCE ON" TESTS – WATER HEATER

Location:				
	Pre-Wx		Post-Wx	
Time appliance is turned "ON":				
L.1.1 Room Ambient CO #3 (Worst Case)	**Pre-Wx**		**Post-Wx**	
(Locations same as F.2)	**Testo**	**Draeger**	**Testo**	**Draeger**
Start or Finish Outdoor Ambient CO Level =				
Room Ambient CO Level =				
Indoor Temperature	**°F**		**°F**	
Time (2400)				
L.1.2 Appliance Ambient CO				
Water Heater CO Level =				

L.2 OPEN-DOOR TESTS

[ ] Not feasible (attic unit or crawl space)

L.2.1 Water Heater: Instrumented Draft Test

[ ] Not feasible (attic unit or crawl space)	**Pre-Wx**	**Post-Wx**
Test Start Time:		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**

L.2.2 Water Heater: In-Flue CO Tests

		Pre-Wx		**Post-Wx**	
Test Start Time:					
CO in flue before dilution air.		As-Measured ppm	Air-Free ppm	As-Measured ppm	Air-Free ppm
Location					
Flue/Port #1	Side 1 Baffle A				
Flue/Port #2	Side 1 Baffle B				
Flue/Port #3	Side 2 Baffle A				
Flue/Port #4	Side 2 Baffle B				
Flue/Port #5					

L.3 CLOSED-DOOR TESTS

[ ] Not feasible

L.3.1 Water Heater: Instrumented Draft Test

[ ] Not feasible (attic unit or crawl space)	**Pre-Wx**	**Post-Wx**
Test Start Time:		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**

L.3.2 Water Heater: In-Flue CO Tests

		Pre-Wx		**Post-Wx**	
Test Start Time:					
CO in flue before dilution air.		As-Measured ppm	Air-Free ppm	As-Measured ppm	Air-Free ppm
Location					
Flue/Port #1	Side 1 Baffle A				
Flue/Port #2	Side 1 Baffle B				
Flue/Port #3	Side 2 Baffle A				
Flue/Port #4	Side 2 Baffle B				
Flue/Port #5					

M. NATURAL GAS APPLIANCE:______________________

M.1 FUEL TYPE

Gas: [ ] *Natural* [ ] *Propane* [ ] **Fuel Oil**

M.2 SYSTEM TYPE

M.3 LOCATION OF HEATING UNIT

[ ] **Inside Conditioned Space** [ ] *Enclosed (closet opens to interior)* [ ] *Open*

[ ] **Outside Conditioned Space** [ ] *Enclosed (closet opens to exterior)*

[ ] *Roof* [ ] *Attic* [ ] *Garage*

[ ] *Slab/Ground* [ ] *Basement* [ ] *Crawlspace*

M.4 PILOT

[ ] **Standing**: [ ] *On* [ ] *Off*

[ ] **Luminous / Resistance** [ ] **Electronic IID**

M.5 COMBUSTION TYPE

[ ] **Open:** [ ] *Natural Draft* [ ] *Induced Draft*

[ ] **Closed:** [ ] *Vertical Flue* [ ] *Horizontal Direct Vent*

[ ] **Unvented** [ ] **Other – list:**

M.6 NAME PLATE DATA

Manufacturer: ______	Input Rating (KBTUH) = ______
Model:	Or Default Rating (KBTUH) =

M.7 COMBUSTION VENTILATION

Additional appliance(s):	Total Appliance KBTUH: =
Combustion Air Source(s)	**Total KBTUH Input =**

[ ] Outdoors Only

[ ] Indoors Only, from: [ ] *Conditioned Space* [ ] *Unconditioned Space*

[ ] Indoors and Outdoors

Combustion Air Vent(s)

Upper: [ ] Vent [ ] Duct [ ] None **Condition:** [ ] Clear [ ] Blocked

Lower: [ ] Vent [ ] Duct [ ] None **Condition:** [ ] Clear [ ] Blocked

Volume: [ ] Room/Enclosure only [ ] Vent(s) to adjacent space present

CVA Calculation(s)	**Existing**	**Required**	
Upper Openings NFV area =			sq. inches
Lower Openings NFV area=			sq. inches
Room Volume =			cu. feet
Is existing CVA acceptable?	Yes [ ] **No** [ ] If “No”, note repairs in Sec. E.1.		

M.8 HEATING SYSTEM - SAFETY

M.8.1 Combustibles

	Pre-Wx	Post-Wx
Are any combustible products located near gas appliance?	**[ ] Yes** [ ] No	**[ ] Yes** [ ] No
If Yes, where materials removed?	[ ] Yes **[ ] No**	[ ] Yes **[ ] No**

M.8.2 Gas Leaks

M.8.2.1 Olfactory Tests	Pre-Wx	Post-Wx
Are gas odors present:	[ ] No **[ ] R/R**	
• Near or around appliance?	[ ]	
• Around valves or fittings?	[ ]	
• Other locations	[ ]	

M.8.2.2 Soap/Bubble Test	Pre-Wx	Post-Wx
Were gas leaks detected by bubbles?	[ ] No **[ ] R/R**	
Where?		
• First fitting/Shut-off valve	[ ]	
• Gas Flex	[ ]	
• Appliance fitting	[ ]	
• Appliance regulator/control	[ ]	
• On appliance	[ ]	
• Other:	[ ]	

M.8.2.3 Gas Leak Repair	Pre-Wx	Post-Wx
Fixed by:		
• RHA Technician:	[ ]	
• Gas Service Technician	[ ]	
• Other:	[ ]	

M.8.3 Aldehyde Olfactory Tests

Are aldehyde odors present:	Pre-Wx	Post-Wx
• In the room or space?	**[ ] Yes** [ ] No	
• Near or around appliance?	**[ ] Yes** [ ] No	

Safety Notes:

M.9 VISUAL INSPECTIONS

M.9.1 Visual Check of Heater Flue/Vent System

Location	Inspection	Pre-Wx	Post-Wx
	Disconnections	[ ] OK **[ ] R/R**	
	Leaks	[ ] OK **[ ] R/R**	
	Obstructions	[ ] OK **[ ] R/R**	
	Improper pipe type	[ ] OK **[ ] R/R**	
	Slope	[ ] OK **[ ] R/R**	
	Termination	[ ] OK **[ ] R/R**	
	Draft hood	[ ] N/A	
	misaligned	[ ] OK **[ ] R/R**	
	missing	[ ] OK **[ ] R/R**	
	double	[ ] OK **[ ] R/R**	
	Other	[ ] OK **[ ] R/R**	
		List repairs needed in Sec. E.1.	

M.9.2 Visual Check of Combustion System

Inspection	Pre-Wx	Post-Wx
Heat exchanger defects (cracks, holes, warping, metal fatigue, etc.).	[ ] OK **[ ] R/R**	
Excessive soot	[ ] OK **[ ] R/R**	
Scorching	[ ] OK **[ ] R/R**	
Corrosion	[ ] OK **[ ] R/R**	
Burners clogged (soot, rust, etc.)	[ ] OK **[ ] R/R**	
Burners damaged	[ ] OK **[ ] R/R**	
Burners misaligned	[ ] OK **[ ] R/R**	
Pilot properly aligned with pilot generator	[ ] OK **[ ] R/R**	
Air shutters obstructed or abnormal	[ ] OK **[ ] R/R**	
Venturies obstructed or abnormal	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
	[ ] OK **[ ] R/R**	
	List repairs needed in Sec. E.1.	

M.9.3 Gas Control Valve

Inspection	Pre-Wx	Post-Wx
Damaged valve or missing parts	[ ] OK **[ ] R/R**	
Damaged wires and/or burned insulation	[ ] OK **[ ] R/R**	
Bypassed safety/locked-open ASO	[ ] OK **[ ] R/R**	
Other:	[ ] OK **[ ] R/R**	
	List repairs needed in Sec. E.1.	

M.10 APPLIANCE TESTING

M.10.1 "Appliance On" Tests	Pre-Wx	Post-Wx
M.10.1.1 Pilot	[ ] N/A	
Standing Pilot operating properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
Electronic Pilot ignites properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
Pilot in proper position	[ ] Yes **[ ] R/R**	
M.10.1.2 Burner Ignition		
Start-up Time		
Burners operate properly?	[ ] Yes [ ] **No**	[ ] Yes [ ] **No**
If **"No"**, what is the problem?		
Rollout	[ ] No **[ ] R/R**	
Delayed ignition	[ ] No **[ ] R/R**	
Short cycling	[ ] No **[ ] R/R**	
Other	[ ] No **[ ] R/R**	
M.10.1.3 Burner Flame Characteristics		
Color — Normal	[ ] Yes [ ] **No**	[ ]Yes [ ]**No**
>50% Yellow	[ ] OK **[ ] R/R**	
Strength		
Normal / Adequate	[ ] Yes [ ] **No**	[ ]Yes [ ] **No**
Soft, lazy	[ ] No **[ ] R/R**	
Under-gassed	[ ] No **[ ] R/R**	
Over-gassed	[ ] No **[ ] R/R**	
Other	[ ] No **[ ] R/R**	
Interference from air handler? [ ] N/A	[ ] No **[ ] R/R**	
M.10.1.4 Visual Check of Heat Exchanger - Burners On		
Heat exchanger defects (cracks, holes, warping, metal fatigue, etc.).	[ ] OK **[ ] R/R**	

M.10.2 OPEN DOOR Draft & Spillage Tests

[ ] Not feasible (attic unit or crawl space)	Pre-Wx	Post-Wx
M.10.2.1 Tactile Test for Spillage		
Evidence of spillage?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**
M.10.2.2 Smoke Draft Test		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
M.10.2.3 Instrumented Draft Test		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**

M.10.3 OPEN DOOR In-Flue CO Test

[ ] Not feasible	Pre-Wx		Post-Wx	
CO in flue before dilution air.	As-Measured	Air-Free	As-Measured	Air-Free
Location (describe)	ppm	ppm	ppm	ppm

M.10.4 CLOSED DOOR Draft & Spillage Tests

[ ] Not feasible (attic unit or crawl space)	Pre-Wx	Post-Wx
M.10.4.1 Tactile Test for Spillage		
Evidence of spillage?	[ ] No **[ ] R/R**	[ ] No **[ ] R/R**
M.10.4.2 Smoke Draft Test		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**
M.10.4.3 Instrumented Draft Test		
Measured Draft [ ] iwc or [ ] Pa		
Draft standard (Table H-2)		
Unit drafts properly?	[ ] Yes **[ ] R/R**	[ ] Yes **[ ] R/R**

M.10.5 CLOSED DOOR In-Flue CO Test

[ ] Not feasible	Pre-Wx		Post-Wx	
CO in flue before dilution air.	As-Measured	Air-Free	As-Measured	Air-Free
Location (describe)	ppm	ppm	ppm	ppm

Appendix D

Technical Data on Instruments

Table D-1: Testo 325 Technical Data

Probe type (measuring value)	Measuring range	Reaction time		
Piezoresistive pressure sensor (Draught/Pressure)	-16.0 ... 16.0 inH2O		Accuracy	+/-0.012 inH2O (-16.0 ... 1.2 inH2O) +/-1.5% of mv (1.2 ... 16.0 inH2O)
			Overload	+/-1.0 inH2O (-16.0 ... 16.0 inH2O)
			Resolution	+/-0.0040 inH2O (-16.0 ... 16.0 inH2O)
Type K (NiCr-Ni) (Temperature)	-40.0 ... 600.0 °C	90.0 - t98	Accuracy	+/-0.5 °C (0.0 ... 99.9 °C) +/-0.5% of mv (100.0 ... 600.0 °C)
			Resolution	+/-0.1 °C (-40.0 ... 600.0 °C)
Piezoresistive pressure sensor (Draught/Pressure)	-40.0 ... 40.0 hPa		Accuracy	+/-0.03 hPa (-40.0 ... 3.0 hPa) +/-1.5% of mv (3.0 ... 40.0 hPa)
			Overload	+/-1.0 hPa (-40.0 ... 40.0 hPa)
			Resolution	+/-0.01 hPa (-40.0 ... 40.0 hPa)
Calc. parameter (Efficiency)	0.0 ... 120.0 %		Resolution	+/-0.1 % (0.0 ... 120.0 %)
Calc. parameter (Flue gas loss)	0.0 ... 99.9 % qA		Resolution	+/-0.1 % qA (0.0 ... 99.9 % qA)
Electrochemical (Oxygen)	0.0 ... 21.0 Vol.% O2	40.0 - t90	Accuracy	+/-0.2 Vol.% O2 (0.0 ... 21.0 Vol.% O2)
			Resolution	+/-0.1 Vol.% O2 (0.0 ... 21.0 Vol.% O2)
Calc. parameter (Carbon dioxide)	0.0 ... -9999.0 Vol. % CO2	40.0 - t90	Accuracy	+/-0.2 Vol. % CO2 (... Vol. % CO2)
			Resolution	+/-0.01 Vol. % CO2 (null ... null Vol. % CO2)
Electrochemical (Carbon monoxide)	**0.0 ... 2000.0 ppm CO**	**40.0 - t90**	**Accuracy**	**+/-20.0 ppm CO (0.0 ... 400.0 ppm CO)** **+/-5.0% of mv (401.0 ... 2000.0 ppm CO)**
			Resolution	+/-1.0 ppm CO (0.0 ... 2000.0 ppm CO)

Table D-2: Dräger Sensor XS EC CO (68 09 105)

Measuring Range default minimum maximum	 0 to 500 ppm CO 0 to 100 ppm CO 0 to 2,000 ppm CO
Resolution	1 ppm or 0.5% of measured value, whichever is greater.
Warm-up time	- 12 hours to obtain the specified technical data - maximum 30 minutes for four-times measuring error - <10 minutes when a warm-up station is being used.
Calibration/adjustment of zero point	Waiting time for measured value to stabilize = up to 3 minutes
Ambient Conditions	-40 to 50 C 700 to 1300 hPa 10 to 90% relative humidity
Recommended storage conditions	0 to 30 C 30 to 80% relative humidity
Expected sensor life	>30 months
Repeatability Zero Sensitivity	 < or = 2 ppm < or = 1% of measured value
Linearity tolerance	< or = 5% of measured value
Effect of temperature (-20 to 50 C) Zero Sensitivity	 < or = 5 ppm < or = 0.4% of measured value
Effect of pressure Zero Sensitivity	 no effect < or = 0.02% of measured value/hPa
Effect of humidity Zero Sensitivity	 < or = 0.02 ppm/% r.h. < or = 0.4% of measured value/% r.h.
Effect of air flow (0 and 6 m/s) Zero Sensitivity	 no effect < or = 10% of measured value
Long term drift at 20 C Zero Sensitivity	 < or = 1 ppm/month < or = 1% of measured value/month
Response time at 20 C	< or = 35 seconds
Alarm response time	< or = 5 seconds at 20 C

Appendix E

Literature Review

E.1 Introduction

The general purpose of Phase 4 of the Natural Gas Appliance Testing Study is to obtain information that will allow the development of a set of recommendations regarding uniform Low Income Energy Efficiency (LIEE) program standards, policies and procedures regarding natural gas appliance testing. This literature review synthesizes evidence found in the literature with respect to a variety of issues relating to carbon monoxide (CO) testing policies. The following specific issues are covered:

- Description of CO and its effects on health,
- CO levels found in residential buildings,
- CO emissions from specific residential combustion appliances,
- Policies and practices relating to appliance testing and CO measurement in other programs,
- Linkages between infiltration rates and CO concentrations, and
- CO detection and monitoring procedures and devices.

Sources of data for this review include CO studies mentioned in other CO-related literature reviews, government documents (such as EPA guidelines) and other CO studies. This literature review is designed to serve as a starting point for further discussions on LIEE standardization, to provide some guidelines for the CO tests that will be conducted in Phase 4, and to provide a context in which the results of the CO tests can be assessed.

E.2 CO Sources and Health Effects

CO Sources

CO is a non-irritating, colorless, odorless, potentially lethal gas produced by natural processes and human activities. In the natural environment, trace levels of CO are considered normal, because plants can produce and metabolize CO. Major human activities leading to the formation of CO are fossil fuel combustion (i.e., via transportation, and coal, oil, or natural gas burning), biomass burning (i.e., via agricultural clearing, wood and refuse burning, and forest fires), and oxidation of methane and non-methane hydrocarbons (i.e., via landfills, coal mining and drilling in the natural gas and petroleum industry) (EPA 2000).

CO in the indoor environment can be the result of the following factors:

- Outside CO entering the home through doors, windows, cracks, separations and mechanical ventilation systems;
- Emissions from home combustion appliances, including cooking ranges, ovens, space heaters, furnaces, clothes dryers, and water heaters[1];
- Emissions from fireplaces and woodstoves;
- Emissions from motor vehicles in attached garages, and
- Tobacco smoke.

Section 1.3 summarizes the findings of relevant studies that have explored CO levels in residential buildings.

Potential General CO Health Effects

Prolonged exposure to high levels of CO can have dire consequences on human health. COs affinity to bind with hemoglobin is 200 times higher than that of oxygen. When CO is present in the body, it binds with hemoglobin to produce carboxyhemoglobin (COHb), and therefore inhibits the delivery of oxygen in the body (EPA, 2000 and Clancy, 1996). In general, as blood COHb levels become higher and higher, the symptoms of CO poisoning become more and more severe. Blood COHb levels vary as a function of time and level of exposure, respiratory rate, age of the patient, and presence of underlying illness.

Initial symptoms of CO poisoning include headache, fatigue, shortness of breath, nausea, and dizziness. Extended exposure to high levels of CO leads to cardiovascular and neurological symptoms and can eventually result in unconsciousness and death. Since the early symptoms of CO poisoning are similar to the symptoms of influenza (but without the fever), and many of the other symptoms are not specific, the diagnosis of CO poisoning is more likely to be made when clinical suspicion is high.

Inkster (2000) states that the Health Sciences staff at the Consumer Products Safety Commission consider levels above 20% COHb an immediate threat of death or permanent neurological damage. As a general rule, Health Sciences staff considers that keeping COHb levels from reaching 10% protects the majority of healthy consumers. The lowest exposure

[1] It should be noted here that most combustion appliances are vented. The operation of these appliances will not emit CO into the indoor ambient air unless venting systems are not working properly.

that can result in 10% COHb is about 65-70 ppm for at least four to five hours and is dependent on activity level.

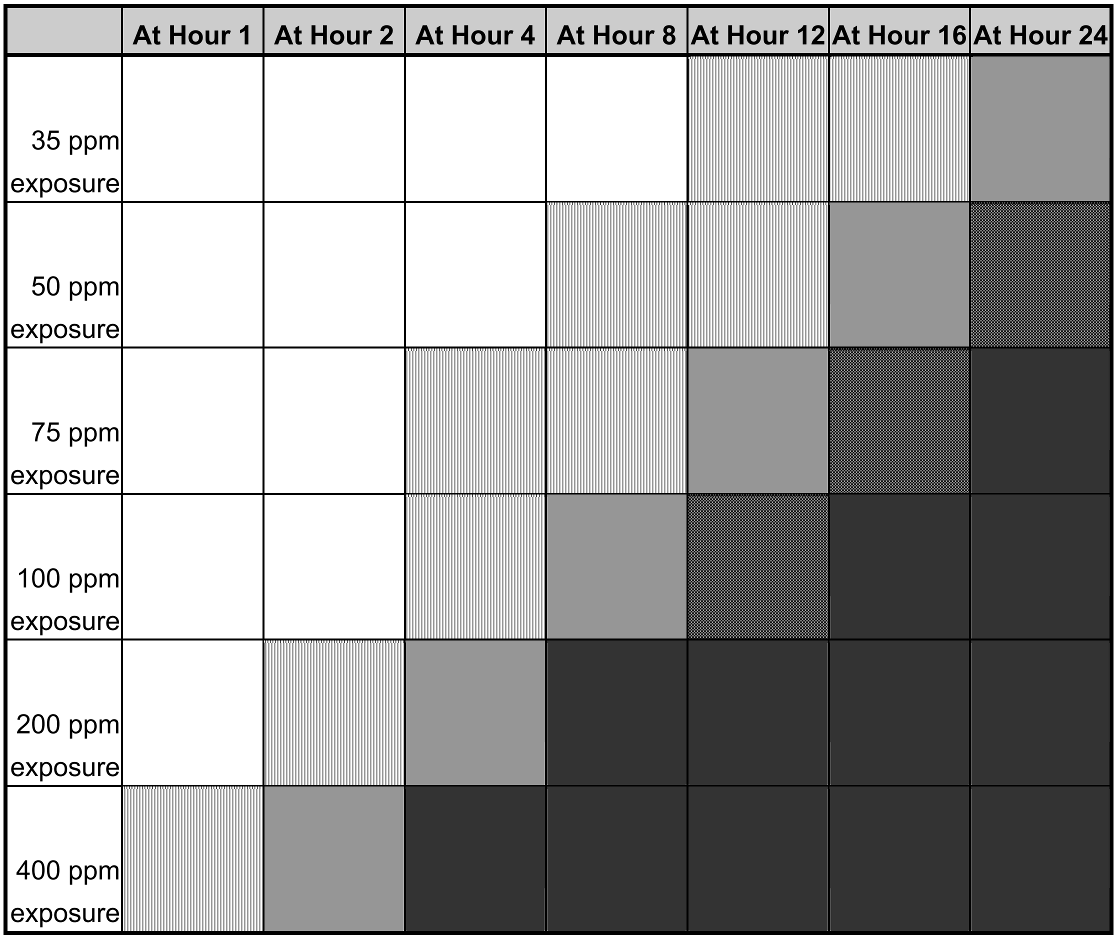
Oklahoma State University summarizes the toxicity of CO exposure as shown in Table E-1.

Table E-1: CO Toxicity Levels

CO (Parts Per million)	Percent CO in Air	Symptoms
100	0.01	No symptoms
200	0.02	Mild headache, few other symptoms
400	0.04	Headache after 1-2 hours
800	0.08	Headache after 45 minutes, nausea, collapse, and unconsciousness after 2 hours
1,000	0.10	Dangerous, unconsciousness after 1 hour
1,600	0.16	Headache, dizziness, nausea after 20 min.
3,200	0.32	Headache, dizziness, nausea after 5 min., unconsciousness after 30 minutes
6,400	0.64	Headache, dizziness after 1-2 minutes, unconsciousness after 10-15 minutes
12,800	1.28	Immediate unconsciousness, danger of death in 1 to 3 minutes

In addition to the health effects mentioned above, prolonged exposure may increase symptoms. For example, at 400 ppm for one hour, most adults will have minimal symptoms. At 400 ppm for two hours, most adults will feel a slight headache, be drowsy, and may begin vomiting. At 400 ppm for four hours, for most adults, death is certain. Figure E-1 shows the relationship between toxicity level and length of exposure (www.nadi.com). While these data are from an alarm manufacturer, we find that this graphic illustrates the relatively important point that carbon monoxide poisoning is a function of levels of exposure as well as length of exposure. Exact correlations of CO exposure levels and symptoms of CO poisoning are difficult to find. This is a result of the difficulty of conducting such experiments and a scarcity of data. Therefore, there is no single answer to exactly what level of CO exposure causes exactly which symptoms. However, the data found in Table E-1 and Figure E-1 were checked with several other sources and compare reasonably well.

Figure E-1: CO Toxicity Levels and Length of Exposure



Symptoms:

- Minimal symptoms
- Headache, nausea, vomiting
- Alaxia, cognitive impairment, amnesia, unconsciousness, coma
- Unlikely to survive

Notes: Based on data obtained from The Toronto Hospital and the Occupational Safety and Health Administration (OSHA)
Source:www.nadi.com (North American Detectors, Inc. webpage)

Effects of CO on Specific Disease Conditions

The U.S. E.P.A. (2000) conducted an extensive review of published results of controlled-exposure studies and population-exposure studies on the effects of CO on health. Since the studies summarized were examining CO levels in the human body, the unit of measurement was COHb levels in the blood. For comparison purposes, it should be noted that the lowest exposure that can result in 10% COHb is about 65-70 ppm for at least four to five hours.

The EPA (2000) overview of the effects of CO on health found the following.

- No effects were observed during submaximal exercise in healthy individuals at COHb levels as high as 15 to 20%. However, maximal exercise duration and performance in healthy individuals has been shown to be reduced at COHb levels of 2.3% to 4.3% -- these decrements, however, were small and likely to effect only competing athletes.
- Decreased exercise tolerance has been observed consistently in patients with coronary artery disease and reproducible exercise-induced angina (chest pain) at COHb levels of 3 to 6%.
- Recent analyses indicate that significant behavioral impairments in healthy individuals should not be expected until COHb levels exceed 20%; however, mild central nervous system effects have been reported in the historical CO literature at COHb levels between 5 and 20%.
- Ambient levels of CO are not known to have any direct effects on lung tissue.

Analyses of CO-related Deaths

Analyses of CO-related deaths help in determining the trends associated with CO poisoning. Clues about the major risk factors for CO poisoning can be obtained from answers to questions such as: Are certain segments of the population more likely to suffer from CO-related deaths? Is poisoning more likely to occur at certain times of the year? What are the sources of CO for these deaths? We reviewed a number of studies that have attempted to answer these questions. For ease of reading, we divided these studies into national analyses and California-specific analyses.

National Analyses of CO-related Deaths

In a report published in June 1997 by the Gas Research Institute, Koontz et al. studied unintentional CO-related deaths between 1979 and 1993. Unintentional CO-related deaths are considered such because the victim's death was accidental (not planned). Intentional CO-related deaths would include instances where victims die by purposefully planning to take their lives, for example, by dumping CO-laden motor vehicle exhaust gases into their cars. Unintentional CO-related deaths typically constituted 500 to 1,000 cases per year. To illustrate, in 1989, there were 4,630 cases of CO-related deaths. Of these, 813 were categorized as unintentional CO-related deaths. Table E-2, reproduced from Koontz et al., shows that the number of CO-related deaths and the percent of unintentional deaths decreased between 1979 and 1993.

Table E-2: Number and CO-Related Deaths and Subset of Unintentional Deaths, 1979-1993 Nationally in the U.S.

Year	Number of CO-Related Deaths	Number (percent) of Unintentional Deaths
1979	5,921	1,440 (24%)
1980	5,711	1,190 (21%)
1981	5,748	1,220 (21%)
1982	5,622	1,190 (21%)
1983	5,547	1,143 (21%)
1984	5,449	1,046 (19%)
1985	5,548	1,033 (19%)
1986	5,644	939 (17%)
1987	5,664	816 (14%)
1988	5,279	804 (15%)
1989	4,630	813 (18%)
1990	4,333	667 (15%)
1991	4,123	651 (16%)
1992	3,930	549 (14%)
1993	4,042	612 (15%)

Further analysis by Koontz et al. shows that unintentional CO-related deaths are disproportionately a cold weather phenomenon. Table E-3, from Koontz et al., shows that the coldest months (November-February) had the highest number of unintentional CO-related deaths while the warmest months (July-August) had the fewest deaths

Table E-3: CO-Related Deaths and Unintentional CO Deaths by Month Nationally in the U.S.

Month[1]	All CO-related Deaths	Unintentional CO-related Deaths
January	585	146
February	505	109
March	517	86
April	439	68
May	376	48
June	322	45
July	309	37
August	313	36
September	331	45
October	411	73
November	479	105
December	558	139

[1]Average for each month across years 1979 – 1993

Given that unintentional CO-related deaths are to some extent a cold weather phenomenon, it is no surprise that death rates in California are lower than rates in other colder states. Koontz et al. found that the national unintentional CO-related death rate was 0.28 deaths per 100,000 persons per year between 1988 and 1992), while the corresponding death rate in California was 0.14 deaths per 100,000 persons. Of course, variations in death rates across states are probably also partly attributable to factors other than climate, like appliance stocks and housing features.

Koontz et al. further analyzed the place of accident for unintentional CO-related deaths. Table E-4 summarizes their findings. As shown, the total number of unintentional deaths has fallen by more than half between 1979 and 1993—both in total and at home. However, the percentage of unintentional CO-related deaths occurring at home has stayed relatively constant at about 50%.

Koontz et al. also assessed selected causes of unintentional deaths in homes. The causes analyzed included pipeline gas, LP gas, other domestic fuels, and motor vehicle exhaust. Figure E-2, reproduced from Koontz et al., shows that as many as 62% of deaths that occur at home are due to motor vehicle exhausts (988 out of 1603 deaths at home between 1988 and 1992 occurred because of motor vehicle exhausts).

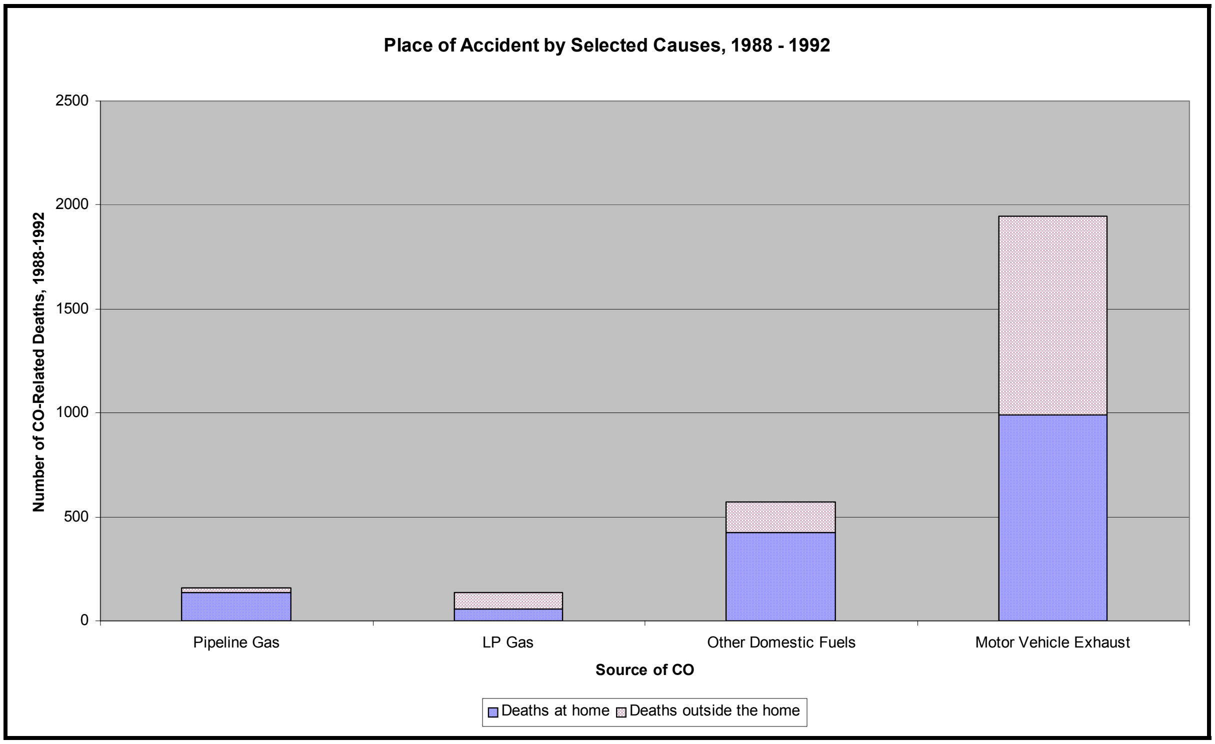
Table E-4: Place of Accident for Unintentional CO-Related Deaths 1979 – 1993 Nationally in the U.S.

Place	1979	‘80	‘81	‘82	‘83	‘84	‘85	‘86	‘87	‘88	‘89	‘90	‘91	‘92	‘93
Home	43%	46%	46%	49%	46%	46%	47%	49%	49%	50%	52%	51%	53%	50%	52%
Farm	1%	1%	0%	1%	2%	1%	1%	1%	0%	1%	1%	1%	0%	1%	1%
Mine	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%
Industrial	8%	8%	10%	8%	8%	7%	7%	6%	6%	7%	7%	5%	5%	6%	6%
Recreational	1%	1%	1%	2%	2%	1%	2%	1%	2%	1%	2%	2%	3%	2%	2%
Street	6%	5%	5%	4%	6%	5%	5%	5%	5%	4%	2%	3%	2%	3%	2%
Public bldg	3%	3%	2%	2%	3%	3%	3%	3%	2%	3%	2%	2%	3%	2%	1%
Institutional	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Other	38%	35%	36%	33%	34%	37%	34%	34%	36%	35%	33%	36%	33%	35%	36%
Total	**1440**	**1190**	**1220**	**1190**	**1143**	**1046**	**1033**	**939**	**816**	**804**	**813**	**667**	**651**	**549**	**612**

Source: Koontz et al. (1997)

Figure E-2 also shows that 8.4% and 3.6% of all unintentional CO-related deaths in homes were a result of pipeline gas and LP gas respectively. This implies that at a maximum, CO from gas appliances caused only 12% of total unintentional CO-related deaths occurring in homes. While pipeline gas appliances can be attributed for 8.4% of unintentional CO-related deaths nationally in homes and LP gas for 3.6% of deaths in homes, it should be noted that 61.9 million U.S. households use pipeline gas in their homes while only 8.1 million U.S. households use LP gas in their homes (Energy Information Administration, 1997). Therefore, CO from LP gas appliances is responsible for more deaths on a per household basis.

Figure E-2: Place of Accident by Selected Causes, 1988 – 1992



Source: Koontz et al. (1997)

<u>California-specific Analyses of CO-related Deaths</u>

Girman et al. (1993) examined unintentional CO-related deaths in California between 1979 and 1988. Girman et al. based their analysis on information taken from death certificates. A total of 522 reports were evaluated and 444 of these were judged to be authentic cases of unintentional death from CO poisoning. The remaining 78 cases were judged to be misclassified, which included homicide, suicide, gas poisoning, burn victim, etc.

The study conducted by Girman et al. (1993) shows the following.

- The proportion of male decedents (72.5%) was about 2.5 times the proportion of female decedents (27.5%). The 1980 Census shows the split of males to females as 49% to 51% in California.
- The proportion of blacks among the total unintentional CO-related deaths (15.1%) was twice the proportion of blacks among the California population (7.5% based on 1980 Census data).
- The proportion of adults over 50 years among the total unintentional CO-related deaths (34.6%) was higher than the proportion of adults over 50 years among the California population (24.3% based on the 1980 Census data).

- The proportion of adults between 20-29 years among the total unintentional CO-related deaths (23.3%) was higher than the proportion of adults between 20-29 years among the California population (18.0%).
- A seasonal variation may exist. The month in which most deaths occurred was December (22.0% of deaths). The least deaths occurred in July (2.5% of total deaths).
- Low socioeconomic status may or may not be a high risk factor for unintentional CO-related poisoning. Girman et al. (1993) tried to examine the relationship between socio-economic status and death rates, but found this difficult as death records do not contain enough data to classify decedents. However, Girman et al. used the limited data available and classified decedents into two groups: "low socio-economic status" and "not low socio-economic status." Based on these classifications, they found that combustion appliances accounted for 42% of deaths in the "not low socio-economic status" category and 30% of deaths in the "low socio-economic status." In contrast, however, they also found that hibachis/grills were the source of 11% of deaths in the "not low socio-economic status" and 21% of deaths in the "low socio-economic status." Percentages of deaths in other categories by socio-economic status were roughly the same. As a result, the data presented by Girman et al. (1993) do not provide conclusive evidence on the relationship between low socio-economic status and risk of CO-related poisoning.

Girman et al. (1993) also categorized the number of deaths and number of episodes by source of CO poisoning. An episode can be thought of as an incidence of unintentional CO-poisoning that resulted in casualties. Since more than one person could have been poisoned per episode, it naturally follows that number of episodes would be less than or equal to number of deaths. Table E-5 summarizes their results.

Table E-5: Number of Deaths and Number of Episodes of Unintentional CO-Related deaths in California During 1979-1988 by CO source

	Vehicle	Appliance Combustion	Small Engine	Camping Equipment	Fire	Grill/ Hibachi	Unknown	Total
Episodes	129 (35.9%)	125 (34.8%)	16 (4.5%)	8 (2.2%)	20 (5.6%)	48 (13.4%)	13 (3.6%)	359 (100%)
Deaths	136 (30.6%)	177 (39.9%)	23 (5.2%)	10 (2.3%)	22 (5.0%)	59 (13.3%)	17 (3.8%)	444 (100%)

As Table E-5 shows, the largest category for unintentional CO-related deaths in California was appliance combustion (e.g., from heating and cooking appliances), followed by exhaust from motor vehicles. These results differ from the results of Koontz et al. (1997) in that in California about 31% of unintentional CO-related deaths are from motor vehicle exhausts while nationally, 69% of unintentional CO-related deaths occur as a result of motor vehicle exhaust. In addition, combustion appliances caused about 40% of unintentional CO-related deaths in California, while natural gas, LP gas, and other domestic fuels nationally caused 31% of unintentional CO-related deaths. Finally, Girman et al. (1993) also found that 31% of deaths involved alcohol consumption and 42% of these deaths involved a vehicle. Koontz et al. (1997) also showed a relationship between the use of alcohol and drugs and unintentional CO-related deaths.

Girman et al. (1993) also further investigated the sources of fuel and types of appliances for unintentional CO-related deaths in California. The results of this investigation are shown in Table E-6

Table E-6: Number and Percentage of Unintentional CO-Related Deaths in California During 1979-1988 by Combustion Appliance and Fuel Type

	Stove	Free Standing Heater	Water Heater	Furnace	Wall Heater	Floor Heater	Misc.	Fuel Total
Natural Gas	14 (7.9%)	21 (11.9%)	14 (7.9%)	13 (7.3%)	58 (32.8%)	13 (7.3%)	--	133 (75.1%)
Propane	15 (8.5%)	11 (6.2%)	2 (1.1%)	2 (1.1%)	8 (4.5%)	--	5 (2.8%)	43 (24.3%)
Kerosene	--	1 (0.6%)	--	--	--	--	--	1 (0.6%)
App. Total	29 (16.4%)	33 (18.6%)	16 (9.0%)	15 (18.5%)	66 (37.3%)	13 (7.3%)	5 (2.8%)	177 (100%)

Table E-6 shows that wall heaters contributed to the most number of unintentional CO-related deaths (37%), followed by free-standing heaters (18.6%) and furnaces (18.5%) in California between 1979 and 1988. In addition, 75% of deaths were caused in homes with natural gas and 24% in homes with propane. Data from 1985 Census shows that 79% of Californians used natural gas as their main heating gas and 3% used bottled/tank/LP gas as their main heating gas (Liu et al. (2000)). Therefore, taking into account shares of type of heating fuel used by California households, it seems that propane is the cause of proportionally more unintentional CO-related deaths than is natural gas from the utility.

Liu et al. (2000) conducted another study of CO-related deaths in California. Like Girman et al., this study also used data from death certificates (from 1979 to 1988) as the primary source of information. Some notable findings from this study are as follows.

- Seventy-five percent (75%) of deaths occurred during a five-month period: November to March. Additionally, the highest number of deaths occurred in December and the lowest number occurred in August. The authors also found that a sharp increase in number of deaths per month was "very apparent during the months that approached winter." While the authors assert that December is not necessarily the coldest month in the winter, it is "most likely the month when most combustion appliances are initially fully used during the heating season."

- Thirty-three percent (33%) of deaths occurred in single family homes, 27% in multiunit homes and 7.4% in mobile homes and/or trailers (the remainder occurring in temporary shelters e.g. cabins, houseboats, converted garages etc). Based on data from the 1985 Census, it was found that 70% of Californians lived in single family homes, 26% in multiunit buildings and 3% in mobile homes and/or trailers. Using the population who lived in single family houses as the reference point, the authors were able to conclude that the "relative risks for living in multiunit dwellings and mobile homes/trailers are approximately 2 and 5 times" respectively.
- Forty percent (40%) of deaths occurred in homes in which natural gas from utilities was used and 11% in homes in which bottled/tank/liquefied petroleum (LP) gas was used. Based on data from the 1985 Census, it was found that 79% of Californians used natural gas as their main heating gas and 3% used bottled/tank/LP gas as their main heating gas.

Summary of CO Effects on Health

CO poisoning occurs when high levels of CO combine with hemoglobin in the blood to form COHb, thereby impeding the flow of oxygen in the body. The symptoms and effects of CO poisoning vary by time and level of exposure, respiratory rate, age of patient, and presence of underlying illness.

Analyses of unintentional deaths due to CO exposure have shown that between 1979 and 1993, the number of unintentional CO-related deaths fell in real numbers and as a percentage of all CO-related deaths. Furthermore, CO poisoning appears to be predominantly a cold weather phenomenon. Death rates in California are low relative to national rates. Nationally between 1988 and 1992, more than 50% of unintentional CO-related deaths occurred at home. However, about 62% of these deaths were due to motor vehicle exhaust and about 40% of unintentional CO-related deaths due to motor vehicle exhaust happened because drivers under the influence of alcohol (and drugs) left their cars running while in their garages. National data from 1988-1992 imply that, at a maximum, CO from gas appliances caused 12% of total unintentional CO-related deaths in homes. In contrast, California data show that 39% of unintentional CO-related deaths had combustion appliances as a source. Finally, California data also show that CO levels tend to be higher in multi-family dwellings and temporary shelters than in single family homes. Additionally, bottled, tank, and LPG fueled appliances exhibit a greater tendency to CO problems than natural gas-fired appliances.

E.3 Standards on Threshold Levels of CO

There are no U.S. agency standards for CO levels in indoor residential environments. However, varieties of organizations do have published standards for ambient CO in other environments. Standards vary across agencies for a variety of reasons, including the specific populations to which they apply. Most standards recognize the susceptibility of sensitive population segments like those with heart disease, anemia, blood disorders, or chronic lung disorders, as well as pregnant women, fetuses, and children. **Error! Reference source not found.** presents several standards relating to ambient CO. The length of time over which the CO level in question is experienced is indicated in parentheses. These standards are discussed below.

U.S. Environmental Protection Agency (USEPA). The USEPA sets national standards for outdoor air, which applies to the overall population and recognizes the susceptibility of some segments of the population. As shown in **Error! Reference source not found.**, the eight-hour CO standard is 9 ppm and the one-hour standard is 35 ppm. While this standard applies to outdoor air, USEPA recognizes the potential risks of indoor CO.

U.S. Department of Labor Standards (USDoL). The USDoL sets Occupational Safety and Health Administration sets standards for industrial work places. These standards relate to adults and pertain to exposures in the work place during a typical work week. USDoL's eight-hour CO standard is 50 ppm.

World Health Organization (WHO). The WHO standard is an international standard for indoor ambient CO. The WHO eight-hour CO standard is 10 ppm and the one-hour standard is 25 ppm.

U.S. Centers for Disease Control (USCDC). The USCDC is an agency of the Department of Health and Human Services. It assists in the development and application of disease prevention and control, environmental health, and health promotion and education activities. Its eight-hour CO standard for industrial environments is 35 ppm.

California Air Resources Board (CARB). The CARB is a part of the California Environmental Protection Agency, an organization that reports directly to the Governor's Office in the Executive Branch of California State Government. CARB's ambient air quality standard, which was developed by the Department of Health, is 9 ppm (eight hours) and 20 ppm (one hour). Note that CARB's one-hour standard is somewhat lower than the comparable EPA standard.

Canadian Ministry of Health. The Canadian Ministry of Health has published a set of CO guidelines developed by the Canadian Federal-Provincial Advisory Committee on Environmental and Occupational Health. These guidelines were developed in a way that recognizes the vulnerability of sensitive populations.

Consumer Product Safety Commission (CPSC). CPSC worked with Underwriters Laboratories (UL) to help develop the safety guideline for CO alarms. CPSC also works with industry to develop voluntary and mandatory standards for fuel-burning appliances. According to CPSC, "effects from exposure to CO levels of approximately 1 to 70 ppm are uncertain, but most people will not experience any symptoms. Some heart patients might experience an increase in chest pain. As CO levels increase and remain above 70 ppm, symptoms may become more noticeable (headache, fatigue, nausea). As CO levels increase above 150 to 200 ppm, disorientation, unconsciousness, and death are possible." (See CPSC Document #466).

Table E-7: Comparison of Threshold Levels of CO

Organization	Type of Environment	Ambient CO Standard
U.S. Environmental Protection Agency	outdoor environments	35 ppm (1 hr.) 9 ppm (8 hrs.) Not to be exceeded more than once per year
U.S. Department of Labor (Occupational Safety and Health Administration)	Industrial environments	50 ppm (8 hrs.)
World Health Organization	indoor environments	90 ppm (15 mins.) 50 ppm (30 mins.) 25 ppm (1 hr.) 10 ppm (8 hrs.)
U.S. Centers for Disease Control	Industrial environments	200 ppm (ceiling over 8 hrs.) 35 ppm (8 hrs.)
California Air Resources Board	outdoor environments	20 ppm (1 hour) 9 ppm (8 hours)
Consumer Product Safety Commission	Indoor environments	See text above
Canadian Ministry of Health	Indoor environments	25 ppm (1 hour) 11 ppm (8 hours)

E.4 CO Levels Found in Residential Buildings

This section reviews available evidence on CO levels found in residential buildings. Studies relating to residential CO levels are important from the perspective of the Phase 4 study for two reasons. First, their results provide a backdrop against which metered results obtained in the course of Phase 4 can be assessed. Second, insights gained in the course of prior studies can assist in the design of the Phase 4 effort. Insofar as the Phase 4 study relates directly to low-income homes, it would have been extremely useful to have found other studies of CO levels in such homes. Unfortunately, we were able to find no published studies relating directly to low-income homes. Nonetheless, more general studies of CO in residential structures were identified, and are reviewed in this section. These studies cover both ambient levels and appliance-specific levels. Accordingly, the remainder of this section discusses evidence concerning CO levels in residential buildings and summarizes information relating to appliance sources of CO.

Studies of Ambient CO Levels in Residential Buildings

Evidence on ambient CO levels in residential structures is scant. Wilson et al. (1993) and Colome et al. (1994) performed a survey that measured the indoor and outdoor CO levels of nearly 300 randomly selected California residences for a 48-hour period during one winter. One of the goals of this project was to determine the association of average indoor pollutant concentrations with building characteristics, appliance use, and outdoor concentration. The authors of the survey believed that high participation rates would allow the results of the survey to be generalized to the service territories of PG&E, SoCalGas, and SDGE. Therefore, one of the objectives of the study was to have participation rates of at least 60%, and this objective was met. When the project was completed, the final sample size was 129 houses from PG&E, 75 homes from SoCalGas and 89 homes from SDG&E. Measurements were made over 48 hours using passive samplers that were installed inside the home.

Table E-8, adopted from Wilson et al. (1993), shows the indoor and outdoor CO levels for all the homes tested in the project.

Table E-8: CO Levels for all Homes in ppm.

All homes	Indoor Average					Outdoor average				
	48 hrs.	Max 10 min	Max 30 min	Max 1 hr	Max 8 hrs.	48 hrs.	Max 10 min	Max 30 min	Max 1 hr	Max 8 hrs.
Mean	1.6	5.2	4.8	4.5	2.9	1.0	5.5	4.3	3.8	2.0
Standard Dev	1.7	5.5	4.8	4.4	2.9	1.2	6.7	4.4	4.0	2.4
Maximum	12.9	37.9	36.7	35.8	23.5	10.8	68.7	31.5	27.3	17.3
95th percentile	4.3	15.1	14.2	13.2	8.3	2.7	16.1	12.3	10.6	6.3
75th percentile	1.8	6.6	6.0	5.8	3.4	1.3	6.1	5.2	4.8	2.2
50th percentile	1.2	3.5	3.1	3.0	2.0	0.8	3.3	2.9	2.6	1.4
25th percentile	0.7	2.0	2.0	2.0	1.2	0.3	2.0	1.9	1.5	0.9
5th percentile	0.1	1.0	1.0	1.0	0.5	1.0	1.1	1.0	1.0	0.3
Minimum	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
Sample size	277	277	277	277	277	277	277	277	277	277

The maximum values shown for the 10 min., 30 min., 1 hr. and 8 hr. columns are the highest concentration that occurred during the 48-hour monitoring period. The authors also note that the maximum one-hour or eight-hour concentrations for the inside and outside monitors did not necessarily occur at the same interval during the two-day sampling. For example, the maximum indoors could have occurred during the first day while the maximum outside occurred on the second day. The table shows that CO levels inside the home are higher than the 9 ppm over eight-hour standard recommended by the Clean Air Act for fewer than 5% of the homes. In addition, outdoor levels of CO over 48 hours are generally lower than indoor levels (48 hour mean is 1.6 ppm indoors and 1.0 ppm outdoors).

Wilson et al. also reported the CO level data separately by utility. PG&E and SDG&E homes have lower 48-hour means of 1.3 and 1.0 ppm indoors, respectively, and 0.7 ppm (for both) outdoors. SoCalGas homes have both higher indoor and outdoor CO mean levels at 2.7 and 1.9 ppm, respectively. SoCalGas serves the Los Angeles basin, which is "out of compliance" (i.e., has higher outdoor concentrations of CO than recommended by federal standards) regarding ambient air quality standards for CO. As discussed below, this may be a factor in higher indoor CO levels.

Given the data from the study, Wilson et al. (1993) conclude that, for most California homes, the indoor concentration of CO is closely associated with and appears largely determined by the CO concentration observed outside of the home. In addition, the data analyzed by the study team in another project (Wilson et al. 1994) show that outdoor CO accounts for 55% of the variability of indoor CO for the 48-hour period. In addition, 60-70% of the homes had indoor CO that is not significantly greater than the outdoor concentrations, indicating that those homes may have no discernible emissions of CO indoors.

Outdoor levels of CO are reportedly the biggest influence on indoor levels. As a result, impacts of indoor conditions on CO levels are generally shown using the differences between indoor and outdoor concentrations. Table E-9, reproduced from Wilson et al. (1993) and Colome et al. (1994), shows that elevated levels of CO are more likely to be found in homes that are smaller multiple family homes, cook with gas ranges that have standing gas pilots, have gas-fired wall units, have occupants that smoke, or keep their homes warmer than average.

Table E-9: Profile of the Highest and Lowest Decile 48-Hour CO Homes (Indoor Level Minus Outdoor Level over 48 Hours)

Recorded Parameters	Lowest 10% of Indoor Minus Outdoor CO	Highest 10% of Indoor Minus Outdoor CO
48-hour CO concentration in ppm		
Average Indoor	0.9	4.5
Average Outdoor	1.7	1.4
Heating Unit		
No heating unit in home	0%	4%
Electric	14%	18%
Wall (gas)	4%	36%
Forced air (gas)	71%	29%
Floor (gas)	4%	4%
Cooking Type		
Electric	61%	21%
Gas without standing pilot	25%	18%
Gas with standing pilot	11%	57%
Space heating with range	4%	14%
Smoking in Home	7%	50%
Building Type		
Single family detached	71%	43%
Single family attached	7%	7%
Multiple family	18%	46%
Average delta temp in-out	10.2 degrees F	15.4 degrees F
Average home volume	13,557 cf	7,672 cf
Average air exchange	0.5	0.6

Note: the difference between the indoor and outdoor 48-hour CO concentrations were calculated and ranked from low to high. The two extremes of that distribution were selected for comparison.

Another study by Conibear et al. measured CO levels and sources found in a random sample of 84 homes in Chicago during the 1994-1995 heating season. The authors found that initially (with no combustion appliances running), 97.6% (82) of the homes had CO levels ranging from 0-6 ppm. The two remaining homes with higher CO levels had CO measurements of 13 and 15 ppm. However, when combustion appliances in the home were turned on, only 88% of homes had CO measurements between 0-8 pm while the rest of the 12% of homes had CO measurements ranging from 9-22 ppm. It should be noted that the methods used by Conibear et al to measure CO levels were called into question by a technical report sponsored by GRI.[2]

Studies of CO Emissions from Appliances

Improperly maintained or vented appliances can increase indoor levels of CO. Many combustion appliances are routinely vented to the outside (e.g., heating units) while other appliances (e.g., gas ranges) are not normally vented. This section discusses the levels of emissions found near appliances. CO emissions from appliances are difficult to measure—it is generally important to measure CO emissions when there is no excess air (also known as air free ppm). This is because even small changes in excess air can cause big variations in the CO emissions in ppm. Ideally, we would like to report air free CO emissions. However, some of the studies we reviewed did not measure CO emissions as air free emissions. While the measurements reported by these studies may be somewhat misleading in terms of absolute levels, the general results may be useful in determining which appliances are more likely to have higher CO emissions.

Metropolitan Minneapolis-St. Paul Study

As part of a sound insulation program for the Minneapolis-St. Paul Metropolitan Airports Commission, Bohac et al. are currently conducting extensive indoor air quality evaluations on single family houses before and after participation in an airport sound insulation program. Insofar as the sound insulation measures are very different from the infiltration-reduction measures installed under the LIEE Program, the changes in CO levels from this study are not particularly relevant to the Phase 4 study. However, the pre-insulation levels of CO may provide evidence with respect to pre-existing conditions in single family homes. Unfortunately, complete results of the study are apparently not yet available. Although 4,900 homes had been insulated and evaluated as of September 1999, the only available report covers only 100 homes evaluated between January and September 1997 (Bohac and Brown, *Results from IAQ Evaluations*). Moreover, ambient CO levels (which are of primary interest in Phase 4) were not measured. However, individual gas appliances were tested for levels of CO emissions, using a digital type gauge with the probe inserted in the throat or flue of a combustion appliance after five minutes of burner operation.

Bohac et al calculated frequency distributions of flue CO for natural gas ovens, water heaters, and furnaces. The study results indicate that 52% of natural gas ovens, 5% of water heaters, and 11% of furnaces had flue CO levels over the program guideline of 100 ppm. There are several reasons to treat these results with caution. First, these results are based on a small sample and may or may not be representative of the levels of CO measured for the overall

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[2] See Appendix 2 of the *GRI Topical Report: Critique of ANSI Z21.1 Standard for CO Emissions from Gas-Fired Ovens and Ranges*.

population of program participants. Second, it is unclear how the program guideline (100 ppm) was chosen and how it relates to CO levels generated in the flue gas of normally functioning appliances. Third, since CO readings were taken only in flue gas, it is impossible to tell the extent to which the observed levels of CO contributed to ambient levels.

San Diego Port District Policy on CO Testing

The San Diego Port District has also been conducting sound insulation of homes near the San Diego Airport, and has been assessing CO levels as part of a study. Unfortunately, formal results of this study are not yet available. In discussions with RER, however, a representative of the Port District indicated two general findings. First, the Port District found that CO levels were commonly related to weather (with higher levels in the winter). Second, elevated CO levels tended to be traceable to cases where furnaces and water heaters shared the same venting system. Therefore, the Port District decided that new furnaces would be vented separately from the water heater venting system. In addition, the Port District policy will conduct CO tests on a few homes both pre- and post-insulation, and will make results of these tests in spring 2002.

Impacts of Stove Operation

Sterling et al. (1979) measured CO levels in nine homes with gas stoves selected at random from student, staff, and faculty homes at Simon Fraser University in British Columbia, Canada. Measurements were made by placing a CO measuring device at an elevation of 5 ft from the floor. This study showed that ambient CO levels in the kitchen were initially 5 to 8.5 ppm (matching outdoor CO levels), but after 20 minutes of stove operation, rose to 29 to 120 ppm. After turning off the stove, the researchers also measured CO levels in the living and dining rooms. Immediately after turning off the stove, levels were between 19 and 105 ppm. Thirty minutes after turning off the stove, levels were between 8 and 65 ppm. Ninety minutes after turning down the stove, levels were between 8 and 50 ppm.

Impacts of Gas Ovens Usage

It is clear that CO emissions from some appliances can depend upon their mode of operation. The use of gas ovens for heating purposes may be a particularly troublesome practice in this regard. Despite the fact that the California utilities regularly warn their customers against this practice, a study by Slack et al. (1997) collected data on approximately 20,000 adults and their use of gas ovens for heating purposes. According to this study, about 9% of adults who used gas ovens for cooking also used them for heating once during the year. Improper use of ovens as a heating device was about twice as common among low-income households (14.5%) than among high-income households (6.1%).

Additionally, Persily (2000) modeled the CO emission results found by Davis (2000). Persily modeled eight ovens over four different operational modes:

- ***Space heat:*** oven put on bake mode, oven door left open and oven kept on for four hours and off for four hours
- ***Space heat:*** oven put on bake mode, oven door left open and oven kept on for one hour and off for seven hours
- ***Bake:*** oven put on bake mode, oven door closed and oven kept on for two hours and off for six hours
- ***Self clean:*** oven put on self clean mode, oven door closed and oven kept on for three hours and off for five hours.

Inkster (2000) used data from Persily (2000) and Davis (2000) to create a model that predicted likely CO emission levels in ppm from gas ovens. She made the following key assumptions in her model: varied size of room, varied air change rate, and varied emission levels from oven. Inkster then used rules recommended by Health Services (in the Unvented Gas Space Heater – UVGSH and Kerosene Heater (KH) projects) to determine whether CO levels were unacceptable. In particular, the UVGSH and KH project staff had recommended that ambient CO levels above 15 ppm for eight hours and 25 ppm for one hour were unacceptable.

Inkster's results showed that when gas ovens were used as space heat for long periods (four hours on and four hours off), they were most likely to emit unacceptable levels of CO. Modeled CO levels ranged from 36 ppm to 2,663 ppm over eight hours for small room sizes and from 3 ppm to 266 ppm over eight hours for large room sizes (these modeling results also depended on air change rate assumptions and the levels of CO emissions from gas ovens). In addition, when ovens were used to provide space heat for shorter periods (for one hour on and seven hours off), they could still emit unacceptable levels of CO, but only when emissions from gas ovens themselves were high.

These results suggest that the risks of CO may increase substantially when gas ovens are used for heating purposes and when the combustion air opening is covered with aluminum foil. As a result, the incidence of this practice is an important consideration in assessing potential risks.

While gas ovens can cause high CO levels when misused for heating purposes, another study by Tsongas and Hager, 1995, showed alarming results even when ovens were used for their appropriate purpose. Tsongas and Hager studied ovens in 60 small apartments by setting the oven on "broil" and keeping the oven door closed. The authors then measured ambient CO levels in the kitchen (at an elevation of 5 ft. from the floor) and found that in about half the kitchens, indoor CO levels were higher than 9 ppm over eight hours. Another 15% of homes had CO levels higher than 35 ppm over one hour. Tsongas and Hager found these relatively high levels of CO even though they judged the apartments "quite leaky." It is important to note, however, that the 60 apartments studied were located in only two buildings (41 in one building and 19 in another building). Buildings were located in Portland, Oregon and one building was 60 years old while the other was about 80 years old. Additionally, none of the apartments had been weatherized. Since we are aware that any number of factors can cause high CO levels, this lack in sampling diversity may have influenced the results. In addition, a technical review by Reuther (1996) of the Tsongas and Hager papers analyzes the data collected by Tsongas and Hager using a different statistical method (logarithmic transformation of data in order to determine the geometric average of the distribution). Using this statistical approach, Reuther found that "CO levels are 2-3 times lower than claimed" by Tsongas and Hager. In addition, Reuther shows using this statistical method, that "ovens do not appear to pose a 'widespread' health threat with regard to exposure to CO emissions. The probability of posing a threat is more like ~5% rather than 50%."

Emissions from Gas and Electric Ovens

A recent study by Kelly (2000) investigated the emissions from common cooking activities. Kelly used chamber tests to determine relatively high-emitting activities. These activities included pan frying of ground meat, bread baking, oven broiling and use of the automatic oven cleaning cycle. After determining these high-emission activities, Kelly performed these activities in a research house in triplicate with both gas and electric appliances under realistic conditions. Kelly found that "gaseous emissions of combustion products such as nitrogen oxides and CO were usually greater with the gas range, as expected, but CO was produced by the electric range as well in broiling of steak and automatic oven cleaning." In fact, Kelly found that "the emissions of CO were about the same with the gas and electric appliances in automatic oven cleaning." Kelly also mentions that similar results were found by a separate study conducted by the California Air Resources Board.

Unvented Kerosene and Gas-Fired Space Heaters

Before discussing the CO emissions from unvented space heaters, it is important to note that the California Health and Safety Code, Section 19881-19882, states that "no person shall sell or offer for sale, any new or used unvented heater that is designed to be used inside any dwelling, house or unit, with the exception of an electric heater or decorative gas logs for use in a vented fireplace" and that a violation of this chapter will be "considered a misdemeanor."[3] However, this provision has been in effect only since 1970, and some unvented space heaters are encountered in the LIEE Program.

Unvented gas space heaters can use both natural gas and propane. Since unvented space heaters are not vented to the outside, the pollutants they emit are less likely to leave the home and therefore, can reduce the quality of the indoor air. Studies (Traynor et al. 1983, 1985, and 1987 and Girman) conducted in the 1980s were aimed at measuring the pollutant emissions from kerosene and/or gas-fired space heaters. These studies concluded the following:

- CO emissions were much more variable than other pollutants. In repetitive tests, the same heater would emit highly variable rates of CO (Girman).
- Unvented kerosene fired space heaters emitted from 1-26 ppm of CO if they were well tuned, but could emit as much as 89 ppm if badly tuned (tuning is a proxy for the air to fuel ratio). In addition, one study showed that nine out of 18 tests resulted in CO levels of higher than 9 ppm over eight hours (Traynor et al., 1985)
- Convective heaters were less polluting than radiant heaters (the major difference between a convective heater and a radiant heater is that the convective heater primarily heats air in a room while a radiant heater sends out a beam of heat which heats objects e.g., people that are near the heater). Traynor et al. (1987) showed that despite closing and opening windows and doors, convective heaters emitted between 1-3 ppm while radiant heaters emitted between 9-18 ppm of CO. As would be expected, higher levels of CO were found when doors and windows were kept closed. However, when windows and/or doors were opened only slightly, the CO levels did not fall. This was because the heaters had to be operated for longer periods of time (and therefore, they emitted more CO) in order to achieve the same increase in temperature

Most of the above studies were conducted in the 1980s and showed that unvented gas and/or kerosene-fired space heaters were likely to increase CO levels inside the home. In contrast, Hedrick and Kurg's 1991 study, published in 1995, shows that the unvented gas-fired space heaters they tested did not exceed the EPA standard of 9 ppm over eight hours—in fact, the maximum CO level emitted by these heaters was 5 ppm over 24 hours. This could be a function of improved combustion technology or could be an anomalous result.

[3] Conversations with representatives from the California State Housing Law Program indicate that there are some exceptions to this provision. Selected unvented space heaters have been approved for use in California – these approvals are based, among other criteria, on levels of carbon monoxide emissions.

Summary and Implications of Review of CO Studies

Relatively few studies have measured ambient CO levels in residential buildings, and it is difficult to generalize the findings of the few studies that were available for review. Nonetheless, the literature reviewed as part of this project suggests that:

- Inside ambient CO levels are highly correlated with outside levels. One of the implications of this finding is that the Phase 4 protocol will call for "zeroing out" outdoor measurements. Measured levels of CO will reflect differences between indoor and outdoor levels.
- High indoor ambient CO is often the result of motor vehicle exhaust or other phenomena unrelated to combustion appliances. These factors will be considered in the design of the testing protocols.
- The literature offers relative little guidance on CO levels in low-income homes. This results from two factors. First, available studies do not focus explicitly on low-income homes, so we are forced to rely on studies of the general low-income sector. Second, the results of these studies vary considerably. Measurements of indoor ambient CO generally show low levels, although some studies have found levels that would exceed the current LIEE action level of 10 ppm. Variations in study results may be related to a variety of factors including differences in housing and appliance features as well as variations in specific testing equipment and/or procedures. The Phase 4 study can be expected to add substantially to the body of literature on CO.
- CO levels tend to be higher in the winter than in other seasons, presumably due to the use of combustion heating and reduced air exchange rates. The CO testing protocols will take this into account by conducting some tests under "winter conditions."
- Smaller homes tend to have higher levels of ambient CO than larger homes. The Phase 4 study will test this relationship further.
- The use of gas ovens for space heating could cause elevated CO levels. While the Phase 4 study will not test for CO levels with ovens used for long periods as space heaters, it will assess the CO levels associated with normal oven operation.

E.5 Policies and Practices Relating to Natural Gas Appliance Testing and CO Measurement in Other Programs

This section explores the policies and practices used by other state and utility low-income weatherization programs. This is useful from the perspective of the Phase 4 study as it provides benchmarks with respect to practices in other programs.

Practices: PPM Levels Considered Acceptable

Andrews (1998), in a survey of federally funded state weatherization programs, finds that 44 of 51 states have a standard and testing protocol for CO emissions from heating units. Weatherization program managers indicated threshold CO emission levels for ***appliances***. These threshold levels were based over the time of measurement of the appliance (in most cases, the time of measurement was between two and three minutes). For most states (22), the acceptable level is 100 ppm. Finally, six more states have acceptable levels of CO ranging from 200 – 400 ppm. Since these weatherization programs measure CO emissions from appliances (primarily heating and cooking appliances) and not ambient CO levels, it is difficult to determine what the corresponding ambient levels of CO would be.

Policies: When Testing is Conducted

In 2000 and later in 2002, RER interviewed low-income program managers of federally funded and utility ratepayer funded programs in a number of states regarding their programs and CO testing. Specifically, the following questions were asked:

- Is your program funded through federal, state or ratepayer funds?
- Do you conduct blower door testing? When is this testing done?
- Do you test for CO levels? When is this done? And do you test for ambient or appliance specific levels of CO?
- What do you do if CO levels are too high (exceed a program action level)?

Responses to these questions are summarized in Table E-10.

Table E-10: Weatherization Policies in Other State Programs

State	Time of Blower Door Testing	Time of CO Testing	Appliance or Ambient CO Testing	What if CO Levels are High?
Rate-payer or utility funded programs				
Minnesota Minnegasco program	Before	Before	Appliance specific and ambient	Repair problem themselves. Don't weatherize until problem fixed
New Hampshire (electric utility)	Before, during and after	Done before if customer has gas stove	Appliance specific	Customer informed about problem. Don't weatherize until problem fixed
New Jersey – Comfort Partners Program	Before, during and after (for air sealing work)	Before. If air sealing work, test under worst case depressurization conditions	Appliance specific and ambient	Repair problem themselves. Don't weatherize until problem fixed.
New Jersey – (electric utilities)	Before and after	Not done since they serve electric homes	Not applicable	Not applicable
Oregon – PGE and PacifiCorp ratepayers (electric utilities)	Before	Before and after (in homes with combustion appliances)	Appliance specific and ambient	Don't weatherize until problem fixed
Pennsylvania	Only done when doing air sealing work (rarely done)	Before and only if customer has gas appliances; occasionally measure after installation	Appliance specific	Inform utility of problem. Don't weatherize until problem fixed
Federal, state and utility funded programs				
Arizona	Before, during and after	Before and after in all homes	Appliance specific and ambient	Replace appliance, install CO alarm and continue weatherization
Colorado	Before	Before and after	?	Don't weatherize until problem fixed
Illinois	?	Before and after	Appliance specific	Replace appliance and then weatherize
Minnesota	Before	Before	Appliance specific and ambient	Repair problem themselves. Don't weatherize until problem fixed
Nevada	Don't have a weatherization program	Not applicable	Not applicable	Not applicable
New York	?	Before and after	Appliance specific	?
Texas	Before, during and after	Before	Appliance specific	Inform customer of problem. Don't weatherize until problem fixed
Washington	Before and after	Before and after	Appliance specific	Forward problem to service rep. Don't weatherize until problem fixed
Wisconsin	?	Before and after	Appliance specific	Repair problem. Don't weatherize until problem fixed

Table E-10 shows that most weatherization programs conduct blower door testing and test for high CO levels in cases where customers have gas appliances. Virtually all the program managers interviewed indicated that they checked CO emission levels before weatherizing homes. Some indicated that testing was also done during or after measure installation.

A 1998 study (Equipose Consulting) also evaluated California weatherization programs run by the utilities. This study recommends that weatherization contractors should be responsible for performing pre-installation Combustion Appliance Safety testing (rather than have these tests performed by utility crews). This practice was recommended as it potentially reduces the number of customer contacts required, potentially increases the installation of infiltration measures, and improves the contractor's knowledge of the job status. Of course, the authors also pointed out that a disadvantage of this proposal is that the entity conducting the test may have a vested interest in inflating results (potentially resulting in more work for the contractor), and therefore potentially biasing the results.

Summary of Other Programs

A survey of state weatherization programs found that most states had threshold levels for CO emissions from appliances, but not necessarily for the ambient air. In addition, many state weatherization programs conduct CO tests before and after weatherization work is completed.

E.6 Linkages, if any, Between Infiltration Rates and CO Levels

This section considers previous evidence on the potential impacts of infiltration reduction on ambient CO levels. We first consider the theoretical basis for positing a link between infiltration reduction and ambient CO. We then review the (scant) empirical evidence on this potential impact.

Theoretical Background

Air enters the house in three ways: 1) through infiltration (i.e., outdoor air flows through the house through openings, joints, cracks in walls, floors, and ceilings and around windows and doors), 2) through natural ventilation (i.e., when air moves through opened windows and doors), and 3) through mechanical ventilation systems. The overall impact of infiltration reduction on ambient CO may depend on three factors: reduced escape of CO to the outside, decreased heating requirements, and impacts on backdrafting and spillage.

Reduced Escape of CO. Infiltration reduction measures may significantly reduce air exchange rates and lessen the escape of CO to the outside. As joints, cracks in walls, floors and ceilings and around windows and doors become sealed, the rate at which outdoor air replaces indoor air is lowered (i.e., infiltration rates are lowered). To the extent that significant internal sources of CO are present, ambient CO levels may increase because of the reduced flow of air through the home and the associated reduction in escape of the CO to the outside (source: airservicewv.com).

Decreased Heating Requirements. Infiltration reduction and other weatherization measures may significantly reduce the amount of heating needed. If heating systems are responsible for CO concentrations, these CO emissions from heating appliances should also decrease. If most pollutants inside the home are by-products of heating appliances, then the emission of these pollutants may remain constant or actually decrease (Traynor et al. 1988).

Backdrafting and Spilling. Finally, apart from the low air exchange rates mentioned above, another infiltration related problem is that air exhaust systems can remove too much air from the house, thus creating a slight negative pressure inside the house. When too much air is removed, the negative pressure can become large enough to reverse the natural flow of gases up the furnace flue and instead cause the flue to become a passageway for the supply of outside air into the house. If the furnace burner is operating at that time, its products will not escape through the flue but will instead enter the house. Steel and Leonard theorize that this could cause dangerous levels of CO to build up in the home. Unfortunately, Steel and Leonard have not estimated the percentage of homes that are likely to have such problems.

The relationship between negative pressure inside the house and infiltration reduction measures also is not clear. This is because negative air pressure results from two primary causes. The first cause is the stack effect, where warm air escapes the house through openings near the top of the structure and cold air enters the building through lower openings. A large stack effect creates negative air pressure in the home and combustion gases may not flow out of the house. The stack effect can be reduced using infiltration reduction measures (e.g., sealing ductwork that will reduce the negative air pressure inside the home, and thus, reduce CO levels in the home). The second cause of negative air pressure is through exhaust devices—in small or tightly built homes, even a small exhaust fan can create a potentially dangerous level of depressurization. In these cases, the tighter the home is, the more likely it is for downdraft conditions to be created and, therefore, for pollutants from appliances such as furnace burners to enter the home (Boe 1996).

On a priori grounds, then, it is not clear if infiltration reduction measures would actually increase or decrease the levels of CO found inside the home. Conclusions with respect to this net impact must be based on empirical evidence. Some evidence found in the literature is reviewed below.

Evidence

In a study conducted in 1995, Levins et al. investigated the impacts of weatherization on infiltration and air leakage rates. They studied 337 houses—222 houses were weatherized and 115 were control houses. For the weatherized houses (222), 86% had general caulking and weatherstripping of doors and windows performed, 54% had air sealing work done (using a blower door), about 33% received attic insulation, 25% received floor insulation, and 20% received wall insulation. Additionally, structural infiltration reduction measures such as replacing broken window panes or entire window units, reglazing windows and fixing or replacing doors was done on 80% of the weatherized houses. Levins et al. were able to collect robust pre and post weatherization air leakage data on only 167 houses (113 weatherized and 54 control houses). Weatherized homes had air leakage reduction of 570 cfm50 (i.e., from 3295 cfm50 pre-weatherization to 2725 cfm50 post-weatherization), which was a 17% reduction in air leakage. In addition, the authors noted that this air leakage reduction was statistically different from zero at a 0.05 level of significance. Levins et al. concluded that "air leakage measurements showed that weatherized houses were more airtight following weatherization than before, but they are still much leakier than minimum ventilation guidelines."

In 1998, the CEC commissioned a study to evaluate compliance approaches (outlined in the Residential Alternative Calculation Methods (ACM) Approval Manual) for the 1998 Residential building standards. This particular study was performed because existing compliance approaches had been modified to "allow for increased infiltration reduction as a path to energy efficiency above existing levels" and because Section 25402.8 of the Public Resources Code required the CEC to "assess the potential impact of the modifications on indoor air pollution problems." The major finding from this study was that the changes to the ACM Manual (and hence, changes in the compliance approaches) would "not have a significant effect on indoor air quality and thereby not affect occupant safety and health."

The CEC maintained that a reasonable level of ventilation in a building would prevent pollutants from accumulating to levels capable of inducing health symptoms in occupants. The CEC used the ASHRAE Standard 62.2 to define "reasonable levels of ventilation." The standard requires an annual effective air change rate of 0.35 air changes per hour and states that this level is normally met through infiltration and ventilation through windows. Finally, regarding unusually tight buildings, the study reports that "vented fuel-fired appliances could reverse draft under conditions of continuous exhaust operation" and therefore, the study proposes that "unusually tight ventilation have supply ventilation.

Finally, the study concludes that Title 24 guidelines would not significantly impact indoor air quality. If infiltration rates in weatherized homes are greater than these standards, this would suggest that weatherization should not create problems under normal circumstances.

Another study, conducted in 1983 by Grimsrud et al. investigated indoor air quality in a relatively small sample (36 homes) of energy efficient residences. This study did not only measure indoor CO levels but also measured other indoor pollution products such as radon, formaldehyde, and other combustion products. Only half of the 36 houses in the sample had combustion appliances. The authors found that the maximum average value of CO was 3.3 ppm. Since other indoor air pollutants were also measured, the authors were able to derive an interesting finding—the houses in their study had both low infiltration rates as well as low pollutant concentrations. The authors also noted that the range of concentrations of pollutants was generally much larger than the range of infiltration rates in the houses. The authors suggest that these results are consistent with the point of view that indoor air quality in houses is often dominated by pollutant sources rather than by pollutant removal mechanisms (i.e., ventilation). These results would imply that weatherization programs that reduce infiltration rates while ensuring that combustion sources are well maintained and ventilated would be effective and not dangerous for occupants.

We have not found any research indicating how common this negative air pressure problem is in California homes. However, one study by Conibear et al, conducted in Chicago during the 1994 – 1995 heating season, concluded that approximately 10.7% (9) of the single family detached homes they tested showed evidence of depressurization conditions that could lead to backdrafting of furnace or water heater flue gas. These results may not be an indicator of the number of homes in California that may have negative air pressure since these homes were a randomly selected sample of homes in Chicago. It should also be noted that the risk of depressurization in this study was determined through visual inspections that looked for evidence of spillage or backdrafting. Another study conducted in Minnesota by Klossner (1996) indicates that the "three most prevalent sources of CO triggered by CO alarms were:

- Attached garages 74%
- Gas cooking appliances 28%
- Gas water heaters and furnaces that produced CO only during back drafting 16%"

While this study was conducted on a relatively small sample (50 houses), it does provide evidence that suggests that a correlation between back drafting and ambient CO may exist. Finally it should also be noted that backdrafting of this type would also be likely to result in large amounts of fresh outside air being drawn into the home and therefore diluting CO emissions.

Summary of Linkages Between Infiltration Rates and CO Levels

In this section, we have considered the potential effects of infiltration reduction and CO levels. Our review of the research suggests two somewhat offsetting effects of reduced infiltration. First, reduced infiltration may increase CO levels since indoor emissions would not be replaced by outside air as quickly as before. Second, reduced infiltration rates may decrease CO levels since combustion appliances may need to be operated for shorter periods to maintain internal temperatures and therefore generate less CO. Third, it is possible that infiltration reduction may cause changes in the indoor air pressure and therefore, could cause backdrafting conditions.

Empirical studies do not offer strong evidence of a relationship between infiltration reduction and ambient CO. While weatherization can be expected to reduce infiltration, it may not reduce it to levels low enough to cause problems under normal circumstances. According to one study, infiltration is not reduced to the levels required for new energy efficient construction, and the CEC has found that these new construction standards cause no internal air quality problems. We have not been able to locate research on the incidence of backdraft conditions in California homes.

E.7 CO Detection and Monitoring Procedures and Devices

In this section, we discuss standards for alarms, summarize findings on the performance of alarms, and discuss cost-effectiveness of CO alarm programs.

Standards for CO Alarms

UL 2034 lays out standards for CO alarms. In particular, the standard specifies that the maximum response times for concentrations of 70+/-5 ppm, 150+/-5 ppm, and 400+/-10 ppm should be 60-240 minutes, 10-50 minutes and 4-15 minutes, respectively.

Performance of CO Alarms in Laboratory and Field Tests

Kramer et al. (1999) presents a summary of questionnaires that were completed between October 1994 and spring 1998 by gas company employees each time they investigated a home following CO alarm activation. Over 35,000 records were obtained from gas utilities across the United States and Canada. About 71% of investigations in the 1997-98 season following activations found CO levels of less than 10 ppm in the indoor air (these measurements were taken in homes that were not allowed to “air out”). These data indicate that nearly three-quarters of CO alarm activations that resulted in an investigation were probably nuisance investigations. In addition, the study found that CO levels were, on average, higher in homes in which people reported feeling ill. However, even in these homes, 66% of homes had CO levels less than 10 ppm (at this level, symptoms are not *supposed* to occur). Finally, the study also showed that alarms used one of two sensor technologies: colorimetric and metal oxide. In their study, colorimetric alarms were more likely to sound when CO levels were less than 10 ppm than were metal oxide alarms.

The study by Kramer et al. (1999) also found that most of the activations occurred during the heating season (five months) but there was little correlation with day-to-day outdoor temperatures. Alarms were more likely to activate during weekdays than on weekends (perhaps reflecting increased outdoor CO due to increased use of automobiles) and that alarms were more likely to activate between 8:00 and 11:00 am (perhaps reflecting typical household activities).

In another study conducted in 1995, SoCalGas inspected 4,000 residences with gas appliances in Los Angeles in a six-week period. Wilson (1997) analyzed and summarized the results of these inspections. Wilson indicates that residential indoor CO detectors in alarm mode initiated 70% of inspections. Interestingly, the activation of these residential alarms was correlated with local ambient monitoring station data. On any one day, certain areas along the foothills or coast had numerous detector alarms while other areas had few alarms. A comparison with the nearest CO monitoring station data confirmed that the frequency of detector alarms seemed to increase as outdoor CO levels increased. Additionally, no increase in the number of malfunctioning appliances was observed for residences inspected in response to the activation of CO alarms.

Wilson (1997) asserts that the correlation between the activation of residential CO alarms and the levels of CO in the outside air suggests that there is a "non-indoor source or interference with the detectors" and that this evidence would support the hypothesis that "outdoor sources contribute to a large number of" detector alarm activations. Additionally, Wilson, 1997 found that residences in which detectors alarmed had fewer appliances that were in an unsatisfactory condition and therefore, "gas appliances were not a major contributor to the frequency of alarms." Given this evidence, Wilson concludes that "the detectors are not instrumental in mitigating potentially dangerous CO exposures and that the accuracy and precision of the detectors over time as installed in residences needs examination." Finally, Wilson believes that CO detector technology must be significantly improved before they can be considered a reliable indicator of dangerous indoor levels of CO." These findings may support the findings of Wilson et al. (1993), where the indoor level of CO is closely associated with, and appears to be largely determined by the CO concentration observed outside of the home.

Hedrick, 1998 also tested 96 residential CO alarms. Each unit was tested according to the specifications laid out in UL Standard 2034 test procedures. The results of the testing showed that a large number of units did not perform according to the standards laid out in UL 2034. In addition, the study found that low humidity levels caused the alarms not to activate. Clifford et al. (1998) also tested 80 (nine brands) residential CO alarms and found that most alarm brands suffered from serious deficiencies in performance. These deficiencies included out-of-box failures and manufacturing defects (17% for one brand and 38% for a second brand), poor control of sensitivity to CO (one brand alarmed late and only one brand alarmed when tested at low humidity levels), false alarms on exposure to common interference gases and late alarms (especially as alarms were aged) and inaccurate digital displays.

Given the results of Wilson (1997) and other similar studies, further studies were conducted in 1999 (Wilson 1999). Two hundred units from one manufacturer were evaluated in an environmental exposure chamber and then placed at three air quality monitoring sites that routinely measure CO levels. Ambient air caused some of these units to go into "warning" or "alarm" mode. During these alarm events, the CO levels was low (less than 5 ppm) but the relative humidity was high. This happened in contrast to Hedrick (1998) and Clifford et al. (1998), where low humidity levels caused suppression in alarm activation. In addition, chamber tests confirmed that relative humidity directly influenced the behavior of the detectors. Wilson (1999) also conducted several tests on units made by other manufacturers. While the results of each test varies by manufacturer, the following striking finding was made: some units would go into warning mode at a few hours of exposure to high humidity and very low carbon monoxide but will not alarm when there is enough CO to be deadly. Other units went into warning mode at elevated levels of CO but never alarmed. Finally, the last group of units tested was found to be very sensitive to humidity but did alarm with increasing CO exposures. At this point, it is interesting to note that the most common symptoms of tight, under-ventilated houses are condensation and moisture build-up (Nelson et al.).

Wilson (2000) also conducted a preliminary evaluation of a CO alarm for responsiveness to CO and transient electrical signals. The units tested responded accurately to CO levels from 0 to 200 ppm, but gave false values when exposed to portable telephone, cellular telephone, and ham radio signals.

The research conducted by Kramer et al., Hedrick and Wilson (Wilson 1997, 1999, 2000) show that CO alarms may malfunction during a few different occasions:

- When levels of CO in the outside environment are high,
- When humidity levels are high (or low)
- When transient electric signals, such as those from portable and cellular telephones and ham radio signals, are present.

In addition, CO alarms were also found to activate even when CO levels inside the home were relatively low, i.e., not above U.S. EPA standards.

Cost-Effectiveness Analysis

Chernoff et al. performed a study to assess the cost-effectiveness of nationwide use of CO detectors in U. S. residences. The study quotes the Consumer Product Safety Commission (CPSC) in saying that about 250 people die annually from unintentional, non-fire-related exposures to CO in residences. The study claims that about 170 of these 250 deaths occur in permanent residences (including attached garages). Therefore, in principle, CO detectors could help avoid 170 deaths and perhaps 10,000 illnesses per year.

The study further assumes that acquisition and operations costs of installing CO alarms in permanent residences would cost $1.7 billion a year. In addition, the study assumes response costs to be about $1.4 billion (given current detector performance and response protocols). Therefore, the authors calculate the combined cost of detectors and responses exceeds $18 million per life saved. The authors compare this $18 million per life saved to statistical valuations of ranging from $2 million (published studies) to $5 million (CPSC estimates). Even assuming that CO detectors were 100% reliable as CO absorbers (i.e., no alarm, no response, no false positives etc), the cost per life saved would exceed $10 million. Therefore, the authors conclude that assuming complete saturation of the residential market with CO alarms, the net losses to the economy would be billions of dollars per year compared to the estimated valuation of life. However, the authors do not investigate the impact of installing CO alarms in homes that have a likelihood of having high CO levels. It is possible that if only this segment of the population had CO alarms installed, the benefits of CO alarms may outweigh the losses to the economy.

Summary of CO Detection and Monitoring Procedures and Devices

Analyses of CO alarm performance have revealed a variety of problems. In the studies surveyed here, alarms have tended to malfunction under a variety of conditions, including high outdoor CO levels, extreme humidity levels, and the presence of transient electric signals. On the other hand, CO alarm technology may be improving and these problems may have been at least partly mitigated. To test this hypothesis, a portion of the Phase 4 study will be devoted to testing CO alarms in a subsample of buildings.

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Appendix F

Workshop Comments

The Standardization Team scheduled two public workshops to receive public input on a draft of the Phase 4 report. The first workshop was scheduled in San Francisco at the Pacific Energy Center on April 22, 2003. The second was scheduled in San Diego at Sempra's headquarters on April 24, 2003. Two members of the public attended the first workshop: Bob Burt of the Insulation contractors Association and John Proctor of Proctor Engineering Group. No members of the public attended the second, at it was adjourned without comments.

At the April 22 workshop, a brief presentation of the Natural Gas Appliance Testing study was made by the Standardization Team, and the floor was opened for public input. The comments received in the April 22 workshop are summarized below.

John Proctor registered a concern that he had not been given adequate notice of the workshop and that he was not being given adequate time to submit written comments. He also made the following points:

- A recent Underwriters laboratory report found that CO alarms are reliable, and adequately warn customers of elevated CO levels.
- The NGAT survey should have tested plug-in CO alarms, not just battery-powered alarms.
- Gas utilities have always been opposed to CO alarms.

Mr. Proctor noted that CO alarms have been used in the Low Income Home Energy Assistance Program (LIHEAP), and asked if the Standardization Team had tested LIHEAP homes as part of the study. The Team informed him that we had not.

Mr. Burt asked if the Team had analyzed the experience with CO alarms in LIHEAP, and the Team said that it had not, but that it was unaware of any analysis that had been done on the LIHEAP experience with CO alarms.

Mr. Proctor asked how the homes were chosen to receive CO alarms and data loggers, and the Team replied that they were randomly chosen.

Mr. Proctor questioned the recommendation that homes with non-IOU combustion fuels not receive infiltration reduction measures, and the Team explained its rationale for this recommendation. Mr. Proctor commented that these homes with electric space heat pay a considerable amount for electricity, and should get the measures. Both Mr. Proctor and Mr. Burt suggested that this recommendation could conflict with the recent Commission instruction to SCE that it should install all feasible measures in homes participating in its LIEE Program.

Mr. Proctor argued that smoke tests are not as effective as instrumented tests for identifying inadequate draft, and that he had a considerable amount of data supporting this point. The Team noted that these two tests gave virtually identical results in the homes for which both could be implemented. A member of the Team from PG&E indicated that PG&E had initially recommended instrumented tests, but that they had changed its position in response to other data indicating that the instrument test is not a good predictor of draft performance under other weather conditions.

Mr. Proctor asked if the recommendations entailed testing for CO in all rooms with natural gas appliances, and was assured that they did.

Bob Burt noted that the Phase 4 report doesn't include a history of IOU practices in the area of CO testing. The Team replied that this history had been provided in an earlier report filed with the Commission.

Mr. Burt questioned the Team's use of net indoor CO levels (indoor levels net of outdoor levels) in the analysis, on the grounds that health effects depend on gross, not net, CO levels. The Team responded that outdoor levels were very low, and that the use of net indoor levels had little impact on the results of the study.

Mr. Burt suggested that the report put too great an emphasis on averages, rather than focusing on extreme cases. The Team suggested that a major portion of the report dealt with homes above the action level of 10 ppm.

Mr. Burt suggested that the Team point out in the final Phase 4 report that even ambient CO of 10 ppm could cause health problems for some particularly vulnerable customers.

Mr. Burt raised an objection to disqualification of homes with non-space heating propane appliances from receiving infiltration reduction measures.

Mr. Proctor suggested that the Team put more information in Section 3 about the long-term effects of low-levels of CO.

Mr. Proctor suggested that flue CO tests are superior to ambient CO tests in identifying CO problems. He said that contractors did a lot of CO testing for SDG&E's Residential Contractor Program, and that they found problems with flue CO tests that weren't identified with ambient CO tests.

Mr. Proctor said that all cases he had heard of where backdrafting caused CO-related deaths involved very high winds. He said that backdrafting can also be caused by HVAC air handlers.

Appendix G

Comments by the Insulation Contractors Association on the Issue of Combustion Gas Testing

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I. Introduction

Comes now, the Insulation Contractors Association (ICA), to present follow-on comments on the Natural Gas Appliance CO Testing Study Report (Study) dated April 7, 2003. The ICA is a voluntary non profit association of persons involved in construction insulation. Most members also follow other interests.

II. Summary

1. In summary, we would like to emphasize that our Comments do not so much deride the Report as hope to supplement it, partly by providing argument that the problem addressed is (at least in some locations) probably worse than portrayed and the whole process deserves serious care, detailed attention and judicious oversight. We believe the Study generally reflects a high level of professionalism and sheds an accurate light on the vexed subject it addresses.

2. We only challenge three of the fundamental recommendations of the Report; here briefly summarized.

a) We believe that the testing of CO Alarms (primarily covered in Chapter 8 of the Study) failed to provide an objective study of the best available alarms, including in its study Alarms which had known (and avoidable) failings. So its findings are invalid. It also failed to take advantage of the well-known extensive LIHEAP experience with CO alarms. We therefore believe that those findings must be rejected and a further, truly objective and unbiased, study conducted.

b) We believe that the recommendation to NOT do weatherization of homes receiving IOU electric service and using non IOU fuel conflicts with the recent recommendation in a parallel study: that SCE do more broad-based LIEE work (which would have to include weatherization), even at the expense of doing fewer homes. We believe that recommendation is more sound than the above noted related recommendation in this Study and should govern Commission policy in this area. While that recommendation only referred to SCE, its principle properly applies to similarly situated homes served by other utilities.

c) *We are persuaded by Dr. Procter's testimony that flue testing should be retained, not made optional*. We do not here expand upon this recommendation, deferring to Dr. Procter's testimony at the Workshop as the expert. As to the cost impact of this recommendation on ratepayers, we note that PG&E's budget for even more extensive CO testing process would have very trivial effect upon a ratepayer bill.

3. We took serious note in our Workshop remarks of the routine Study methodology of using "net" CO measurements, e.g. measurements from which the known outdoor CO level was subtracted. As the last sentence on Section 4.2.1 observes, "... outdoor CO levels are generally low." This is generally true and, in all those specific locations where it is actually true, no significant harm was done. However, heavy motor traffic has a tendency to cause significant CO buildup in some inner cities (where many poor people live). So this seems an egregious practice in those locations. There, this practice could have overlooked some dangerous exposure. The blood particles have no concern about the outdoor level of CO, only that to which they are exposed. We do not here suggest any redoing of the Study's extensive work. We simply seek recognition in the implementation effort that greater danger is involved in those areas where outdoor levels of CO are often high.

III. I. CO Alarms Deserve Better Study

4. It is well known that the LIHEAP program in California routinely installs CO alarms. That program generally expends more per home than does the LIEE, so the increased cost of CO alarms would have a proportionately lesser impact upon its overall costs. Apparently, the Study made no effort to take advantage of, or learn from, the LIHEAP experience.

5. The Study elected to test CO Alarms that had known defects. The testing found a number of their trial alarms that failed sensitivity tests. The earlier discussion in the same chapter pointed out that mimetic devices, of which some were noted to be on the market, do not fail such tests. We note that Group III, assumedly a different type of alarm, had 9 members which all passed this test. (Table 8-7, page 8-11). The inclusion of a significant number of alarms that fail this test was simply an unnecessary loading of the test procedure with samples which would allow a finding of failure. As was noted in the discussion, the widespread battery failure problem could be avoided by using AC powered meters. While easy AC access could result in alarm location in slightly less than optimum points, they could still be located where they would give alarm in the event of real occupant hazard. To the extent that CO alarms are used in LIEE, a procurement bid for the whole state's needs would greatly reduce the cost by eliminating the fully appropriate (but in our case, unnecessary) retail costs.

6. *We strongly recommend that the Commission NOT accept the Study recommendation on CO Alarms, but that it order an analysis of LIHEAP experience in this area, followed by an unbiased, objective test of CO Alarms, using alarms which are not subject to sensitivity or battery failure, the primary reasons cited in the Study for not using CO alarms.*

IV. Rural Homes Which Receive Electric Service Deserve Weatherization

7. As noted above in par 1. b), we believe that a policy recommendation in a different portion of this work conflicts with the Study recommendation to not provide weatherization services for homes which receive electric service, but use non-IOU fuel. We believe those

who made this Study recommendation had their minds too closely bound to consideration of CO from combustion sources, neglecting the basic LIEE mission. The LIEE is an equity program designed to provide energy efficiency services to people too poor to take advantage of more conventional energy efficiency services. It therefore should consider the energy efficiency needs of rural users of electricity. The other study recommendation to which we refer directed SCE to provide a more broad based LIEE service. It was recognized that this would increase the cost per home, thereby reducing the number of homes that could be served. It was also noted that this could also reduce the cost effectiveness of the SCE program, which has concentrated on highly cost effective electric-related actions, such as refrigerator replacement and CFB installation.

8 However, that study still called for expanded SCE service. A significant number of rural people in PG&E and SDG&E territories are in the same situation as SCE customers who receive non-IOU fuel. These rural customers logically should receive the same consideration. In the past, the Commission has shown special concern for rural LIEE customers, requiring them to be separately reported on by the utilities in their compliance reports. Those who do not use electric heat should at least benefit from the fact that their situation is analogous to those subject to the policy recommended for SCE.

9. The discussion in the Study apparently did not recognize that some of the homes under consideration actually use electric heat and therefore could easily fit into the normal concept for LIEE weatherization service.

10. The Study recommendation to refer these homes to LIHEAP is not very realistic. LIHEAP does considerably fewer homes than LIEE and it is quite possible that the LIHEAP funds would be exhausted in the area where we seek their help.

11. Long Beach is a separate situation. This is the only significant municipal natural gas service in California. Munis are required by law to provide LIEE type service. However, with the exception of SMUD and MID, we note that their efforts tend to be more in the direction of discounts or trumpeted services to come in the future than actual services delivered. Here, there is a more reasonable basis for exclusion of electric customers receiving non-IOU natural gas service, since (in this case) the non-IOU gas is provided by a utility with an obligation to provide LIEE type service. Perhaps, if Long Beach is formally asked what will be their response to electric LIEE customers in their service territory who use their fuel, they might be impelled to provide some service or even to arrange a coordinated effort similar to that between SCE and SoCalGas.

V. Not just Fatalities, But Chronic Ill Health

12. Chapter 3 of the Study provides a reasonably good background on the risks of CO fatality, with passing mention of other adverse effects. We believe that it is also important to recognize that some of our clients are of a vulnerable nature. We know that the absence of CO in our evolutionary past makes all of us face the dangerous situation that our hemoglobin is up to 100 times more attracted to CO than to the oxygen it is designed to carry. This means

that lengthy exposure without significant time in air with very low CO content will allow a steady buildup of blood particles which have picked up a molecule (or more) of CO (becoming COHb) and are unable to function in their proper capacity of bringing oxygen to our tissues. This can have adverse effects on general health: especially causing chronic flu-like symptoms or low mental acuity (the brain needs up to a quarter of all our blood-born oxygen). For example, heart patients (who are often homebound), can be dangerously affected by far lower levels of CO than we normally are concerned about. Steady exposure to 9 ppm over a period of a week could generate an unhealthy level of COHb, as high as 90 cc, a level well short of death, but causing serious health effects. The EPA and CARB standard of 9 ppm for 8 hours is intended to provide a safety factor which would avoid this effect. So too, we should avoid the same danger inside the homes of our clients. We therefore believe that our implementation procedures should consider vulnerable populations.

VI. Areas Of Periodic High Outdoor CO Levels Deserve Special Treatment

13. As noted above (par 3), the practice of taking "net" CO readings (where the outside CO level is effectively subtracted from the reading) is not likely to cause any adverse effect in the bulk of the state. The problem arises in those (primarily urban) areas where CO buildup is common, normally from being adjacent to high motor traffic sites. Modern car catalytic converters, once warmed, do a pretty good job of getting rid of CO, so this may be a problem of declining importance as older cars a phased out.

14. Still, if the outdoor CO is approaching violation level, (CARB says 9ppm for 8 hours or 20 ppm for 1 hour, Study page 3-5) this "net" practice could have overlooked some serious interior ambient exposure. The local Air Pollution Control Districts (APCD) could probably provide information as to the locations where such episodes are common or are frequently approached. In these locations, we should recognize that our clients face a greater hazard of CO exposure. It might not reach the level causing fatalities, but there is still a significant health effect from chronic non-fatal exposure.

15. *As we note below, we support the recommendation that CO testing be AFTER weatherization. However, in the vulnerable areas cited above, where significant outside CO levels could be important, we recommend that LIEE weatherizers install CO Alarms even if it is not deemed an appropriate general practice.*

VII. General Comments

16. We note the absence of any history of CO testing, prior to the Commission order on this subject. Surely, the experience of the various utilities, especially the incidence of serious CO poisoning under various past systems of testing, would be worth study. The whole procedure seemed to be designed to stoutly ignore any routine past experience available. Gas utilities have been worried about CO ever since they were created. The LIEE situation can reasonably be considered a special case, but we should still learn from a century of past experience.

17. *While it may generate controversy, we support the recommendation that CO testing be conducted AFTER weatherization.* We are persuaded by the extensive testing the Study reports that this does not cause a significant hazard. We are also influenced in this matter by the experience of our contractors who have worked in the PG&E area in the past (where testing is prior to installation). They have (sometimes because of poor communication) been subject to draconian "hazard fail" procedures. With the possible exception of the areas where there is a high build up of outside CO (discussed above) we believe the primary real hazard in these situations is to the contractor's pocket book and the frustration level of his crews. If a CO alarm is installed in the homes situated where high buildup of outside CO is common, the alarm could provide warning in the case of any real hazard.

Respectfully submitted, *ss*
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