NBSIR 84-2869

Test Methods for the Direct Measurement of Stack Energy Loss During the Off-Period of Space Heating Equipment

Esher Kweller
Robert A. Wise

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Building Equipment Division
Gaithersburg, MD 20899

August 1984

Sponsored by:

**The Department of Energy
Office of Conservation and
Renewable Energy
Washington, DC 20585**

NBSIR 84-2869

TEST METHODS FOR THE DIRECT MEASUREMENT OF STACK ENERGY LOSS DURING THE OFF-PERIOD OF SPACE HEATING EQUIPMENT

Esher Kweller
Robert A. Wise

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Building Equipment Division
Gaithersburg, MD 20899

August 1984

Sponsored by:
The Department of Energy
Office of Conservation and
Renewable Energy
Washington, D.C. 20585

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

FOREWORD

The subject of this report involves an alternative test method toward arriving at a part-load or seasonal efficiency for vented space heating equipment (furnaces and boilers). In order for the reader to better understand this subject it would be desirable to first have an understanding of the existing DoE test procedures for this equipment. It is therefore desirable that at least some background review of references 1, 4, and 6 be attained. See page 17 for these references.

ABSTRACT

Evaluations have been made of a possible alternative to the tracer gas test method now being used to measure off-period energy loss of space heating equipment with vent dampers.

This alternative method offers the potential of a direct measurement method without the need for expensive tracer gas type instrumentation. The method uses a controlled flow of gas to a small gas fueled burner to simulate normal flue or stack temperatures previously measured during a cool-down test. Energy metered though the gas burner during the simulation gives a direct measurement of the thermal energy losses out of the stack. Results in comparison with the tracer gas method of test were lower for off-period energy loss meaurements. A trend to better agreement between the two methods was noticeable for test furnaces with greater fuel input rates. Further development testing and evaluation will be required before the simulation can be considered as an acceptable alternative test method.

Keywords: boilers; fossil fueled heating systems; furnaces; household heating equipment; part load efficiency; stack energy loss.

NOMENCLATURE

Br	$L_{S,OFF}$ during simulated cool down test determined by a metered burner.
C_p	Specific heat of air = 1.0 Kj/kg • °C (0.24 Btu/lb • °F).
C_T	Concentration by volume of tracer gas in stack (ppm).
C_T'	Concentration by volume of active tracer gas in a tracer gas supply (ppm).
$L_{I,OFF}$	Off-cycle infiltration loss, in % of the fuel input rate.
$L_{I,ON}$	On-cycle infiltration loss, in % of the fuel input rate.
L_L	Latent heat loss, in % of the fuel input rate.
$L_{S,OFF}$	Off-cycle sensible heat loss, in % of the fuel input rate.
$L_{S,ON}$	On-cycle sensible heat loss, in % of the fuel input rate.
$L_{S,SS,A}$	Sensible heat loss at steady-state operation, in % of the fuel input rate.
M	Mass flow during an increment of time (1 minute) during off-period.
MLOS	Summation of the mass flow M from the start of the cool down to each time increment during cool down.
$M_{S,OFF}$	Mass flow rate through the stack during total off-period, kg/s (lb/min).
P_B	Barometer pressure KPa (inches of mercury).
P_F	Ratio of $Q_P \div Q_{in}$ = pilot fraction.
P_V	Partial pressure of water vapor in the combustion products of a known fuel gas at a given excess air value (CO_2 value known) in the flue gas.
P_{VS}	The saturated partial pressure of water vapor in combustion products of a known fuel gas at a given flue gas temperature.
Q	Calculated energy during an increment of time KJ/min (Btu/min)during cool down period based on metered gas flow.
Q_{in}	Fuel energy input rate at steady-state operation (including any pilot light input), in But/h. $Q_{in,min}$ at minimum input, $Q_{in,max}$ at maximum input rate.
Q_I	Summation of the off-period infiltration heat loss through the stack from the start of the cool-down KJ (BTU).

Q_{LOS} or Q_S	Summation of the off-period sensible heat loss through the stack from the start of the cool down to each time increment during the cool down KJ (Btu).
Q_{out}	Fuel energy output rate - $Q_{out,min}$ at minimum input rate, $Q_{out,max}$ at maximum input rate.
Q_P	Fuel energy input rate to pilot light in Btu/h.
tg	$L_{S,OFF}$ during simulated cool-down period determined using a tracer gas test method.
TG	$L_{S,OFF}$ during normal cool-down period determined using a tracer gas method.
t_{off}	Off-time per cycle, in minutes.
t_{on}	On-time per cycle, in minutes.
T_{oa}	Average outdoor air temperature applicable during the heating season.
T_{RA}	Laboratory room temperature, in °C (°F).
$T_{S,OFF}$	Stack temperature during the cool-down period °C (°F).
η_u	Part load efficiency in %
ρ_s	Density of stage gas Kg/m^3 (lb/ft^3).
ϕ	Infiltration factor (dimensionless and assumed = 0.7).

Table of Contents

Table of Contents (Continued)

List of Tables

List of Figures

List of Figures (Continued)

1. INTRODUCTION

1.1 BACKGROUND

As a part of the Department of Energy's (DoE) energy conservation program for consumer products, the National Bureau of Standards (NBS) developed test procedures for gas and oil-fired furnaces and household heaters [1]. The Department of Energy published their rules and regulations covering test procedures for furnaces and vented heaters in the Federal Register on May 10, 1978 [2]. These procedures involve measuring values of flue gas temperature during a heat-up and cool-down test together with a thermal efficiency measurement by the flue loss method at steady-state conditions. Either measured or assigned draft stack factors (D_F, D_S, or D_P) which depend on the heater design are then used with the measured temperatures to calculate the part load utilization efficiency (η_u)*.

Part load space heater efficiency requires the determination of five flue losses. These are on-period sensible heat loss ($L_{S,ON}$), latent heat loss (L_L), on-period infiltration loss ($L_{I,ON}$), off-period infiltration loss ($L_{I,OFF}$), and off-period sensible heat loss ($L_{S,OFF}$). Measurement of the off-period losses is the objective of this report.

On-period Sensible Heat Loss, ($L_{S,ON}$) is sensible energy leaving the building up the stack which represents energy required to raise the stack gas from room temperature to stack temperature. This loss depends upon the heat exchanger effectiveness and the amount of excess combustion air used.

Latent Loss, (L_L) is the energy loss involved in the formation of water due to the combustion process. Hydrogen in the fuel combines with the combustion air oxygen to form water vapor. This water vapor requires potentially available heat if it does not condense (latent heat of vaporization). Latest DoE procedures now provide credit for the recovery of the latent heat of vaporization for high efficiency condensing furnaces [4, 7].

On-period Infiltration Loss, ($L_{I,ON}$) applies to heaters installed indoors and using indoor air for combustion and draft dilution. The energy loss is equivalent to the amount of energy used to heat air from the average heating season outdoor temperature of 6°C (42°F) to the indoor temperatures assumed to be 21°C (70°F).

---

* Part load efficiency (η_u) is defined as:

$$\eta_u = 100 - L_L - \frac{t_{on}}{t_{on} + PF \times t_{off}} (L_{S,ON} + L_{S,OFF} + L_{I,ON} + L_{I,OFF}) \qquad (1)$$

where the part load losses are described above, t_{on} and t_{off} are the burner on- and off-periods and PF is the pilot fractional input of the total input rate.

Off-period Infiltration Loss, ($L_{I,OFF}$) represents the amount of energy needed to heat the air which leaves the building up the stack while the burner is off. This loss is now determined in the DoE test procedure using an equation that predicts the mass flow during the cool-down test.

The various flow paths are shown in figure 1. A typical set of these part load losses for a vented room heater tested in the NBS combustion equipment laboratory is shown in figure 2. Depending upon the type of heater used, and its firing rate, these part load losses can vary significantly as will be shown by the range of values found in tests. (See reference 3 for details.)

The calculation of $L_{S,OFF}$ in the DoE test procedure is based on a relationship of assigned factors including flue and stack mass flow ratio with the burner on and off and uses measured flue temperatures during a cool-down test from steady-state conditions. These data and assigned values are used to calculate stack energy loss ($L_{S,OFF}$) during the cool-down period from the time the burner shuts down through the time $t_{,off}$. References [1, 5, and 6] include background and discussion of the equations involved.

The DoE procedure with assigned draft factors (D_S and S/F) was applicable for electrically operated dampers but was inappropriate for determining part load efficiency for heaters equipped with thermally activated dampers because the thermal dampers typically have higher off-period leakage rates and the leakage rate is temperature dependent.

In an effort to update the test procedures, DoE requested NBS to develop a method of testing which could be used to compare the annual performance of vented heaters with and without thermally activated vent dampers. NBS investigated the use of a tracer gas method and recommended that method to DoE for testing equipment with thermal stack dampers [3]. DoE published proposed test procedures in the Federal Register on June 17, 1983, for both furnaces and household vented heaters equipped with thermal stack dampers [4]. Those test procedures specify that a tracer gas test method be used to determine the off-period energy losses. DoE also proposed [4] that this tracer gas procedure be an option for all types of stack dampers and that it be the only procedure allowed after a two year period for all types of stack dampers.

1.2 TRACER GAS TEST METHOD FOR MEASURING OFF-PERIOD LOSSES

1.2.1 Off-period Sensible Heat Loss

This method involves measuring mass flow and temperature in the stack during a cool-down period. The product of stack mass flow, specific heat of air, and temperature rise above room temperature when integrated over the burner off-cycle period is equivalent to the off-cycle energy loss:

$$L_{S,OFF} = \frac{100 \times (C_p)}{(Q_{in})\, t_{on}} \sum_{0}^{t_{off}} M_{S,OFF}\,(T_{S,OFF} - T_{RA})\, dt \qquad (2)$$

where

$L_{S,OFF}$ is the off-cycle loss expressed as a percentage of the input rate,

Q_{in} is the burner input rate expressed in KJ/sec (Btu/sec),

t_{on} and t_{off} are the assigned burner cycling times on and off (min),

$M_{S,OFF}$ is the stack mass flow rate, kg/s (lb/min),

$T_{S,OFF}$ and T_{RA} are the stack temperature and room temperature at time t during the cool-down test expressed in °C (°F), and

C_p is the specific heat of air = 1.0 kJ/kg•°C (0.24 Btu/lb • °F).

100 converts the fraction to a percentage.

The method of test used to measure $L_{S,OFF}$ is to measure of the mass flow and temperature continuously during a cool-down period immediately after the heater has been operating at steady-state conditions. A tracer gas measurement using the guidelines described in appendix A was used in these tests to determine mass flow rate. The procedure used to obtain the data was as follows:

1. The unit was turned on and allowed to heat up to steady-state conditions. For heaters equipped with step modulating thermostats, the heater is set to the minimum heat input setting. For heaters with two stage thermostats two tests were run, one at minimum and one at maximum heat input setting. For furnaces equipped with a single stage thermostat the unit was operated at the maximum input rate.

2. When steady-state temperature was achieved, tracer gas was fed at a constant metered rate into the stack at the draft relief opening using guidelines described in appendix A.

3. The burner was shut off and the stack tracer gas concentration and temperature, and room temperature was measured continuously. These values were recorded at the midpoint of each one minute interval during the cool-down period. Sampling delay time was considered in these measurements. Sample delay time is determined as described in appendix A.

4. Barometric pressure was recorded.

After the above data was collected, the calculation of the product of mass flow and temperature could be determined using the summation of the incremental values as described in equation (2).

$\Sigma M_{S,OFF}$ $(T_{S,OFF} - T_{RA})$ is the summation of 20 values* of the quantity $M_{S,OFF}$ $(T_{S,OFF} - T_{RA})$ measured at midpoint of each one minute interval following burner shut down. T_{RA} is the room ambient temperature entering the draft relief opening (averaged during the test) and $T_{S,OFF}$ is an individual reading of the stack temperature.

When a pure tracer gas (a single component gas) is used $M_{S,OFF}$ is calculated from:

$$M_{S,OFF} = \frac{100 - C_T}{C_T} \dot{V}_T \rho_s \tag{3}$$

When a mixture of tracer gas component with inert gas is used as the tracer gas, $M_{S,OFF}$ is calculated from:

$$M_{S,OFF} = \frac{C_T' - C_T}{C_T} \dot{V}_T \rho_s \tag{4}$$

where

$M_{S,OFF}$ = mass flow kg/s (lb/min),

$\dot{V}_T$ = flow rate of tracer gas through the stack in m^3/s (ft^3/min),

C_T = concentration by volume of tracer gas present in the stack gas sample in percent,

C_T' = concentration by volume of the active tracer gas fed into the draft relief opening, and

ρ_s = the density the stack gas would have at the temperature T_T in kg/m^3 (lb/ft^3). It may be approximated by the equation:

$$\rho_s = 1.325 \left(\frac{P_B}{T_T + 460}\right) \tag{5}$$

where

T_T = absolute temperature of tracer gas entering flow meter °F, and

P_B = barometric pressure during the test in inches of mercury (kPa).

---

* Twenty values were taken for the test of the vented heaters and furnaces. A 33 minute cool down period (34 readings) was used when testing the hot water boiler since that is considered its normal off-period in DoE Test Procedures for Boilers.

1.2.2 Off-period Infiltration Loss, $L_{I,OFF}$

The measured mass flow rate through the stack used in determining the $L_{S,OFF}$ is also used in determining the $L_{I,OFF}$. The quantity of energy involved is found from the product of stack mass flow specific heat of air and temperature differences between indoor and outdoor temperatures (i.e., $70-T_{OA}$).

The same data for stack mass flow measured for $L_{S,ON}$ during the cool-down period is used for this calculation. The off-period infiltration loss is calculated from:

$$L_{I,OFF} = \frac{(1.3)\ 100\ C_P\ (\phi)}{(Q_{in})\ t_{on}} (70-T_{OA}) \sum_{0}^{t,off} M_{S,OFF}\ dt \qquad (6)$$

where:

In addition to units previously defined above in equations (2) and (3):

T_{OA} = the average outdoor temperature in the cycling mode, °C (°F), this is taken to be 42°F for furnaces and boilers and 45°F for household heaters as per the DoE test procedures,

ϕ = infiltration parameter, dimensionless, assumed equal to 0.7, (70 percent of the infiltration air is charged to the furnace flow),

70 = assumed indoor average room temperature, 21°C (°F),

100 = conversion factor for percentage,

1.3 = a dimensionless factor for converting laboratory measured stack flow to typical field conditions.

1.3 OBJECTIVE OF ALTERNATIVE METHOD TO TRACER GAS TESTING

Although the tracer gas method is a precise method and applicable to all vented heating equipment, it requires special equipment (as described in appendix A), which typically may not be part of a small manufacturers laboratory facility. Any alternative to the tracer gas test method must be one that offers both direct measurement rather than an analytical approach and be consistent with the tracer gas method in its results. In order to be considered as a substitute to tracer gas measurement an alternate method should offer an advantage over the tracer gas method with respect to the cost of instrumentation required for its use.

The objectives of the following possible alternate method, as with the tracer gas direct measurement method, are:

1. To offer a test method of measurement of the off-cycle loss of equipment with stack dampers for which an analytical approach is not feasible.

2. To provide an alternative method of test in order to reduce the number of waivers from testing because either the equipment or furnace involved is unique in such a way that the current test procedures do not apply, or the assigned factor of stack to flue flow ratios (D_S) is not believed to apply to specific manufacturer's equipment*.

---

* The analytical approach which uses assigned draft factors of mass flow rate, D_F and D_S remains in the DoE procedures for conventional equipment.

2. DESCRIPTION OF THE ALTERNATIVE MEASUREMENT METHOD

2.1 MEASUREMENT OF THE OFF-PERIOD SENSIBLE HEAT LOSS

This method uses a controlled flow of gas to a small flame holder (bunsen burner) in order to duplicate normal stack temperatures that would exit during a cool-down test from steady-state conditions. The amount of energy metered to the burner during this test is equivalent to the normal stack heat lost from residual heat stored in the heat exchanger and lost out the flue during the off-perod ($L_{S,OFF}$). The method is applicable to furnaces and heaters using thermal vent dampers and as such is a potential alternative to the direct though more complex requirements of a tracer gas measurement method required by the proposed DoE procedures in reference [4].

This procedure involves the following steps (refer to figure 3):

1. Determine the stack temperatures vs. time during a normal cool-down period after operating at steady-state (figure 3a).

2. Reheat the unit to steady-state by using either the burner of the heater or furnace or by using a separate burner such as a Bunsen burner positioned at the entrance to the draft hood (figure 3b).

3. Block the heat exchanger exit prior to a second simulated cool-down period.

4. Reproduce the stack cool-down temperature profile originally found (figure 3). This is done by substituting the heat that would have exited the stack with a controlled gas flame placed at the draft hood relief opening. The volume of gas used is metered during this second cool down period and the amount used during each one minute period of cool down is recorded. With the heating value of the gas known, the total volume used is converted to Btu's which gives a direct measure of thermal energy loss through the stack ($L_{S,OFF}$).

In calculating the thermal energy loss, the net heating value of the fuel is used*. The measured higher heating value of the fuel was reduced by approximately 10 percent in those tests to arrive at a net heating value of the natural gas used for testing. This net heating value is dependent upon the fuel gas composition and will vary with the local source of fuel and type used (i.e., natural gas, propane, or butane). Net heating value is used because some of the heat from the fuel is given up to vaporize water formed due to oxidation of hydrogen in the fuel. This latent heat is not available unless there is condensation of water vapor in the stack and it was found that condensation of water vapor did not occur. This was determined by knowing the stack gas

---

* Net heating value, also called lower heating value, is equal to the higher heating value of the fuel minus the latent heat of evaporation of the water vapor formed by combustion of the fuel.

combustion products i.e., CO_2 in the stack gas. If the partial pressure of water vapor in the combustion products (Pv) is less than the saturated partial pressure of water (Pvs) in the flue gas (or stack gas) then relative humidity will be less than 100 percent and condensation will not occur. Figure 4 was prepared to evaluate whether Pv, determined from a known CO_2 value in combustion products would be greater or less than Pvs at the temperature of the combustion products during a test. Data for Pvs and the calculations of Pv used in development of figure 4 may be found in reference [7]. In these tests CO_2 values did not exceed 0.5 percent. Therefore, Pvs was always greater than Pv. Flue temperatures during the cool-down tests are listed for each test in appendix C for one of the heaters tested.

During the early stages of the development of this method the controlled heat source used to reproduce the stack temperature was an electric resistance heating element. A 220 volt power supply connected to an electric clothes dryer heating element was controlled by a variable transformer. The thermal mass of the electric heater limited the response time needed to track rapid changes in temperature during the early stages of cool down. It also required correcting the test results for the energy stored in the heating element at the beginning and the end of the test. A simple gas Bunsen burner with needle valve control was found to eliminate the problem of stored energy and allowed for instantaneous control of heat output. The Bunsen burner was sufficient for those units with external draft hoods but a special burner configuration was designed for the test units with internal draft diverter.

2.2 MEASUREMENT OF THE OFF-PERIOD INFILTRATION LOSS

In order to measure off-period infiltration loss that would result in a home, it is necessary to calculate mass flow through the stack during the cool-down test. Knowing the Btu's of energy flow over a period of time and the average temperature above room temperature during that period of time, the mass flow may be calculated from:

$$M = \frac{Q}{(C_p)(\Delta T)} \qquad (7)$$

where

M is mass flow in an interval of time during the cool-down test,

C_p is the specific heat of air,

Q is energy flow through the stack in an interval of time during the cool-down test, and

ΔT is average temperature above room temperature of the stack or flue gas during the interval of time.

Substituting the metered gas flow converted to Q in Btu into the above equation, the increment of M is determined. In evaluating this alternate test method, the increment of time used was one minute during the first five minutes of cool-down.

The method requires taking a gas meter reading at the end of each minute but when temperature is not falling rapidly, i.e., after five minutes, this increment may be increased to every three, four, or five minutes. The total mass flow during cooldown is obtained by summing the incremental calculated mass flows. Off-period infiltration loss is then calculated using equation (6) where the value of $\sum_{0}^{t_{off}} M_{soff}$ is the sum of the incremental readings. In order to obtain the average temperature during each increment it is necessary to have made a continuous recording of the stack temperature during the simulated cool-down test.

3. TEST EQUIPMENT AND PROCEDURES USED

3.1 EQUIPMENT

3.1.1 Dampers Tested

Three different models of thermally activated vent dampers approved for use with gas fueled heaters were used in these tests. Damper B had a bimetal coil with linkage that moved a damper plate. Dampers A and C use bimetal which serves as both the sensor and damper restriction surface. With either type the principal of operation is the same. When the burner is operating, the hot stack gases impinge upon the bimetal sensor. The resulting movement of the bimetal opens the stack damper. When the burner shuts off the bimetal cools and moves the restriction back to its normally closed position; the damper then remains in the closed position until the burner is again operating. A 102 mm (4 in) diameter and a 127 mm (5 in) diameter model of each type damper was tested. In each case the dampers were installed within one foot of the draft hood outlet.

3.1.2 Heating Equipment

Three gas fueled vented heaters, one furnace, and one boiler described below were used in these tests:

1. A forced convection counter flow room heater rated 13,188 W (45,000 Btu/h) maximum input. This heater was equipped with a hydraulic type thermostat control (step-modulating type control). No combustion air adjustment is provided with this type control other than a manually adjustable primary air shutter on the atmospheric type burner. The unit had a 127 mm (5 in) diameter stack and an external draft hood.

2. A natural convection type (parallel flow) room heater rated 10,255 W (35,000 Btu/h) maximum input. This heater was also equipped with a hydraulic type thermostat control (step-modulating). The stack diameter of this heater was 102 mm (4 in). This heater also had an external draft hood.

3. A forced convection type (counter flow) wall furnace rated 10,255 W (35,000 Btu/h). The draft diverter was internal.

4. A forced air central furnace upflow type (shown in figure 6) rated 120,000 Btu/h. This unit was also operated at 80,000 Btu/h by derating the input in order to increase the test data base and to include input rates consistent with residential equipment. The unit had a five section heat exchanger (5 burners).

5. A hot water boiler (shown in figure 6c) rated 80,000 Btu/h, single burner and an external draft hood.

3.1.3 Laboratory Equipment

Appendix A includes a description of equipment used in tracer gas measurements. In addition to the equipment described in appendix A, a precision liquid manometer was connected to the static pressure leg of a pitot tube to measure stack draft.

A dry test (diaphragm type) and a wet test gas meter 0.1 cu ft per revolution of the dial were used to meter natural gas during the simulated cool-down test. The dry test meter was needed for very low flow rates due to the inability of the wet test meter to turn uniformly at extremely low rates (less than 100 Btu/h).

3.1.4 Test Burners Used to Reproduce Cool Down Temperature Conditions

A Bunsen burner was used to reproduce the cool-down temperature profiles of the two heaters with external draft hood and the boiler during the simulated cool-down tests. A small burner having a needle valve fuel flow control was mounted on a bracket and positioned within the internal draft diverter compartment of the wall furnace. A special burner was designed for use with the forced air furnace. The burner and its positioning in the draft diverter compartment is shown in figure 7. This particular design was chosen in order to uniformly distribute the heat across the width of the heat exchanger to simulate the flow of heat as it would normally occur during the cool down. The higher heating value of the natural gas fuel pipeline supplied from the local utility company, was continuously measured onsite with a recording calorimeter.

3.2 TEST PROCEDURES USED

Each of the heaters was run with each type of vent damper and without any damper. For each test without a vent damper, the currently prescribed DoE test procedure [2] was used to measure flue and stack temperatures during heat-up and cool-down tests. Flue and stack temperatures and CO_2 concentration were measured at the steady-state condition. Each heater was run as if equipped with a single stage thermostat (maximum input) and as though equipped with a step-modulating control (both maximum and reduced input rates).

Tests were run with both a 1.5 m (5 ft) stack installed as per the DoE test procedure and with a 5.2 m (17 ft) stack to stimulate field equivalent conditions (figure 1). Additional details of these field vs. lab tests are described under Test Results (section 4).

3.2.1 Tests on the Room Heaters Having External Draft Hoods

The design of this heater allowed easy placement of a small Bunsen burner at the draft hood relief opening (see figure 6a).

3.2.2 Tests on the Wall Furnace and Forced Air Furnace Equipped with Internal Diverter

Burners used for these test units were described previously (section 3.1). Several burner locations and other test conditions were investigated with the forced air furnace. These are described in table 9 and shown in figure 10.

3.2.3 Tests on the Hot Water Boiler, Equipped with Draft Hood

It was impractical to position the burner inside the flue of this unit since the burner could not be seen and could block the normal flow of air through the flue passage, Instead, the simulated test was run with the stack, draft hood, and flue connector pipe erected above a laboratory bench and tested after the normal cool-down test was run with these parts on the boiler.

The test setups for the normal cool down and for the simulated test of the boiler are shown in figures 5, 6c, and 6d. Various test parameters involving the location for introducing the tracer gas and sampling the diluted tracer gas were investigated. Also the effect of stack draft was investigated. Attempts were made to duplicate the stack draft that existed at the start of the normal cool-down conditions at the start of the simulated test. In order to do this, the length of test stack above the draft hood was varied by + 2 ft to − 2 ft. At the start of the simulated cool down test, the Bunsen burner flame length was believed to be affecting or possibly igniting the tracer gas (carbon monoxide/nitrogen mixture) introduced into the lower section at point B in figure 5. In order to reduce flame length, a screen was positioned above the burner and a radiation shield (aluminum foil) was placed around the burner and screen.

4. TEST RESULTS

4.1 OFF-PERIOD SENSIBLE LOSS BY TRACER GAS MEASUREMENTS (Q_S)

The calculation procedure in computerized format is described in appendix B. An example of each of the tracer gas test results for one of the heaters tested is listed in appendix C. Measured test results are shown in the columns of tracer gas concentration (CONC) and average stack gas temperature (TEMP). The column labelled "M" is the calculated mass flow during the increment of time (one minute in these tests); "MLOS" is the summation of the mass flow from the start to each time; "Q" is the calculated stack loss in Btu during the time increment of one minute; and "QLOS" is the summation of stack loss from the start to each time increment.

Each test result of normal cool down for each test condition of appendix C is followed by the results found under the simulated direct measurement test for the same heater and test condition.

The last result (last line) of each test under the column "QLOS" at the end of the 20 minute cool-down period is the result which is listed in table 1 (under Q_S) for the 45K Btu/h room heater. The computer program, written in FORTRAN, used to calculate these data is included in appendix B. Appendix B also shows a data sheet used to enter test data into the computer. Table 1 also shows results for two other household heaters tested. Tables 2 and 3 list the off-period losses for a gas furnace tested at 80K Btu/h and at 121K Btu/h input for two cool-down periods (20 minutes and 13 minutes*, respectively) and table 4 lists the results for a boiler over a 33 minute cool-down period.

4.2 OFF-PERIOD INFILTRATION LOSS (Q_I)

This loss is found from the summation of "MLOS" (the bottom line of the column under "MLOS") in appendix C and the product of specific heat of air and ΔT; see equation (6). Values of "Q_I", the calculated infiltration loss for each test using tracer gas is shown in tables 1, 2, and 4. A comparison of this value with Q_I as determined by the metered burner method has not been done, since the more important comparison between the two test methods is the sensible loss (Q_S) test results.

4.3 COMPARISON OF THE SIMULATED TEST RESULTS WITH NORMAL COOL-DOWN TEST RESULTS

4.3.1 Comparison of the Tracer Gas Test Results, Cool Down Simulated with Bunsen Burner Versus Normal Cool Down; (tg/TG)

The first column of tables 5 through 9 show this comparison. The ratios were obtained using the values of Q_S shown in tables 1 through 4. The values of Q_S found from the tracer gas measurements during the simulated test are referred to as (tg) and the values of Q_S found from tracer gas measurements during the

---

* Thirteen minutes is the typical burner off-period used in the DoE test procedure for furnaces and 33 minutes for boilers.

normal cool-down test are referred to as (TG) in tables 6 though 9. The ratio of tg/TG is a measure of how well the simulated test condition reproduced the normal cool-down test. The top graph of figure 8 displays all the data in figures 1 through 5 for the comparison of tg/TG. As seen in figure 8, test results from the simulated tests are almost always lower than the values obtained from normal cool down conditions (i.e., the ratio is less than 1.0). A ratio of 1.0 would represent perfect simulation. These data show an overall average of 0.85 for this ratio. There does not appear to be any one type of stack damper that shows consistency in these results or that gives a ratio consistently close to 1.0. However, the amount of data scatter is not as great as for the comparison of burner to tracer gas results which are described below.

4.3.2 Comparison of the Metered Burner Method with Tracer Gas Method During the Simulated Cool Down Test, (Br/tg)

The comparison of metered burner (Br) versus tracer gas (tg) test methods is plotted on the bottom graph of figure 8. The ratio is a measure of the difference between a metered burner and a tracer gas test under identical test conditions (i.e., measurements made simultaneously). These data are the ratio of the Q_S values obtained from tables 1 through 4 to the values for the metered gas method value of Q_S calculated by converting the Bunsen burner fuel used during the test to Btu's. The calculated ratios are shown in tables 6 through 9 in the right-hand column as the ratio (Br/tg). The results show little consistency except for the 80K Btu/h furnace.

The ability to reproduce results of the tracer gas test shows improvement with high fuel input burners (i.e., high initial stack temperature) since a small error in the adjustment of the higher fire rate of the test Bunsen burner during the simulated cool-down test has less effect than at lower fuel input rate to the Bunsen burner. This trend can be seen in figure 9 where average results grouped by fuel input rate shows a trend toward a ratio of 1.0 for (Br/tg) with increasing input rate.

In all cases the critical adjustment of the Bunsen burner is during the first few minutes of the cool-down period. This criticality is made obvious by comparing the rapid changes in temperature (TEMP) and mass flow (M) during the first few minutes (at times one to five minutes) after start of the cool down in the data of appendix C.

4.3.3 Comparison of the Metered Burner Method With Normal Cool-Down Test Method Using Tracer Gas (Br/TG)

The object of the Bunsen burner simulated cool down method is to be a low equipment cost replacement for the tracer gas and measurement equipment needed for the normal cool-down method. A comparison of the two methods was calculated using a ratio Br/TG as shown in the center graph of figure 8. Individual values of (Br/TG) are the product of (tg/TG), top graph, and (Br/tg), bottom graph of figure 8 since

$$(Br/TG) = (tg/TG) \cdot (Br/tg)$$

Noting that this ratio is the product of two other results, it is apparent that Br/TG can be misleading near a ratio of 1.0 since, when tg/TG is lower than 1.0 and (Br/tg) is greater than 1.0, the errors cancel each other. This is the case for the 45K Btu/h and 35K Btu/h room heaters. Conversely, tg/TG could be higher than 1.0 and Br/tg less than 1.0 which would also result in misleading data. This compensating effect must be recognized in drawing conclusions as to the overall applicability of the metered burner test method as a substitute for the tracer gas method.

5. SUMMARY

The results of this evaluation show that a simulated cool-down procedure using a metered burner to reproduce the normal cool-down conditions of a furnace, gave reasonably good results for the most common type of furnace, the central forced air gas furnace with internal draft diverter.

Results for the other type of equipment tested (room heaters, wall furnaces, and hot water boilers) were conflicting.

By conducting a normal tracer gas test and then a tracer gas test while at the same time metering the gas flow to the Bunsen burner during a simulated cool down, it was possible to:

1. Compare both the energy and mass flow for the simulated cool down to the normal cool down. This comparison evaluated the ability to simulate the normal cool-down condition when using a burner to reproduce the cool down temperature profile.

2. Compare the metered burner energy flow during simulated cool down against calculated energy flow using the tracer gas method -- both measured during the same test. This second comparison showed the equivalency of the metered burner method vs. the tracer gas (or standard) method.

It has been found that the metered burner method can be off in one direction while the simulation using tracer gas is off in the other direction making it appear that the metered burner method accurately reproduced the results of a normal cool down when, in reality, it was due to two errors cancelling out.

Overall test results show the simulated method measured by tracer gas in almost all tests gave a lower value than the normal cool-down test. The ability to simulate cool down by the burner method was generally good with a moderate amount of data scatter. Overall, the ratio of the simulated to normal cool down energy flow (t_g/TG) was 0.85.

Comparison of the metered burner results with calculated results by tracer gas under identical conditions (both tests run simultaneously) during the simulated cool-down test show mixed results. Test units with external draft hoods (two room heaters and boiler) show the burner method to tracer gas energy flow ratio is almost always above 1.0. Units with internal draft diverters (wall furnace and forced air sectional central furnace) almost always showed a metered burner method to tracer gas ratio of less than 1.0. Only the 80K Btu/h central forced air furnace showed consistently reproducible results with ratios close to 1.0. Whenever the metered burner technique compared favorably with the tracer gas method under simulated conditions it did so with all of the thermal damper designs tested. Therefore, in the case where this alternative method of measurement reproduces the tracer gas method it offers potential as a substitute test method for the testing of thermal stack dampers.

Further development, testing, and evaluation will be required before this simulation procedure can be considered as an acceptable alternative test method for all equipment.

6. REFERENCES

1. Kelly, George et al., "Recommended Testing and Calculation Procedures for Determining the Seasonal Performance of Residential Central Furnaces and Boilers," NBSIR 78-1543, October 1978, National Bureau of Standards, Washington, DC.

2. Federal Register, 43, No. 9, pp. 20181-20294, May 10, 1978.

3. Kweller, E. R. and Mullis, W. F., "Determination of Annual Efficiency of Vented Heaters Equipped with Thermally Activated Vent Dampers," ASHRAE Transactions, pp. 763-768, Vol. 87, Part 1.

4. Federal Register, 49, No. 61, pp. 12148-12178, March 28,1984.

5. Chi, J. and Kelly, G. E., "A Method for Estimating the Seasonal Performance of Residential Gas and Oil-Fired Heating Systems," ASHRAE Transactions, 84(1), 1978.

6. Park, C. et al., "A Study of the Dynamic Flue-Gas Temperature and Off-Period Mass Flow Rate of a Residential Gas Furnace," NBS Technical Note 999, July 1979, National Bureau of Standards, Washington, DC.

7. Kelly, G. E. and Kuklewicz, M. E., "Recommended Testing and Calculation Procedures for Estimating the Seasonal Performance of Residential Condensing Furnaces and Boilers," NBSIR 80-2110, April 1981, National Bureau of Standards, Washington, DC.

Table 1. Off-Period Energy Losses (Btu) for three Household Heaters

Test Condition	Normal Cooldown — Measured By Tracer Gas Method		Simulated Cooldown (Flue Exit Blocked) — Measured By Tracer Gas Method		Simulated Cooldown (Flue Exit Blocked) — Metered Gas Burner Method
Maximum Input (44640 Btu/h)	Q_S	Q_I	Q_S	Q_I	Q_S
	— Room Heater Rated 45K Btu /h —				NET
Without Stack Damper	393	234	246 289	162 171	249 268
With Damper A	354	86	204	62	272
With Damper B	285	71	188	55	234
With Damper C	353	138	267	123	300
Reduced Input (24520 Btu/h)					
Without Stack Damper	323	239	185	147	221
With Damper A	179	60	134	52	185
With Damper B	137	46	110	40	168
With Damper C	204	110	194	111	235
	— Wall Furnace Rated 35K Btu /h —				
Maximum Input (34310 Btu/h)	Q_S	Q_I	Q_S	Q_I	Q_S
Without Damper	406	112	282	75	183
With Damper A	402	94	326	74	199
With Damper B	354	52	300	65	150
With Damper C	382	105	320	90	176
Reduced Input (19890 Btu /h)					
Without Damper	239	60	221	80	133
With Damper A	243	64	175	48	140
With Damper B	149	30	156	43	99
With Damper C	249	88	214	76	159
	— Room Heater Rated 35K Btu /h —				
Maximum Input (41170 Btu/h)					
Damper A	313	87	249	74	260
Damper B	269	-	198	56	225
Damper C	325	-	268	129	213
Reduced Input (26000 Btu/h)					
Damper A	169	59	165	58	214
Damper B	176	54	152	40	174
Damper C	222	-	194	108	166

Table 2. Off-Period Losses - (Btu) for Gas Furnace (20 Minute Cooldown Period)

-- Operating at 80K Btu/h --

Test Condition*	Normal Cooldown (Notes)*	Normal Cooldown Tracer Gas Q_S	Normal Cooldown Tracer Gas Q_I	Simulated Cooldown Tracer Gas Q_S	Simulated Cooldown Tracer Gas Q_I	Simulated Cooldown Metered Burner Q_S	Simulated Cooldown (Notes)*
No Damper	(1)	517	205	388		311	(2)
				372		307	(3)
				386		282	(4)
				407		285	(5)
Damper A	(1)	426	87	414	97	388	(5)
Damper B	(1)	374	76	464	161	389	(5)
	(1)	382	77	461	157	391	(3)
Damper C	(1)	453	136	317	77	263	(5)
-- Operating At 121K Btu/h --							
No Damper	(5)	752	257	777	268	448	
Damper A:							
5 ft. Stack		603	123	601	119	543	
21 ft. Stack		755	173	661	154	501	
Damper B:							
5 ft. Stack		656	111	470	98	604	
21 ft. Stack		557	155	521	117	687	
Damper C:							
5 ft. Stack		751	203	---	---	661	
21 ft. Stack		761	208	658	186	568	

*See Figure 10 for details of test conditions corresponding to each note.

Table 3. Off-Period Energy Losses (Btu) for Gas Furnace for (13 Minute Cooldown Period)

Test Condition	Normal Cooldown Tracer Gas Q_S	-- Simulated Cooldown -- Tracer Gas Method	Metered Burner Method	Footnotes
	-- Cooldown from 80K Btu/h --			
No Damper	474	363	295	(1)
		346	293	(2)
		262	262	(3)
		384	263	(4)
Damper A	403	386	438	(5)
Damper B	354	425	358	(5)
	366	426	358	(6)
Damper C	421	299	254	(5)
	---	315	248	(6)
	-- Cooldown from 121K Btu/h --			
No Damper	702	723	447	(1)

*See footnotes on Figure 10.

Table 4. Off-Period Energy Loss - (Btu) for Gas Boiler (33 Minute Cooldown Period)

Run No.	Test Condition		Normal Cooldown Tracer Gas Q_S	Normal Cooldown Tracer Gas Q_I	Simulated Cooldown Tracer Gas Q_S	Simulated Cooldown Tracer Gas Q_I	Simulated Cooldown Bunsen Burner Q_S (NET)
1)	Stack Insulated	(a)	1516				
2)		(a)	1576				
3)		(b)	1621	542			
4)	Stack Uninsulated	(a)	1402				
5)		(b)	1478	544	1444	531	1680
6)		(b)	1416	497			1665 (d)
7)		(c)			1226	434	1807
8)		(c,d)			1275	450	1815
9)		(c,d,e)			1008	358	1602
10)		(c,d,f)			1172	419	1638

By Calculation per DoE Procedure $Q_S = 1134$, $Q_I = 413$

Test Conditions

(a) Tracer gas in at "A", sampled at "B" in figure 5.
(b) Tracer gas in at "C", sampled at "D" in figure 5.
(c) Tracer gas in at "B", sampled at "D" in figure 5.
(d) Bunsen Burner flame impinging on radiant screens, aluminum foil skirt positioned around Burner and Screen.
(e) Stack Height reduced by one foot.
(f) Stack Height increased by one foot.

Table 5. Off-Period Energy Loss Ratios for Room Heater Rated 45K Btu/h

See Table 1 for Btu Values.

Ratio of $L_{s,off}$

Test Condition	Measured during simulated cooldown test using tracer (tg) ÷ measured during normal test using tracer gas (TG)	Simulated cooldown test method using burner (Br) ÷ Normal cooldown with tracer gas (TG)	Simulated cooldown test method using burner (Br) ÷ Simulated test with tracer gas (tg)
No Damper	(tg/TG)	(Br/TG)	(Br/tg)
Max Input	0.63[(1)]	0.63[(2)]	1.01[(3)]
Reduced Input	0.57	0.68	1.20
Stack Damper A:			
Max	0.58	0.77	1.33
Reduced	0.75	1.03	1.38
Stack Damper B:			
Max	0.76	0.85	1.12
Reduced	0.80	1.23	1.53
Stack Damper C:			
Max	0.76	0.85	1.12
Reduced	0.95	1.15	1.21

Note: tg/TG and Br/TG are simulated cool-down compared to normal cool-down as the reference. (Br/tg) is the direct Burner compared with measured tracer gas method during the simulated cool-down as the reference.

(1) Referring to Table 1. The ratio 0.63 = 246 ÷ 393
(2) Referring to Table 1. The ratio 0.63 = 249 ÷ 393
(3) Referring to Table 1. The ratio 1.01 = 249 ÷ 246

Table 6. Off-Period Energy Loss Ratios for 35K Btu/h Wall Furnace

See Table 1 for Btu values.

Ratio of $L_{s,off}$

Test Condition	Measured during simulated cooldown test using tracer ÷ measured during normal test using tracer gas	Simulated cooldown test method using burner ÷ Normal cooldown with tracer gas	Simulated cooldown test method using burner ÷ Simulated test with tracer gas
Without Stack Damper	(tg/TG)	(Br/tg)	(Br/tg)
Maximum Input	0.69	0.45	0.65
Reduced Input	0.92	0.56	0.60
Damper A			
Maximum Input	0.81	0.44	0.54
Reduced Input	0.72	0.58	0.80
Damper B			
Maximum Input	0.85	0.42	0.50
Reduced Input	1.05	0.66	0.63
Damper C			
Maximum Input	0.84	0.46	0.55
Reduced Input	0.86	0.64	0.74

Table 7. Off-Period Energy Loss Ratios for Room Heater Rated 35K Btu/h

(See Table 1 for Btu values.)

Test Condition	Ratio of $L_{s,off}$: Measured during simulated cooldown test using tracer ÷ measured during normal test using tracer gas	Simulated cooldown test method using burner ÷ Normal cooldown with tracer gas	Simulated cooldown test method using burner ÷ Simulated test with tracer gas
Damper A	(tg/TG)	(Br/TG)	(Br/tg)
Max Firing Rate	0.80	0.83	1.04
Reduced Firing Rate	0.98	1.27	1.30
Damper B			
Max Firing Rate	0.74	0.84	1.14
Reduced Firing Rate	0.86	0.99	1.14
Damper C			
Max Firing Rate	0.82	0.66	0.79
Reduced Firing Rate	0.87	0.75	0.86

Table 8. Off-Period Energy Loss Ratios for an 80K Btu/h Hot Water Boiler - 33 Minute Cooldown Period

Ratio of $L_{s,off}$

Test Condition	Measured during simulated cooldown test using tracer ÷ measured during normal test using tracer gas	Simulated cooldown test method using burner ÷ Normal cooldown with tracer gas	÷ Simulated test with tracer gas
See Table 4:	(tg/TG)	(Br/TG)	(Br/tg)
Run No. 5	0.98	1.14	1.16
Run No. 6	0.57	1.18	--
Run No. 7	0.87	1.28	1.47
Run No. 8	0.90	1.28	1.59
Run No. 9	0.71	1.13	1.40
Run No. 10	0.83	1.16	1.42

Table 9. Off-Period Energy Loss Ratios for a Gas Furnace 80K Btu/h (13 Minute and 20 Minute Cooldown Period)

See Tables 2 and 3 for Btu Values.

Test Condition	Comparison Ratio (Simulated ÷ Normal Cooldown) Tracer Gas (tg/TG) to Tracer Gas (13 min)	(20 min)	Using (Br/Tg) Metered Burner (13 min)	(20min)	Simulated Cooldown Burner ÷ Tracer Gas Values (Br/tg) (13 min)	(20 min)
<u>No Damper</u>						
Max Input (2)*	0.87	0.75	0.62	0.60	0.81	0.80
(3)	--	--	--	--	0.85	0.80
(4)	--	--	--	--	0.72	0.73
(5)	--	--	--	--	0.68	0.70
<u>Damper A</u> (1)	0.96	0.97	0.86	0.91	0.90	0.94
<u>Stack Damper B</u>						
(1)	1.20	1.24	1.01	1.04	0.84	0.84
(3)	1.16	1.21	0.98	1.02	0.84	0.85
<u>Damper C</u> (1)	0.70	0.71	0.60	0.58	0.85	0.83
(3)	--	--	--	--		
	-- Cooldown from 120K Btu/h –					
	(13 min)	(20 min)	(13 min)	(20 min)	(13 min)	(20 min)
<u>No Damper</u>	0.95	1.03	0.63	0.60	0.62	0.58
<u>Damper A:</u> 5 ft. Stack		1.00		0.90		0.90
21 ft. Stack		0.88		0.66		0.76
<u>Damper B:</u> 5 ft. Stack		0.83		1.07		1.29
21 ft. Stack		0.81		0.76		0.94
<u>Damper C:</u> 5 ft. Stack		--		0.88		--
21 ft. Stack		0.86		0.75		0.86

*See footnotes on Fig. 10 for details on test conditions.

TABLE 10

UNITS CONVERSION TABLE: SI/INCH-POUND/SI

TO CONVERT	MULTIPLY BY	TO OBTAIN
Lb (Pounds)	0.454	Kg (Kilograms)
Kg (Kilograms)	2.2046	Lb (Pounds)
Cu. Ft. (Cubic Feet)	28.3	L (Liters)
L (Liters)	0.03531	Cu. Ft. (Cubic Feet)
in (Inches)	2.54	cm (Centimeters)
cm (Centimeters)	0.3937	in (inches)
ft (Feet)	0.3048	m (meter)
m (Meters)	3.281	ft (feet)
BTU (British Thermal Units)	1.055	K J (Kilojoules)
kJ (kilojoules)	0.9479	Btu (British Thermal Units)

TEMPERATURES (T), CONVERSION EQUATIONS:

FOR TEMPERATURE USE:

^{o}F to ^{o}C: $[(T)^{o}F - 32^{o}F]\ (5/9) = (T)^{o}C$
^{o}C to ^{o}F: $[(T)^{o}C]\ (9/5) + 32^{o}F = (T)^{o}F$

FOR TEMPERATURE DIFFERENTIALS OR TOLERANCE USE:

^{o}F to ^{o}C: $(T)\ ^{o}F\ (5/9) = (T)^{o}C$
^{o}C to ^{o}F: $(T)\ ^{o}C\ (9/5) = (T)^{o}F$

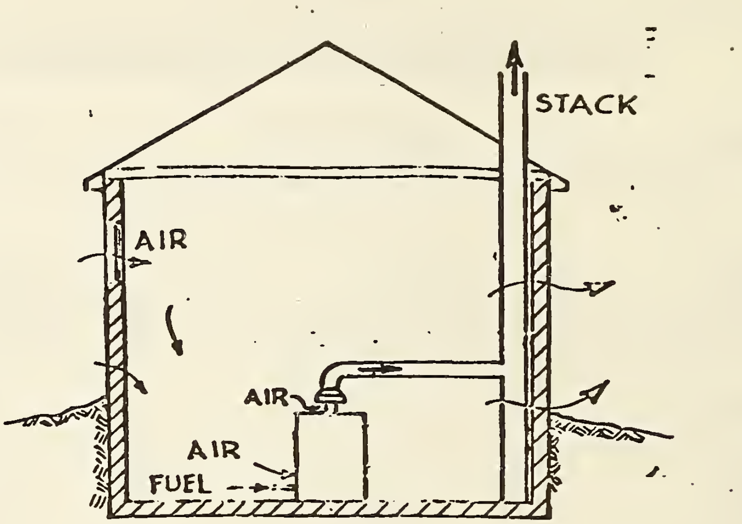


Figure 1. Thermal flow paths of energy losses with vented space heating equipment - stack loss and infiltration air flow.

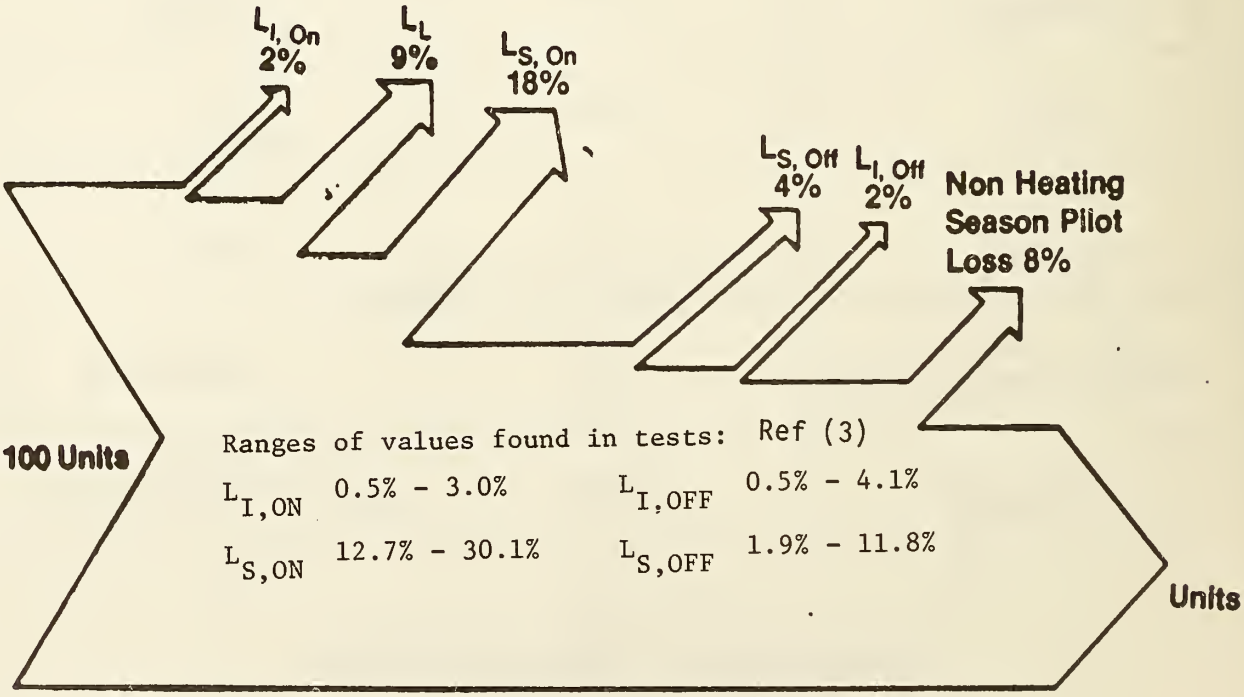


Figure 2. Typical part load losses of an in-space room heater without stack damper

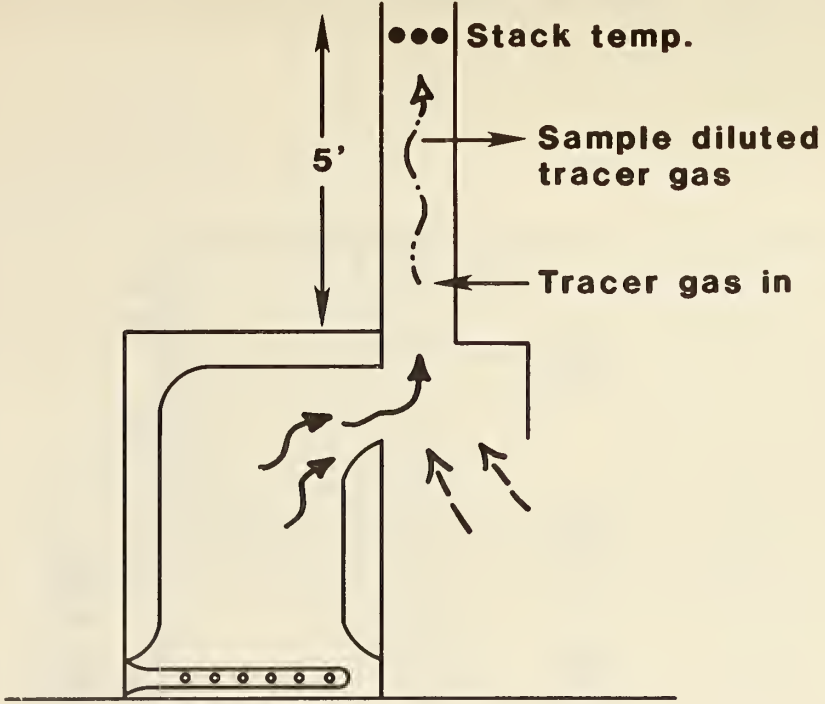


Figure 3a. Normal Cool-down (TG).

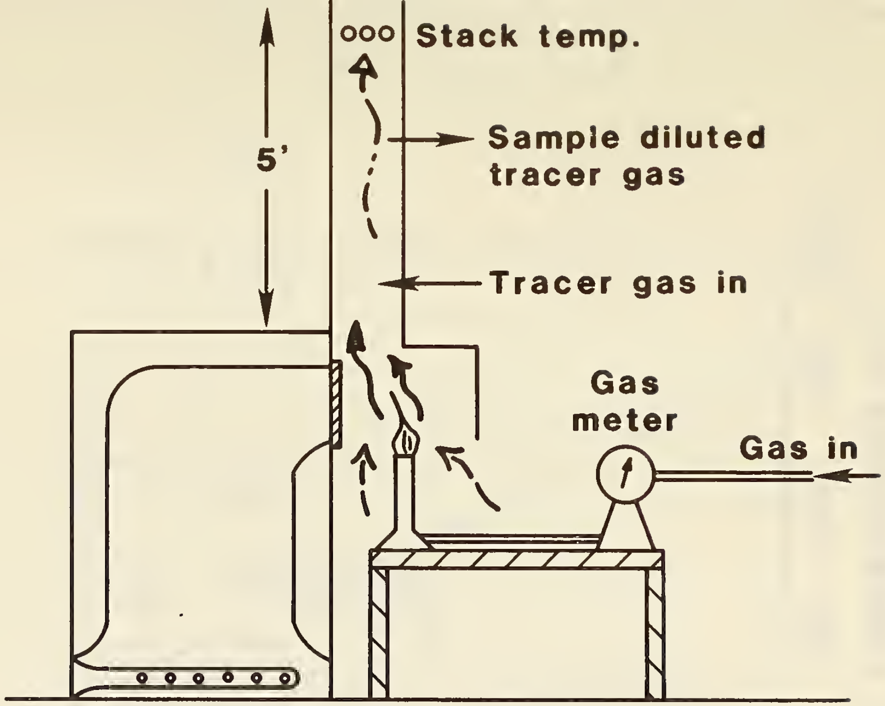


Figure 3b. Reproduced Cool-down (tg and BR).

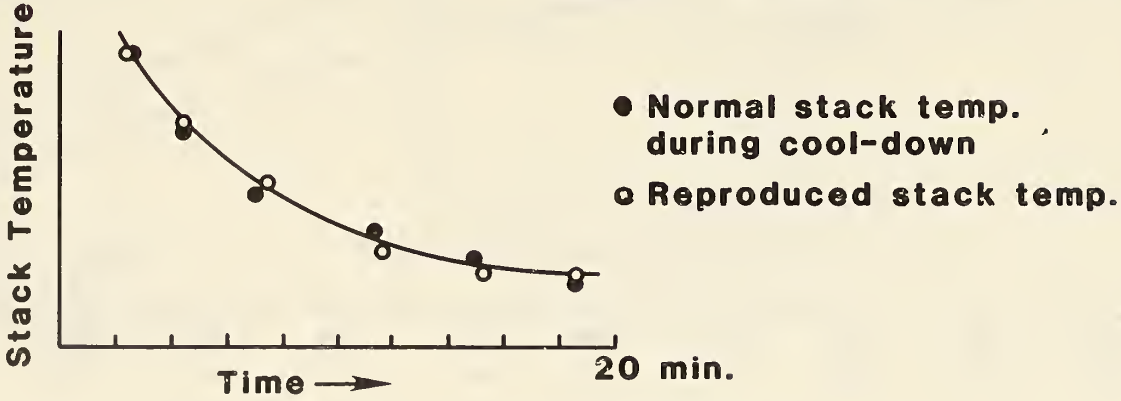


Figure 3c. Normal and Reproduced Cool-down Temperature Profile.

Figure 3. A direct measurement method for the off-period sensible heat losses ($L_{S,OFF}$).

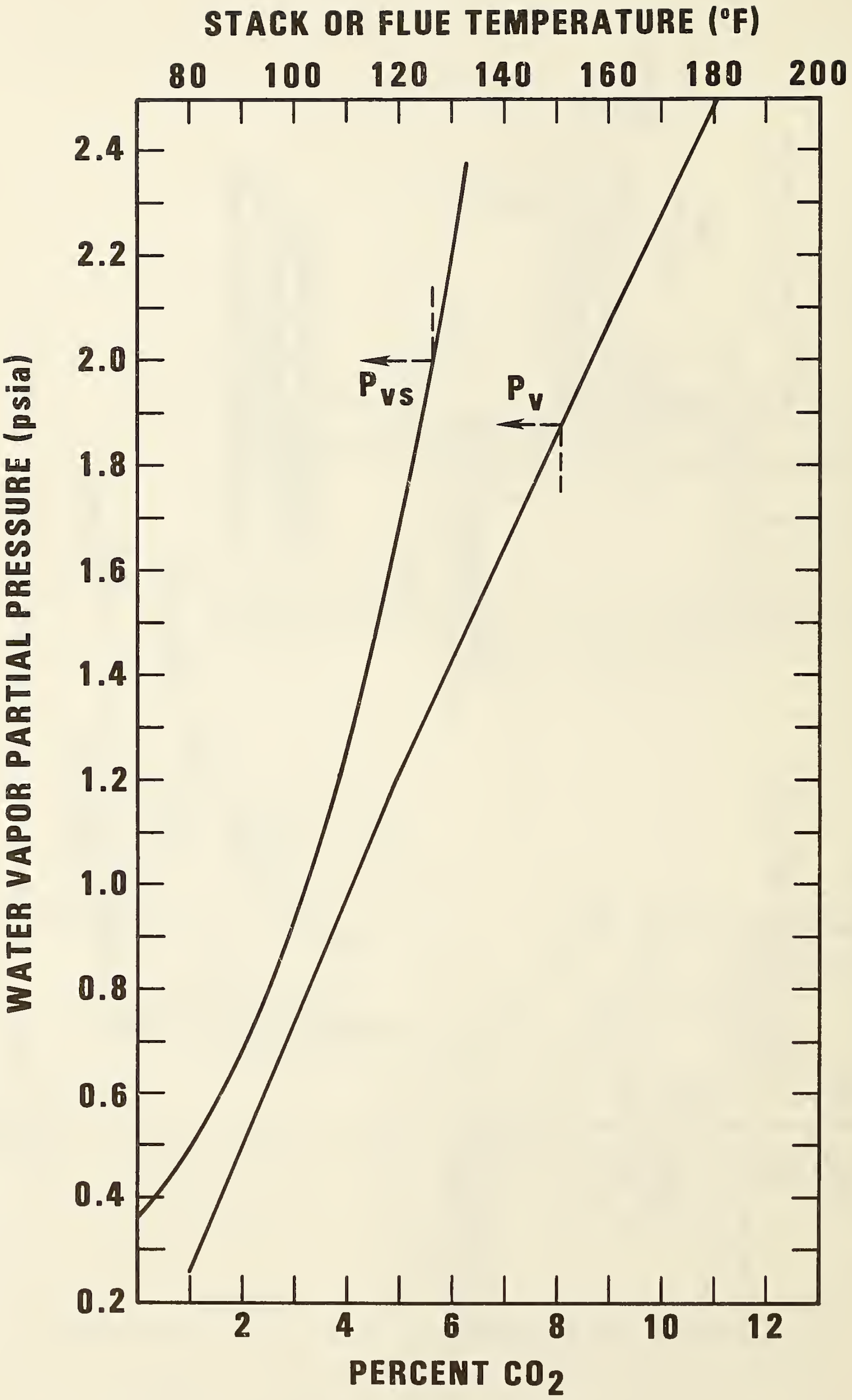


Figure 4. Partial pressure of water vapor in combustion products of natural gas (P_v) & (P_{vs}) vs. percent CO_2 in flue gas and vs. flue gas temperature °F.

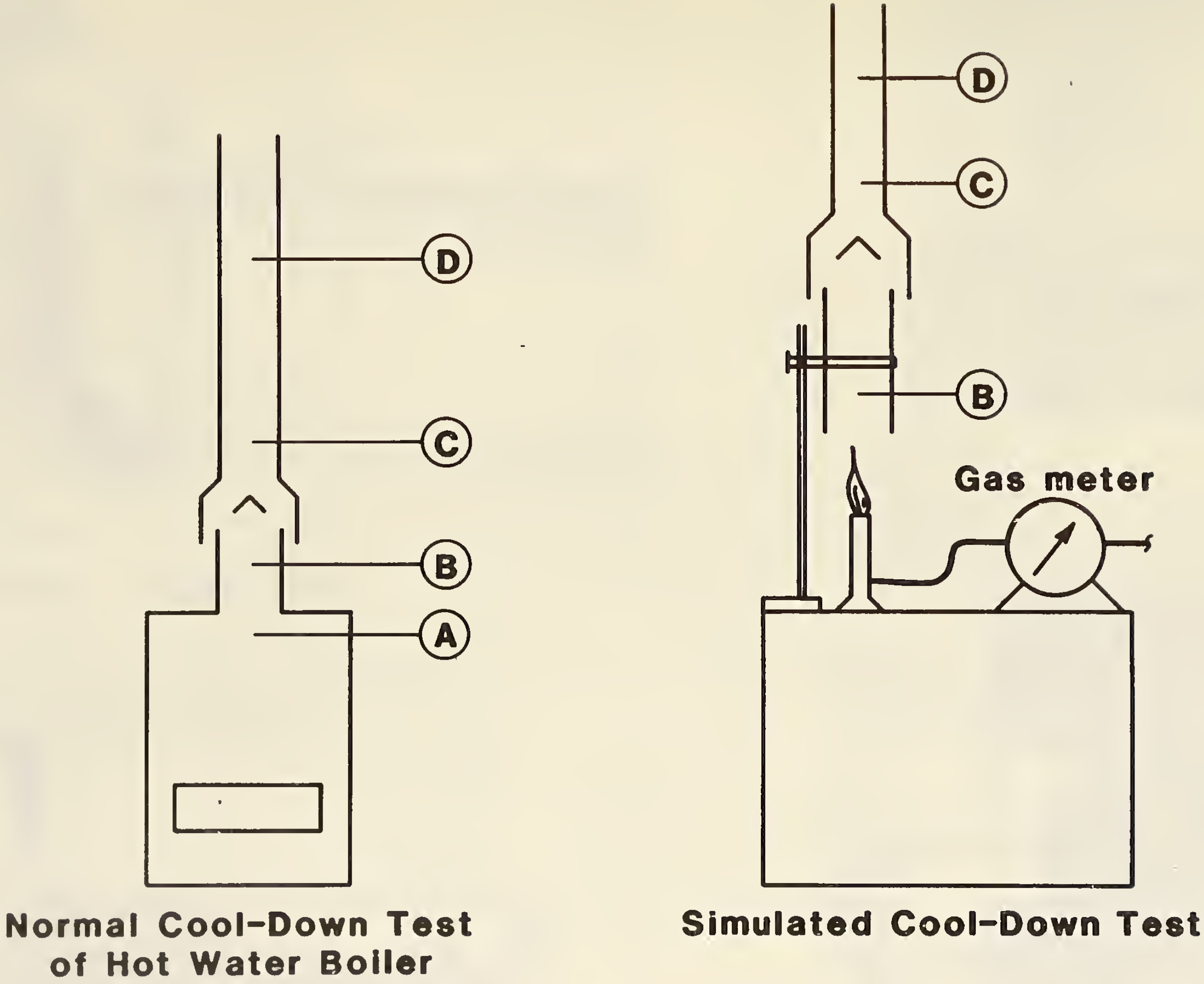


Figure 5. Test conditions of method used in obtaining test data for 80K Btu/h hot water boiler showing locations used to inject and to sample tracer gas in the flue and stack.

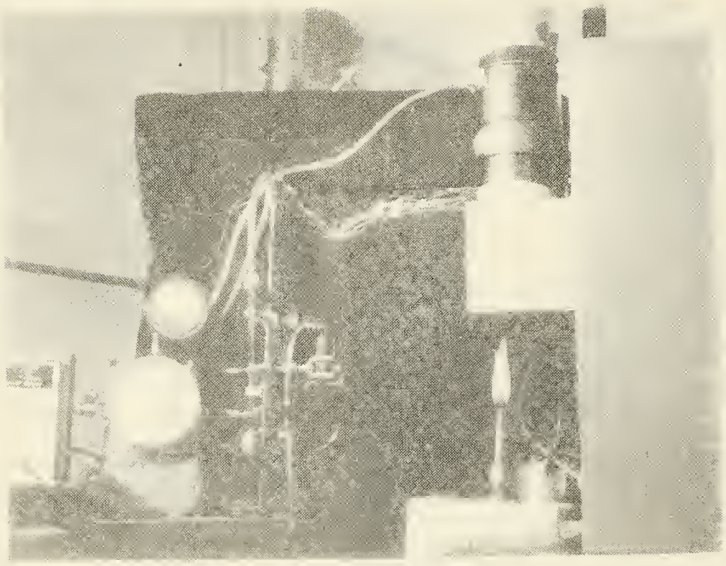


Figure 6a. Simulated cool-down test of room heater. Bubble meter and wet test meter shown on bench.

Figure 6b. Forced air upflow gas furnace.

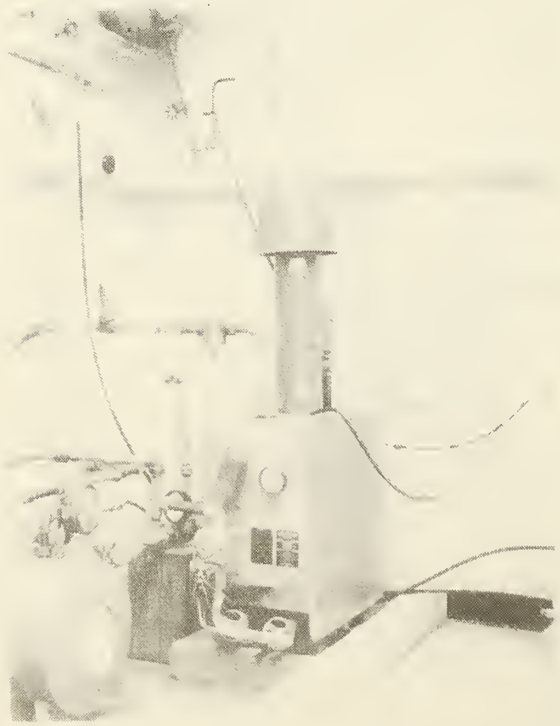


Figure 6c. Hot water boiler set up for normal cool-down test showing tracer gas injection and sampling tubes in stack.

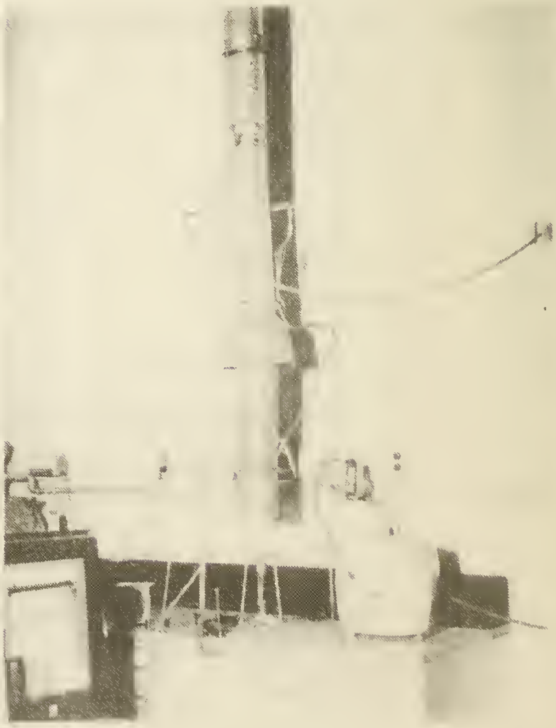


Figure 6d. Simulated cool-down test of boiler stack and draft hood. Bunsen Burner in place and tracer gas injection and sampling tubes in stack.

Figure 6. Equipment used in tests.

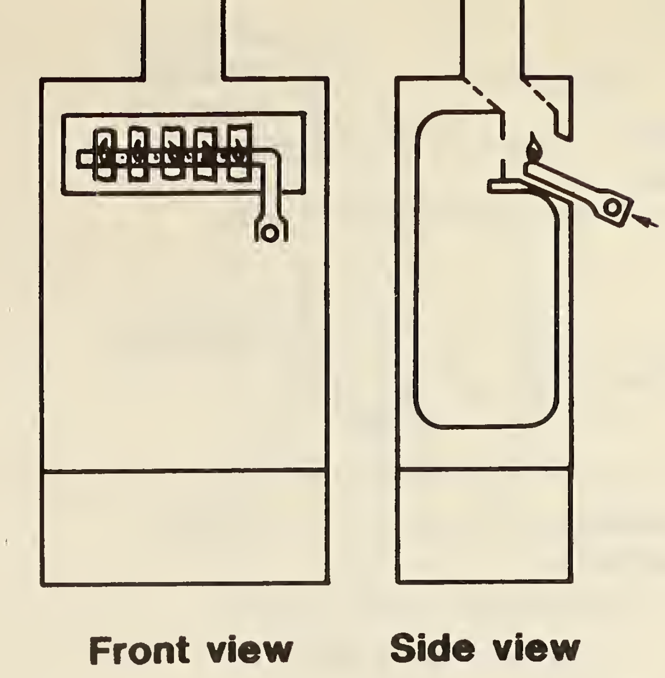


Figure 7a. Forced Air Furnace showing position of Test Burner in Diverter Section at Exit of Heat Exchanger.

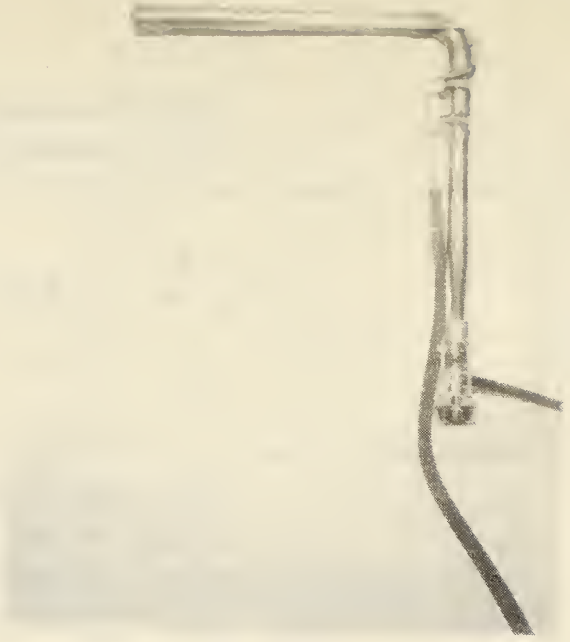


Figure 7b. Test Burner Used for Simulating Cool-Down Temperature of Furnace.

Figure 7c. Exit of Heat Exchangers - in Diverter Compartment.

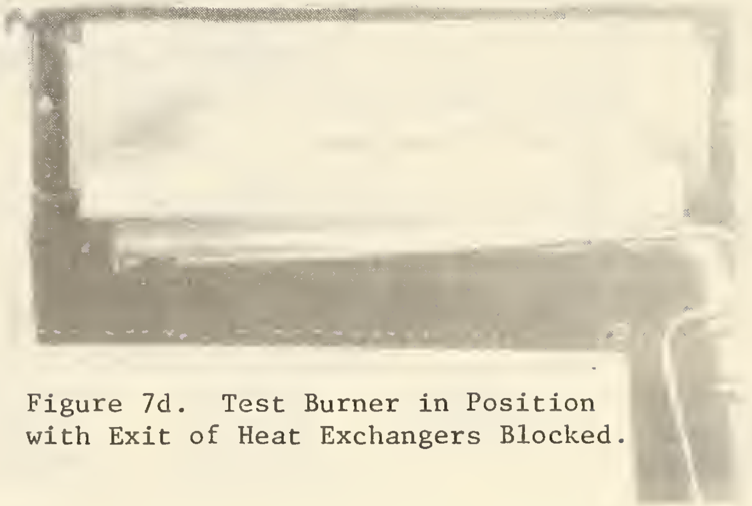


Figure 7d. Test Burner in Position with Exit of Heat Exchangers Blocked.

Figure 7. Description of test burner showing location of burner for simulated cool-down of forced air furnace.

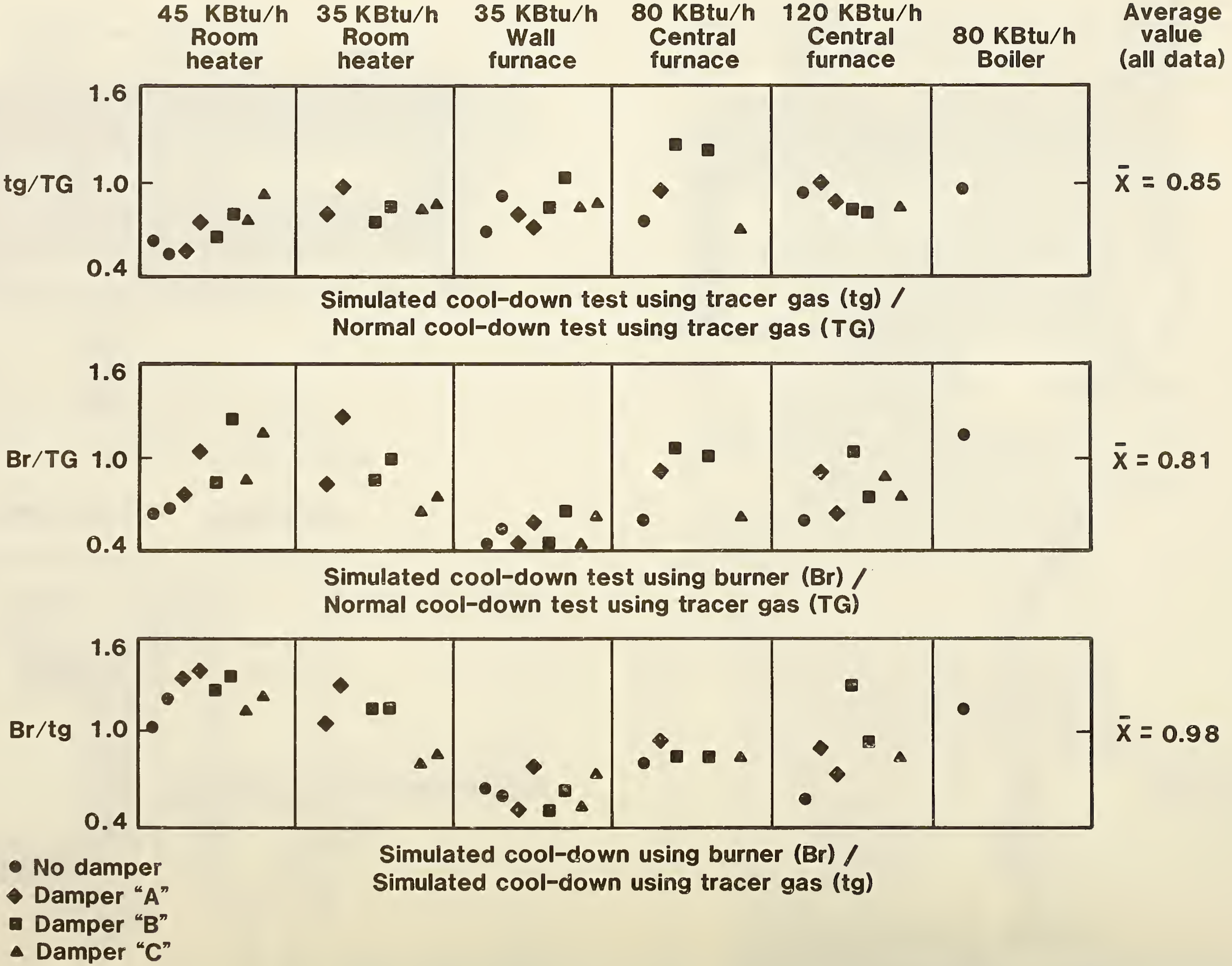


Figure 8. Results of three methods of measuring off-period energy loss using ratios of values measured.

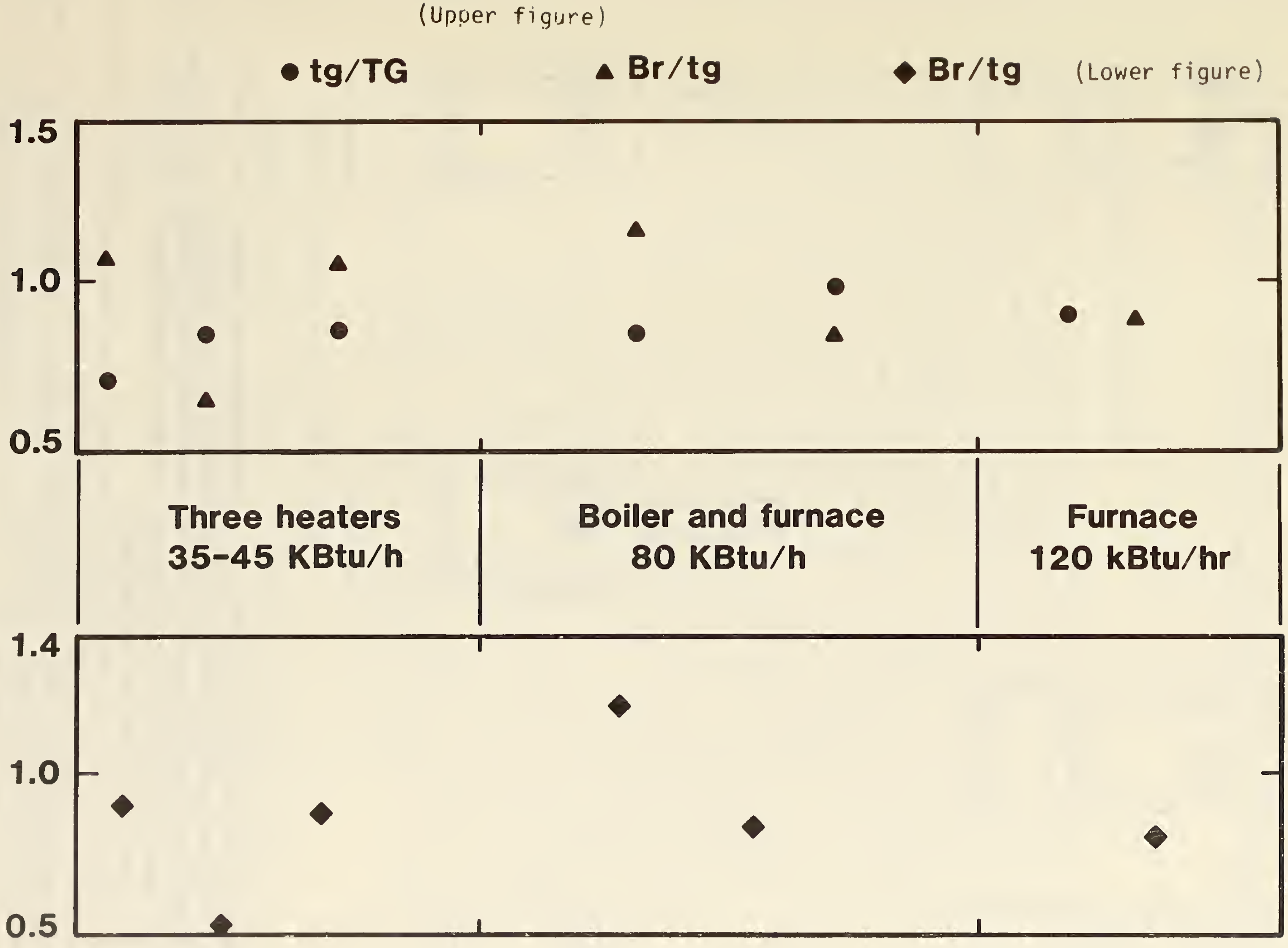
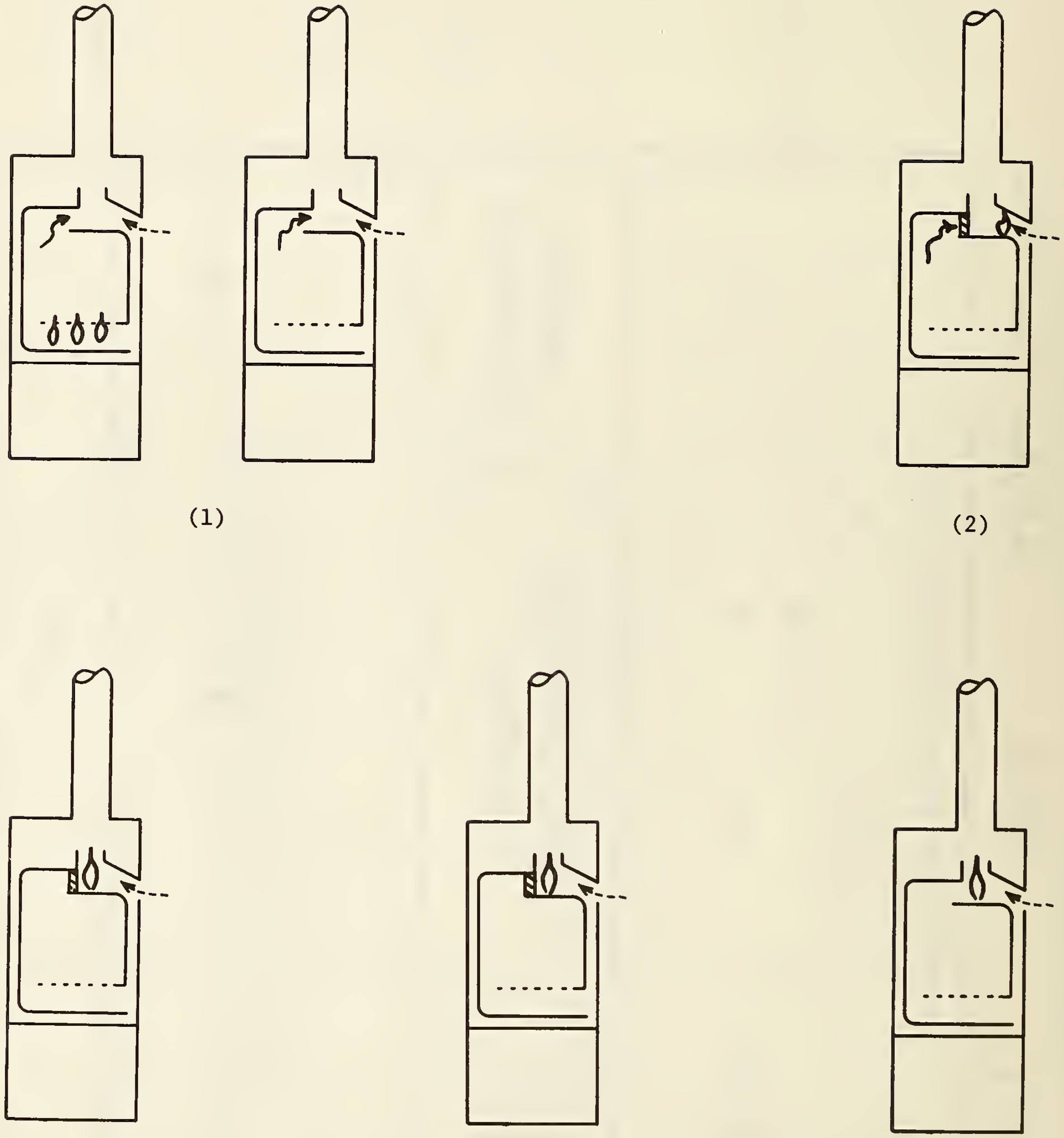


Figure 9. Average off-period energy loss ratios for three test methods with data grouped by input rate



NOTES:
(1) Using Furnace Burner to heat-up to steady-state conditions, heat exchanger open and diverter open for heat-up (left) and cool-down (right).
(2) Same heat-up condition as in (1) heat exchanger exit blocked on cool-down using test burner to reproduce the normal cool-down temperatures. Test burner located toward front of diverter compartment.
(3) Same heat up as in (1) and (2); cool-down with heat exchanger exit blocked with test burner toward rear of diverter section.
(4) Using test burner to obtain steady-state condition for heat-up. Heat exchange exit blocked on cool-down.
(5) Same heat-up conditions as (4) - but with heat exchanger exit open on cool-down.

Figure 10. Various test conditions used to heat-up for normal and for the simulated cool down testing of the 80K Btu/h warm air furnace.

APPENDIX A

Guidelines for Measuring Off-Period Mass Flow Using the Tracer Gas Method

These guidelines are based on tests performed at NBS. Reference to the equipment shown in figure A-1 and techniques used in these tests are made to augment the guidelines.

A. Introducing the Tracer Gas

Tracer gas may be a single gas or a mixture of gases. The tracer gas used in this study was a mixture of carbon monoxide (CO) diluted with Nitrogen. Carbon monoxide was chosen as a tracer gas because its molecular weight (of 28) is close to that of air (mole weight of 29). Also, the instrumentation used in its measurement is generally used by equipment manufacturers and testing laboratories for combustion testing. The injection rate of tracer gas should be as low as practical but sufficient to result in a measurable reading on the analyzer used to measure the diluted tracer gas. The injection of tracer gas should be at the draft relief opening. Either gas wet test or dry meter (diagphragm type) can be used when the flow rate is at least 0.5 cfh. When operating at flow rates of less than 2 cfh, it is best to use the bubble meter. This is simply a glass tube which has a scale etched on the glass: the type used had two scale marks which were approximately 10 in. apart. The meter capacity was 25 cc. The tube shown in Fig. A-2 is available at 25, 50 and 100 ml capacities. The bubble meter Fig. A-2 is used as follows. Adjust the flow to some low rate. A flow meter will be useful to make a rough adjustment in the initial flow rate. A soap solution is first placed into the lower part of the tube where a reservoir of soap solution is held at the bottom in a syringe attached to this tube at the lower end. The tube is attached to a ring stand with the stand held securely in place. The upper end of the tube is connected to the injection manifold using flexible tubing. Tracer gas is introduced into the side arm of the bubble meter tube. The soap solution level is raised up to the level of the side arm using the syringe, to cause a film (bubble) to form and flow upward. The time needed for the film to travel between marks A and B see Fig. A-2 and the known volume between those marks is used to compute the flow rate (cc/s or ft^3/h). Larger volume tubes should be used to minimize time measurement errors.

B. Sampling the Diluted Tracer Gas

A diluted tracer gas sample representative of the flow stream is taken from the stack when measuring $M_{S,OFF}$. Sampling tubes made of 1/4 inch (6 mm) OD stainless steel or copper tubing with one end closed and having several equally spaced holes in the tubing wall were used. Sampling rate will be determined by the analyzer requirements. The sampling rate in these tests was 4 to 6 cfh (31 to 47 ml/s).

In measuring $L_{S,OFF}$ it is necessary to know the sampling delay time. This is the time it takes the tracer gas sample to move through the sampling train to the analyzer sensor and result in a meter response. Sampling delay time is determined as follows:

1. With the sampling flow rate adjusted and pulling room air through the meter the background reading is read.

2. With the heater operating introduce tracer gas at the draft relief opening as described above.

3. Position the sample probe in the stack and immediately begin measuring elapsed time until the meter begins to respond. This elapsed time, or sample delay time must be taken into account whenever starting time for sampling is specified.

C. Measuring the Diluted Tracer Gas

A non-dispersive type infrared analyzer was used in these tests to measure the amount of carbon monoxide in the sample. The instrument used in these tests was a dual range unit with 0-100 ppm and 0-500 ppm calibration scales.

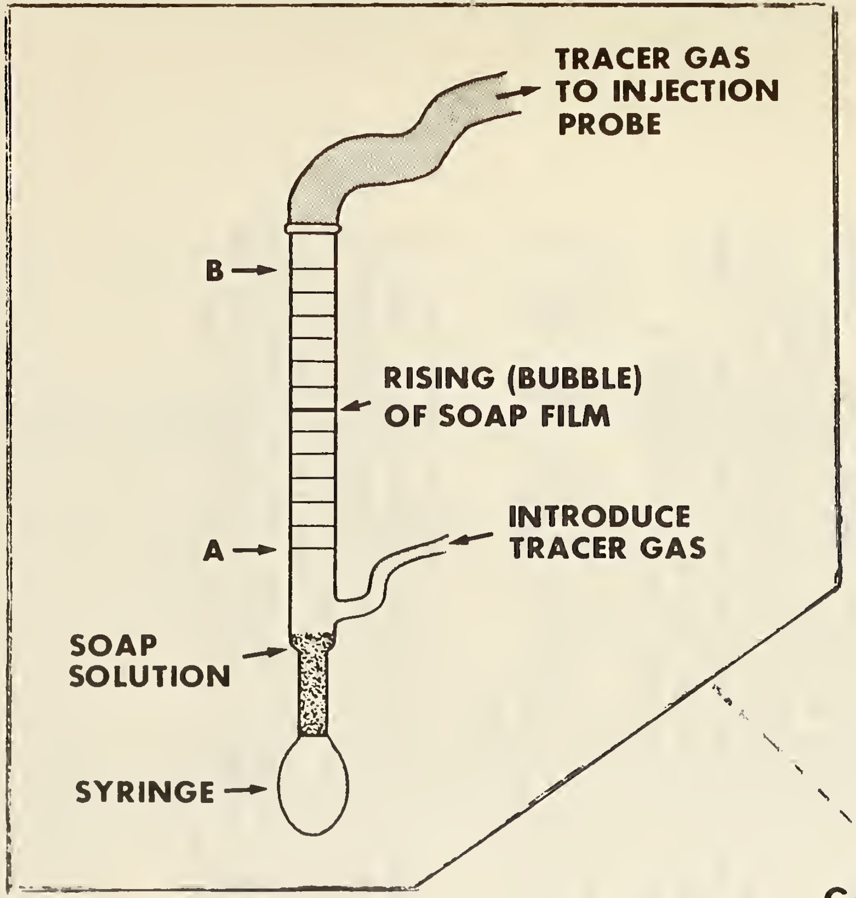


Fig. A-2 Bubble Meter

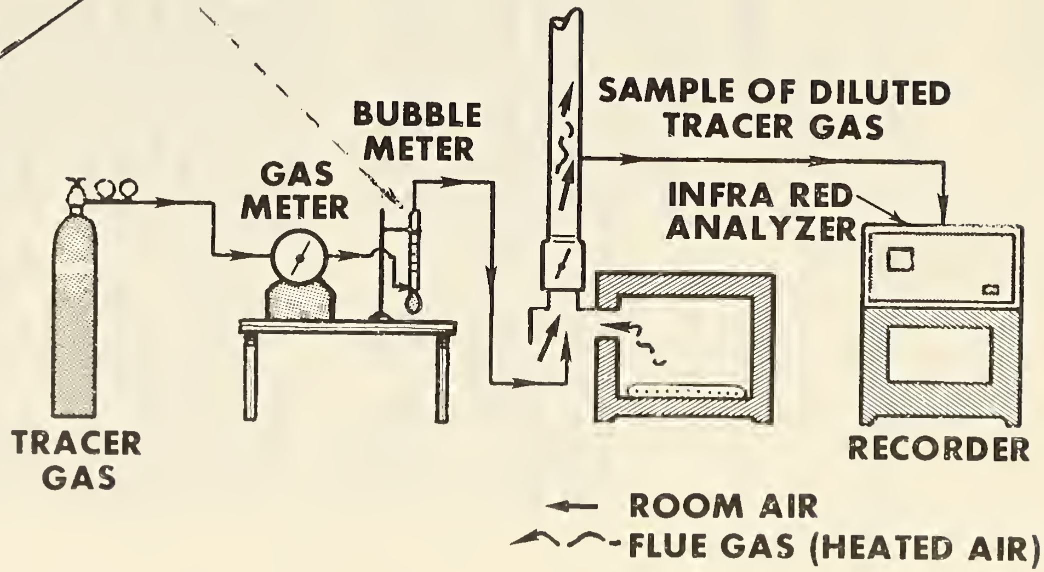


Fig. A-1 Equipment used for tracer gas measurements

APPENDIX B

Computer Calculation Procedure

Appendix B contains four figures illustrating the method of analysis used to obtain the Off-loss results from the data obtained from tests performed for this project. During the test program, many changes were made in the formats used so the illustrations are of the last method used.

Figure 1 shows a data sheet that may be used to manually record data during tests with hand entered data of an actual test.

Figure 2 is an example of the data from Figure 1 as entered into a data file (actually an element or subdivision of a file) in the computer. This data entry was made using an interactive data terminal and the computer used was the main NBS computer. The computer program was written to read data from an input element. The input format is described in the comments at the start of the program listed in Figure 4.

Figure 3 is the output results of running the computer program to analize the data in the element shown in Figure 2. It was the results of such computer runs that were used to develop the Tables of this report.

Figure 4 is a listing of the Fortran program developed to analize the test data of this project. The program uses no subroutines. The comments of the report are self explanatory and the calculations are straightforward. Modifications of the program may have to be made when employing it on a different computer, particularly the use of the free form format of the READ statments which are allowed on the NBS computer and which allow numeric entry in either real or integer form.

Figure B-1 Data Sheet

Test # ______ Date ________ Unit tested xxxx Furnace, 122k

Conditions 5 foot stack no damper

normal cooldown

Gas used 28.9 sec./cu.ft. Calorimeter 1024 Btu/cu.ft.

Gas pres. 4.0 in.H20, Gas temp. 71°

Room ambient 21.0 Baro. pres. 1003

%CO2 Flue 10.7 Stack 6.4

Tracer Gas ____ %, flow 25 cc/15.0 sec., temp. 71

Time	Tracer ppm.	Stack temp
0–1	55	152.5
1–2	60	118.2
2–3	65	95.1
3–4	70	78.8
4–5	75	71.0
5–6	80	65.0
6–7	85	60.0
7–8	90	56.3
8–9	95	52.6
9–10	100	49.2
10–11	105	47.0
11–12	110	44.3
12–13	115	42.6
13–14	120	41.2
14–15	130	39.2
15–16	135	38.0
16–17	140	36.8
17–18	150	35.6
18–19	160	34.6
19–20	165	34.2
20–21		
21–22		
22–23		
23–24		
24–25		

```
XXXXXXX FURNACE 122K BTUH
5FT STACK NO DAMPER
1 0
42 125048 20
508000 2.451 24.0 1007
55 152.5
60 118.2
65 95.1
70 78.8
75 71.0
80 65.0
85 60.0
90 56.3
95 52.6
100 49.2
105 47.0
110 44.7
115 42.6
120 41.2
130 39.2
135 38.0
140 36.8
150 35.6
160 34.6
165 34.2
@EOF
END OF FILE
->
```

Figure B-2 Input Data

```
XXXXXXX FURNACE 122K BTUH
 5FT STACK NO DAMPER
                        TRACER GAS MEASUREMENTS
 TIME    CONC      TEMP       M      MLOS       Q      QLOS
    1     55.0     306.5    3.739     3.74   207.57   207.6
    2     60.0     244.8    3.428     7.17   139.48   347.1
    3     65.0     203.2    3.164    10.33    97.18   444.2
    4     70.0     173.8    2.938    13.27    69.55   513.8
    5     75.0     159.8    2.742    16.01    55.67   569.5
    6     80.0     149.0    2.571    18.58    45.53   615.0
    7     85.0     140.0    2.419    21.00    37.63   652.6
    8     90.0     133.3    2.285    23.29    31.88   684.5
    9     95.0     126.7    2.165    25.45    26.74   711.2
   10    100.0     120.6    2.056    27.51    22.39   733.6
   11    105.0     116.6    1.958    29.46    19.46   753.1
   12    110.0     112.5    1.869    31.33    16.72   769.8
   13    115.0     108.7    1.788    33.12    14.37   784.2
   14    120.0     106.2    1.714    34.84    12.73   796.9
   15    130.0     102.6    1.582    36.42    10.39   807.3
   16    135.0     100.4    1.523    37.94     9.21   816.5
   17    140.0      98.2    1.469    39.41     8.12   824.6
   18    150.0      96.1    1.371    40.78     6.87   831.5
   19    160.0      94.3    1.285    42.07     5.88   837.4
   20    165.0      93.6    1.246    43.31     5.49   842.9

   QSOFF (BTU) =   843.          QIOFF (BTU) =   291.
```

Figure B-3 Output Results

```
* HTRS*FURP.QOFF IS A PROGRAM TO TAKE INPUT DATA FROM A TRACER-
*   GAS TEST, CALCULATE THE FLUE GAS MASS FLOW (MLOS) AND THE
*   HEAT LOSS (QLOS) FOR EACH INCREMENT OF TIME, THEN OUTPUT
*   THE RESULTS AND THE TOTAL LOSSES TO THE TERMINAL (LU#6).
*   WITH THIS PROGRAM, THE INDIVIDUAL DATA POINTS MUST BE TAKEN
*   ONE MINUTE APART AND UP TO 60 DATA POINTS MAY BE ENTERED.
*  The first two input lines are the title and test conditions..
*  The third input line selects the input of CONC to either
*  be %CO2 (ICONC=1) or scale readings from the meter recorder
*  which have to be converted to %CO2 (ICONC=0). It also selects
*  the flue gas temperature readings to be in Deg.F (ITEMP=1) or
*  in Deg.C (ITEMP=0).
*  The fourth line inputs the assumed outside air temperature,
*  (TOA), the input rating of the unit tested (QIN in Btuh),
*  and time on (TON in minutes) of the average heating cycle.
*  The fifth line inputs the input concentration of the tracer
*  gas (CONCI in PPM), the tracer gas flow rate (VTTT in cc/min.),
*  the room temperature (TROOM, C or F), and barometric
*  pressure (BARP in In.Hg. or Mb).
*   The input of BARP is optional, if 0.0 is entered, standard
*   condition is assumed.
*  The remaining input lines (up to 60 lines) each contain
*  two values, CONCI in % and TS in degrees.
*  Either spaces or commas may be used to separate data entries.
*
*    RAW 7-31-83
*
      CHARACTER*6 LAB(12)
      DIMENSION CONC(60),TS(60),OFFLS(60),FLOW(60)
      DIMENSION FLO(60),OFFLSS(60)
*
      BARP=0.0
* ******** Input data *******
      WRITE(6,100)
100   FORMAT(5X,'INPUT DATA FILE -- @ADD FILE.ELEMENT'/)
      READ(5,200)(LAB(K),K=1,12)
      WRITE(6,201)LAB
      READ(5,200)(LAB(K),K=1,12)
      WRITE(6,202)LAB
200   FORMAT(12A6)
201   FORMAT(/1X,12A6)
202   FORMAT(3X,12A6)
      READ(5,*,ERR=999)ICONC,ITEMP
      READ(5,*,ERR=999) TOA,QIN,TON
      READ(5,*,ERR=999) CONCI,VTTT,TROOM,BARP
      READ(5,*,ERR=999,END=11)(CONC(J),TS(J),J=1,60)
11    NPTS=J-1
*  ******** Convert units *******
      IF(TROOM.LT.40.)TROOM=1.8*TROOM+32.
      IF(BARP.LT.10.)BARP=1013.3
      IF(BARP.LT.500.)BARP=BARP*33.867
*
      IF(ICONC.EQ.1) GO TO 10
```

```
      DO 10 J=1,NPTS
      CONC(J)=4.60484*CONC(J)+.148111F-5*CONC(J)**2
     *+.395287E-4*CONC(J)**3
10    CONTINUE
      IF(ITEMP.EQ.1) GO TO 20
      DO 20 J=1,NPTS
      TS(J)=1.8*TS(J)+32.
20    CONTINUE
* ******** Set initial values *******
      OFFL=0.0
      FLOS=0.0
      OFFLI=0.0
* ******** Calculate results *******
      DO 30 J=1,NPTS
      RATIO=(CONCI-CONC(J))/CONC(J)
      FLOW(J)=0.01*VTTT*RATIO*BARP/60960.
      FLOS=FLOS+FLOW(J)
      FLO(J)= FLOS
      OFFLSS(J)=0.24*FLOW(J)*(TS(J)-TROOM)
      OFFL=OFFL+OFFLSS(J)
      OFFLS(J)=OFFL
      OFFLI=OFFLI+0.24*FLOW(J)*(70.-TOA)
30    CONTINUE
* ******** Output results to terminal *******
      WRITE(6,150)
      WRITE(6,160) (J,CONC(J),TS(J),FLOW(J),FLO(J),
     *OFFLSS(J),OFFLS(J),J=1,NPTS)
      WRITE(6,180) OFFL,OFFLI
31    GO TO 990
*
150   FORMAT(20X,'TRACER GAS MEASUREMENTS',/,3X,'TIME',
     ,3X,'CONC',5X,'TEMP',7X,'M',6X,'MLOS',7X,'Q',6X,'QLOS')
160   FORMAT(3X,I3,3X,F6.1,3X,F6.1,3X,F6.3,3X,F6.2,3X,F6.2,3X,F6.1)
180   FORMAT(/5X,'QSOFF (BTU) = 'F6.0,10X,'QIOFF (BTU) = 'F6.0,/)
999   WRITE(6,203)
203   FORMAT(//1X,'***** BAD INPUT FILE, CORRECT AND RERUN *****')
990   STOP
      END
END OF FILE
->
```

Appendix C

Example of computer output of tracer gas test results for the 45K Btu/h room heater for normal cool-down and simulated cool-down test methods. Test results for no damper and for three types of thermally activated vent dampers are presented. See page 10 for a description of test dampers.

Room Heater, 45KBtuh, Damper A, Maximum Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	45.0	238.3	3.449	3.45	139.45	139.4
2	85.0	204.6	1.826	5.27	59.07	198.5
3	155.0	177.6	1.001	6.28	25.90	224.4
4	210.0	158.5	.739	7.01	15.73	240.2
5	235.0	151.3	.660	7.67	12.92	253.1
6	255.0	147.2	.608	8.28	11.30	264.4
7	275.0	143.8	.564	8.85	10.02	274.4
8	280.0	141.1	.554	9.40	9.48	283.9
9	310.0	138.4	.500	9.90	8.24	292.1
10	320.0	136.4	.485	10.39	7.75	299.9
11	335.0	134.2	.463	10.85	7.16	307.0
12	345.0	132.4	.450	11.30	6.76	313.8
13	365.0	131.0	.425	11.72	6.24	320.0
14	400.0	129.4	.388	12.11	5.54	325.6
15	405.0	127.9	.383	12.49	5.34	330.9
16	410.0	127.0	.378	12.87	5.20	336.1
17	420.0	125.8	.369	13.24	4.96	341.1
18	450.0	124.7	.345	13.59	4.54	345.6
19	460.0	123.8	.337	13.92	4.37	350.0
20	465.0	123.1	.333	14.26	4.26	354.2

Room Heater, 45KBtuh, Damper A, Maximum Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	135.0	195.1	1.149	1.15	34.61	34.6
2	145.0	192.2	1.070	2.22	31.49	66.1
3	205.0	171.9	.757	2.98	18.57	84.7
4	245.0	159.3	.633	3.61	13.63	98.3
5	270.0	149.7	.575	4.18	11.05	109.3
6	285.0	151.5	.544	4.73	10.70	120.0
7	300.0	142.0	.517	5.25	8.98	129.0
8	310.0	143.2	.500	5.75	8.84	137.9
9	330.0	138.0	.470	6.22	7.72	145.6
10	350.0	135.5	.443	6.66	7.01	152.6
11	365.0	133.3	.425	7.08	6.50	159.1
12	375.0	132.6	.414	7.50	6.26	165.4
13	395.0	130.3	.393	7.89	5.72	171.1
14	410.0	128.1	.378	8.27	5.31	176.4
15	420.0	127.2	.369	8.64	5.11	181.5
16	435.0	125.8	.356	8.99	4.81	186.3
17	440.0	125.4	.352	9.35	4.72	191.0
18	450.0	121.5	.345	9.69	4.29	195.3
19	465.0	126.9	.333	10.02	4.58	199.9
20	475.0	121.3	.326	10.35	4.05	203.9

Room Heater, 45KBtuh, No damper, Maximum Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	80.0	170.2	4.549	4.55	109.21	109.2
2	90.0	138.7	4.043	8.59	66.51	175.7
3	100.0	119.8	3.639	12.23	43.35	219.1
4	190.0	102.7	1.915	14.15	14.95	234.0
5	200.0	99.7	1.819	15.96	12.87	246.9
6	210.0	98.6	1.732	17.70	11.81	258.7
7	215.0	98.2	1.692	19.39	11.39	270.1
8	220.0	97.7	1.654	21.04	10.91	281.0
9	225.0	98.2	1.617	22.66	10.88	291.9
10	230.0	98.6	1.582	24.24	10.78	302.7
11	235.0	98.1	1.548	25.79	10.35	313.0
12	238.0	97.0	1.528	27.32	9.82	322.8
13	240.0	97.2	1.516	28.83	9.81	332.6
14	243.0	95.7	1.497	30.33	9.17	341.8
15	245.0	95.4	1.485	31.81	8.97	350.8
16	248.0	95.0	1.467	33.28	8.73	359.5
17	250.0	95.4	1.455	34.74	8.79	368.3
18	255.0	95.0	1.427	36.16	8.49	376.8
19	258.0	94.1	1.410	37.57	8.09	384.9
20	260.0	93.6	1.399	38.97	7.84	392.7

Room Heater, 45KBtuh, No damper, Maximum Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	150.0	147.7	2.426	2.43	45.37	45.4
2	160.0	136.6	2.274	4.70	36.44	81.8
3	170.0	131.9	2.140	6.84	31.90	113.7
4	205.0	112.1	1.775	8.61	18.02	131.7
5	235.0	108.7	1.548	10.16	14.44	146.2
6	300.0	96.4	1.212	11.37	7.75	153.9
7	308.0	94.8	1.181	12.56	7.09	161.0
8	312.0	96.8	1.166	13.72	7.55	168.6
9	315.0	96.1	1.155	14.88	7.28	175.9
10	318.0	95.5	1.144	16.02	7.07	182.9
11	320.0	95.5	1.137	17.16	7.02	189.9
12	322.0	95.2	1.130	18.29	6.88	196.8
13	325.0	96.1	1.119	19.41	7.06	203.9
14	328.0	94.5	1.109	20.51	6.56	210.4
15	320.0	93.4	1.137	21.65	6.43	216.9
16	335.0	93.7	1.086	22.74	6.24	223.1
17	340.0	93.0	1.070	23.81	5.96	229.1
18	345.0	92.8	1.054	24.86	5.83	234.9
19	350.0	93.0	1.039	25.90	5.79	240.7
20	355.0	92.3	1.024	26.92	5.53	246.2

Room Heater, 45KBtuh, Damper B, Maximum Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	20.0	211.8	4.091	4.09	139.44	139.4
2	60.0	198.1	1.364	5.45	42.00	181.4
3	150.0	179.2	.545	6.00	14.32	195.8
4	175.0	161.1	.467	6.47	10.24	206.0
5	185.0	152.1	.442	6.91	8.73	214.7
6	195.0	146.3	.419	7.33	7.70	222.4
7	205.0	141.4	.399	7.73	6.86	229.3
8	215.0	137.5	.380	8.11	6.18	235.5
9	225.0	134.4	.364	8.47	5.64	241.1
10	232.0	131.5	.353	8.82	5.22	246.3
11	240.0	128.8	.341	9.17	4.83	251.2
12	248.0	127.0	.330	9.49	4.53	255.7
13	255.0	125.2	.321	9.82	4.27	260.0
14	260.0	123.3	.315	10.13	4.04	264.0
15	268.0	122.0	.305	10.44	3.82	267.8
16	272.0	120.7	.301	10.74	3.68	271.5
17	278.0	119.5	.294	11.03	3.51	275.0
18	282.0	118.6	.290	11.32	3.40	278.4
19	288.0	117.5	.284	11.60	3.25	281.6
20	293.0	116.4	.279	11.88	3.12	284.8

Room Heater, 45KBtuh, Damper B, Maximum Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	35.0	185.7	2.338	2.34	64.81	64.8
2	90.0	195.6	.909	3.25	27.36	92.2
3	160.0	177.6	.511	3.76	13.18	105.4
4	190.0	164.1	.430	4.19	9.70	115.1
5	210.0	154.4	.389	4.58	7.87	122.9
6	222.0	145.2	.368	4.95	6.63	129.6
7	230.0	140.4	.356	5.30	5.99	135.5
8	238.0	136.6	.344	5.65	5.47	141.0
9	243.0	134.2	.337	5.98	5.17	146.2
10	253.0	130.3	.323	6.31	4.66	150.9
11	260.0	128.3	.315	6.62	4.39	155.2
12	268.0	126.7	.305	6.93	4.14	159.4
13	272.0	125.1	.301	7.23	3.96	163.3
14	275.0	123.8	.297	7.52	3.83	167.2
15	278.0	123.3	.294	7.82	3.75	170.9
16	282.0	122.4	.290	8.11	3.63	174.5
17	285.0	121.5	.287	8.39	3.53	178.1
18	290.0	120.4	.282	8.68	3.40	181.5
19	295.0	118.8	.277	8.95	3.23	184.7
20	308.0	116.1	.266	9.22	2.92	187.6

Room Heater, 45KBtuh, Damper C, Maximum Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	62.0	197.2	3.869	3.87	118.33	118.3
2	95.0	163.2	2.525	6.39	56.61	174.9
3	135.0	140.7	1.777	8.17	30.24	205.2
4	180.0	123.8	1.332	9.50	17.27	222.4
5	205.0	118.9	1.170	10.67	13.80	236.2
6	230.0	116.2	1.043	11.71	11.62	247.9
7	240.0	114.8	.999	12.71	10.79	258.7
8	250.0	113.2	.959	13.67	9.99	268.6
9	265.0	112.3	.905	14.58	9.22	277.9
10	275.0	111.2	.872	15.45	8.66	286.5
11	285.0	109.8	.841	16.29	8.07	294.6
12	295.0	109.0	.813	17.10	7.65	302.2
13	303.0	107.8	.791	17.90	7.21	309.5
14	312.0	107.1	.768	18.66	6.87	316.3
15	317.0	106.2	.756	19.42	6.60	322.9
16	325.0	105.8	.738	20.16	6.37	329.3
17	330.0	105.3	.726	20.88	6.18	335.5
18	335.0	104.7	.716	21.60	6.00	341.5
19	345.0	104.0	.695	22.29	5.70	347.2
20	350.0	103.6	.685	22.98	5.56	352.8

Room Heater, 45KBtuh, Damper C, Maximum Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	105.0	163.6	2.284	2.28	51.30	51.3
2	130.0	156.0	1.845	4.13	38.09	89.4
3	145.0	147.4	1.654	5.78	30.72	120.1
4	185.0	130.3	1.296	7.08	18.75	138.9
5	220.0	119.5	1.090	8.17	12.94	151.8
6	230.0	117.3	1.043	9.21	11.84	163.6
7	245.0	115.0	.979	10.19	10.57	174.2
8	255.0	112.5	.940	11.13	9.58	183.8
9	265.0	111.6	.905	12.04	9.02	192.8
10	275.0	110.7	.872	12.91	8.51	201.3
11	282.0	110.7	.850	13.76	8.30	209.6
12	295.0	108.7	.813	14.57	7.54	217.2
13	308.0	107.2	.778	15.35	6.96	224.1
14	315.0	106.7	.761	16.11	6.70	230.8
15	320.0	106.0	.749	16.86	6.47	237.3
16	325.0	104.5	.738	17.60	6.12	243.4
17	330.0	104.4	.726	18.32	5.99	249.4
18	335.0	104.2	.716	19.04	5.87	255.3
19	340.0	104.0	.705	19.74	5.75	261.0
20	345.0	103.6	.695	20.44	5.61	266.6

Room Heater, 45KBtuh, No damper, Reduced Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	85.0	141.4	4.281	4.28	74.12	74.1
2	100.0	117.7	3.639	7.92	42.25	116.4
3	155.0	105.4	2.347	10.27	20.36	136.7
4	195.0	98.2	1.866	12.13	12.96	149.7
5	197.0	97.3	1.847	13.98	12.43	162.1
6	200.0	96.8	1.819	15.80	12.01	174.1
7	202.0	96.6	1.801	17.60	11.81	185.9
8	203.0	97.0	1.792	19.39	11.91	197.8
9	205.0	96.3	1.775	21.17	11.48	209.3
10	207.0	95.9	1.757	22.92	11.22	220.5
11	208.0	95.9	1.749	24.67	11.17	231.7
12	210.0	95.2	1.732	26.40	10.76	242.5
13	212.0	95.0	1.716	28.12	10.58	253.0
14	213.0	94.8	1.708	29.83	10.46	263.5
15	215.0	94.1	1.692	31.52	10.07	273.6
16	216.0	94.3	1.684	33.21	10.10	283.7
17	217.0	93.9	1.676	34.88	9.91	293.6
18	218.0	94.1	1.669	36.55	9.93	303.5
19	219.0	93.7	1.661	38.21	9.74	313.3
20	220.0	93.2	1.654	39.86	9.48	322.7

Room Heater, 45KBtuh, No damper, Reduced Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	145.0	127.0	2.509	2.51	34.77	34.8
2	160.0	113.9	2.274	4.78	24.34	59.1
3	180.0	102.7	2.021	6.80	16.22	75.3
4	295.0	102.9	1.233	8.04	9.95	85.3
5	305.0	94.1	1.193	9.23	7.10	92.4
6	315.0	96.4	1.155	10.38	7.52	99.9
7	320.0	96.8	1.137	11.52	7.50	107.4
8	330.0	97.0	1.102	12.62	7.32	114.7
9	335.0	95.7	1.086	13.71	6.88	121.6
10	345.0	94.6	1.054	14.76	6.41	128.0
11	350.0	94.5	1.039	15.80	6.27	134.3
12	360.0	94.3	1.010	16.81	6.06	140.4
13	365.0	93.9	.996	17.81	5.89	146.2
14	370.0	94.1	.983	18.79	5.85	152.1
15	372.0	93.4	.978	19.77	5.65	157.7
16	375.0	93.9	.970	20.74	5.73	163.5
17	377.0	92.8	.965	21.70	5.45	168.9
18	379.0	92.7	.960	22.66	5.38	174.3
19	380.0	92.8	.957	23.62	5.41	179.7
20	385.0	92.5	.945	24.57	5.25	185.0

Room Heater, 45KBtuh, Damper A, Reduced Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	90.0	205.3	1.724	1.72	55.71	55.7
2	150.0	171.7	1.034	2.76	25.07	80.8
3	235.0	150.6	.660	3.42	12.66	93.4
4	305.0	137.1	.509	3.93	8.11	101.6
5	335.0	131.5	.463	4.39	6.76	108.3
6	345.0	128.8	.450	4.84	6.27	114.6
7	360.0	127.0	.431	5.27	5.83	120.4
8	370.0	125.8	.419	5.69	5.54	126.0
9	385.0	124.9	.403	6.09	5.24	131.2
10	390.0	124.3	.398	6.49	5.12	136.3
11	395.0	123.6	.393	6.88	4.99	141.3
12	415.0	123.3	.374	7.26	4.71	146.0
13	425.0	122.5	.365	7.62	4.54	150.5
14	435.0	122.0	.356	7.98	4.39	154.9
15	445.0	121.5	.348	8.33	4.25	159.2
16	450.0	121.3	.345	8.67	4.18	163.4
17	455.0	120.7	.341	9.01	4.09	167.5
18	460.0	120.6	.337	9.35	4.03	171.5
19	465.0	120.2	.333	9.68	3.96	175.5
20	470.0	119.8	.330	10.01	3.89	179.3

Room Heater, 45KBtuh, Damper A, Reduced Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	160.0	189.1	.970	.97	26.68	26.7
2	190.0	176.4	.817	1.79	19.96	46.6
3	260.0	153.5	.597	2.38	11.31	58.0
4	335.0	138.2	.463	2.85	7.08	65.0
5	365.0	131.0	.425	3.27	5.76	70.8
6	375.0	127.6	.414	3.68	5.27	76.1
7	390.0	124.9	.398	4.08	4.81	80.9
8	410.0	127.8	.378	4.46	4.83	85.7
9	420.0	124.3	.369	4.83	4.42	90.1
10	425.0	122.5	.365	5.19	4.21	94.3
11	430.0	120.7	.361	5.56	4.00	98.3
12	435.0	122.0	.356	5.91	4.06	102.4
13	440.0	123.3	.352	6.26	4.12	106.5
14	445.0	124.2	.348	6.61	4.15	110.7
15	450.0	124.9	.345	6.96	4.17	114.8
16	455.0	123.4	.341	7.30	4.00	118.8
17	460.0	123.8	.337	7.63	3.99	122.8
18	465.0	123.1	.333	7.97	3.89	126.7
19	470.0	122.0	.330	8.30	3.76	130.5
20	475.0	122.5	.326	8.62	3.76	134.2

Room Heater, 45KBtuh, Damper B, Reduced Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	45.0	195.3	1.876	1.88	56.74	56.7
2	160.0	175.3	.528	2.40	13.42	70.2
3	195.0	155.5	.433	2.84	8.96	79.1
4	225.0	140.7	.375	3.21	6.43	85.6
5	245.0	133.0	.344	3.56	5.27	90.8
6	260.0	127.6	.325	3.88	4.54	95.4
7	270.0	124.0	.313	4.19	4.11	99.5
8	285.0	120.9	.296	4.49	3.67	103.1
9	290.0	118.9	.291	4.78	3.47	106.6
10	295.0	117.3	.286	5.07	3.30	109.9
11	300.0	115.9	.281	5.35	3.15	113.1
12	305.0	115.0	.277	5.62	3.04	116.1
13	310.0	114.1	.272	5.90	2.93	119.0
14	315.0	113.4	.268	6.16	2.84	121.9
15	320.0	112.3	.264	6.43	2.72	124.6
16	325.0	111.6	.260	6.69	2.64	127.2
17	330.0	111.0	.256	6.94	2.56	129.8
18	335.0	110.7	.252	7.20	2.50	132.3
19	340.0	110.3	.248	7.44	2.44	134.7
20	345.0	110.1	.245	7.69	2.40	137.1

Room Heater, 45KBtuh, Damper B, Reduced Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	75.0	187.7	1.126	1.13	31.99	32.0
2	165.0	178.7	.512	1.64	13.43	45.4
3	210.0	157.6	.402	2.04	8.52	53.9
4	235.0	143.6	.359	2.40	6.40	60.3
5	250.0	136.6	.338	2.74	5.45	65.8
6	265.0	130.6	.318	3.05	4.69	70.5
7	275.0	126.5	.307	3.36	4.21	74.7
8	290.0	122.9	.291	3.65	3.74	78.4
9	305.0	119.8	.277	3.93	3.36	81.8
10	320.0	117.7	.264	4.19	3.06	84.9
11	330.0	115.5	.256	4.45	2.84	87.7
12	335.0	114.3	.252	4.70	2.72	90.4
13	340.0	113.2	.248	4.95	2.61	93.0
14	345.0	112.5	.245	5.19	2.53	95.6
15	350.0	111.7	.241	5.43	2.46	98.0
16	355.0	111.0	.238	5.67	2.38	100.4
17	360.0	110.8	.234	5.91	2.34	102.7
18	362.0	110.8	.233	6.14	2.32	105.1
19	367.0	110.5	.230	6.37	2.27	107.3
20	370.0	109.8	.228	6.60	2.21	109.5

Room Heater, 45KBtuh, Damper C, Reduced Input, Normal cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	100.0	161.8	2.512	2.51	56.01	56.0
2	160.0	134.2	1.570	4.08	24.62	80.6
3	210.0	118.9	1.196	5.28	14.37	95.0
4	255.0	109.6	.985	6.26	9.62	104.6
5	270.0	106.3	.930	7.19	8.36	113.0
6	295.0	105.8	.851	8.05	7.54	120.5
7	310.0	105.3	.810	8.86	7.07	127.6
8	315.0	104.4	.797	9.65	6.79	134.4
9	320.0	104.4	.785	10.44	6.68	141.0
10	325.0	103.6	.773	11.21	6.44	147.5
11	330.0	103.3	.761	11.97	6.28	153.8
12	335.0	102.7	.750	12.72	6.09	159.9
13	340.0	102.7	.739	13.46	6.00	165.9
14	345.0	102.4	.728	14.19	5.85	171.7
15	350.0	101.7	.718	14.91	5.64	177.3
16	355.0	102.0	.707	15.61	5.62	183.0
17	360.0	101.5	.698	16.31	5.45	188.4
18	365.0	101.1	.688	17.00	5.32	193.7
19	370.0	101.1	.679	17.68	5.25	199.0
20	375.0	100.4	.670	18.35	5.06	204.1

Room Heater, 45KBtuh, Damper C, Reduced Input, Simulated cooldown

TRACER GAS MEASUREMENTS

TIME	CONC	TEMP	M	MLOS	Q	QLOS
1	135.0	149.7	1.861	1.86	36.19	36.2
2	160.0	136.0	1.570	3.43	25.38	61.6
3	195.0	126.9	1.288	4.72	17.98	79.5
4	245.0	115.2	1.025	5.74	11.43	91.0
5	280.0	109.2	.897	6.64	8.72	99.7
6	290.0	104.0	.866	7.51	7.34	107.0
7	295.0	102.4	.851	8.36	6.88	113.9
8	300.0	101.7	.837	9.20	6.62	120.5
9	305.0	102.7	.823	10.02	6.73	127.3
10	310.0	102.7	.810	10.83	6.62	133.9
11	313.0	102.9	.802	11.63	6.59	140.5
12	316.0	102.7	.795	12.43	6.49	147.0
13	320.0	102.7	.785	13.21	6.41	153.4
14	322.0	102.4	.780	13.99	6.30	159.7
15	325.0	101.3	.773	14.76	6.05	165.7
16	330.0	100.8	.761	15.53	5.86	171.6
17	332.0	100.8	.756	16.28	5.82	177.4
18	335.0	100.8	.750	17.03	5.77	183.2
19	340.0	100.6	.739	17.77	5.65	188.8
20	345.0	100.8	.728	18.50	5.60	194.4

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 84-2869	2. Performing Organ. Report No.	3. Publication Date September 1984

4. TITLE AND SUBTITLE

TEST METHODS FOR THE DIRECT MEASUREMENT OF STACK ENERGY LOSS DURING THE OFF-PERIOD OF SPACE HEATING EQUIPMENT

5. AUTHOR(S) E. Kweller
R.A. Wise

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

The Department of Energy
Office of Conservation and
Nenewable Energy
Washington, D.C. 20585

10. SUPPLEMENTARY NOTES

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

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

Evaluations have been made of a possible alternative to the tracer gas test method now being used to measure off-period energy loss of space heating equipment with vent dampers.

This alternative method offers the potential of a direct measurement method without the need for expensive tracer gas type instrumentation. The method uses a controlled flow of gas to a small gas fueled burner to simulate normal flue or stack temperatures previously measured during a cool-down test. Energy metered though the gas burner during the simulation gives a direct measurement of the thermal energy losses out of the stack. Results in comparison with the tracer gas method of test were lower for off-period energy loss meaurements. A trend to better agreement between the two methods was noticeable for test furnaces with greater fuel input rates. Further development testing and evaluation will be required before the simulation can be considered as an acceptable alternative test method.

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

boilers; fossil fueled heating systems; furnaces; household heating equipment; part load efficiency; stack energy loss.

13. AVAILABILITY

[X] Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

65

15. Price

$10.00

USCOMM-DC 6043-P80