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Indoor Environmental Quality Performance of a Radiant-Type Ventless Kerosene Heater:

Pilot Study in a Single-Family Residence

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INDOOR ENVIRONMENTAL QUALITY PERFORMANCE OF A RADIANT-TYPE VENTLESS KEROSENE HEATER: Pilot Study in a Single-Family Residence

by

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ABSTRACT

Out of the recent widespread use of portable ventless kerosene space heaters has developed a lively discussion about their health and safety aspects. Several theoretical and laboratory studies have been conducted concerning the combustion products of the heaters. In this pilot study, tests were made in a single-family house to examine the overall effects of the kerosene heater in-situ and to obtain preliminary data as a basis for a comprehensive study to be conducted later. The protocol developed for this study proved to be useful.

Test results indicated that, in a tight house, maximum NO_x concentrations can be higher than the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' (ASHRAE) and the Environmental Protection Agency's (EPA) air quality standards for continuous NO_2 exposure and can approach the ASHRAE standard for 24 hour exposure of NO. These results also indicated that, in some cases, the NO_x concentrations could be reduced to below the standard NO_2 values by opening a window, and that thermal acceptability could be maintained. However, an energy penalty also resulted by opening the window.

Results show that average 24-hour NO_x concentrations approached the standard NO_2 value in a tight house when the heater was operated for only 6.2 hours. On the other hand, when a window was opened during heater operation to dilute the concentrations to the standard value when the heater was on, the 24-hour average NO_x concentrations were well below the standard NO_2 value. Total exposure to pollutants measured was about the same magnitude in the whole house even though the doors of some rooms were closed during the study.

Other important results indicated that NO_x removal by means, such as chemical reactions, sorption or diffusion, was significant and that thermal acceptability within the radiant envelope of the heater could be maintained when temperatures in the rest of the house were low (12 C - 16 C, 53 F - 61 F).

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1. Introduction

1.1 History

The ventless kerosene heater is a space heating device which burns liquid kerosene. These heaters were used widely in the USA from the twenties to the fifties because of their low initial cost compared to other heating systems. These early devices were technically unsophisticated and resulted in unclean burning and significant fire hazards. Due to the poor fire safety reputation, restrictions concerning the use of these heaters were set in some areas of the country in the late fifties and early sixties.

During the sixties, kerosene heaters virtually disappeared from the marketplace due to other inexpensive fuels and the popularity of central heating systems. However, some old models are still in use, mainly in the southeastern part of the country.

1.2 Recent Popularity of Kerosene Heaters

Rapid increases in heating bills in the seventies promoted the use of space heaters again. Kerosene heaters made their resurgence in 1976 when significant importing from Japan began (in Japan about 92 % of households have these appliances).

Currently, the portable kerosene heater is a popular heating device in U.S. residences. Kero-Sun, Inc. estimates that there are about 10 million units in the U.S.. The popularity of kerosene heaters has been influenced by the following:

- homeowners and renters attempt to reduce heating expenses by maintaining thermal comfort only in the living zone while allowing the temperature to drop in the other parts of the house
- the heaters are relatively inexpensive compared to other energy conservation measures (for example, improving the building envelope)
- the heaters are portable and require no installation
- the appearance of the heater is acceptable
- the heater operation (ignition and termination) is simple
- the heaters have been advertised heavily as energy-efficient and cost-effective
- the radiant heater resembles a fireplace by its effects and hence it is thermally and psychologically attractive
- the public is generally uninformed about the aspects concerning pollutant emission and possible fire and burn hazards of the heater and cannot make an objective decision in a buying situation

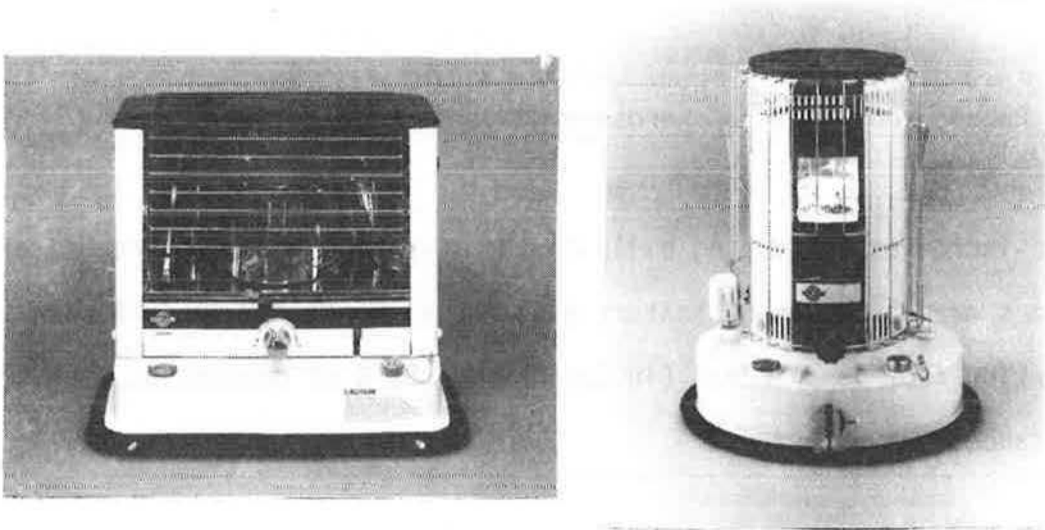

Figure 1. Two modern kerosene heaters. A radiant type is shown on the left and a convective type on the right. The new generation kerosene heaters are technically advanced compared to those of the forties. They have an electrical ignition and an automatic flame shut-off mechanism in case the heater is tipped over.

1.3 Kerosene Heater Controversy

The combustion process of the kerosene heater consumes oxygen from the air and releases combustion products to the surrounding room air. Because of these conditions, health and safety questions have been raised about the use of the appliance.

Some reports suggest that:

- kerosene heaters can produce concentrations of combustion products, (CO, CO_2, NO, NO_2, SO_2) which exceed the limit values of different air quality standards (ASHRAE, EPA, Occupational Safety and Health Administration (OSHA) (5,7,9,10)
- kerosene heaters pose a health hazard (3,8)
- kerosene heaters pose a fire hazard (3,8)
- kerosene heaters are not cost-effective if concentrations of combustion products are diluted to meet the ASHRAE air quality standard by opening a window (heater manufacturers recommend opening a window if there is insufficient air exchange) (4)

Other publications state that:

- air quality calculations and laboratory tests do not represent a real situation and they overestimate concentration levels (11,12,14)
- average room air concentrations are lower than EPA standard values (16)
- heaters do not constitute a potential pollution hazard (13,14,18)
- heaters present no substantial fire hazard (11,12,14,15)
- heaters are cost-effective (14,15)

1.4 Overall Effects of Kerosene Heater

Evaluation of the overall effects of the kerosene heater is a broad and complicated task. The use of these devices involves many factors which have to be surveyed separately and as a whole.

The main factors are:

- Air Quality What are room air concentrations in real operating situations? What are long term exposures, and what are their effects? How do air movements (dilution), gas removal processes (chemical reactions, absorption and diffusion), usage patterns, fuel and heater types affect air quality?
- Safety Are heaters fire safe? Are they safe in other respects? How do usage pattern, fuel and heater type affect safety?
- Thermal Acceptability In what situations is thermal acceptability achieved? How does dilution of room air concentration with outdoor air affect thermal acceptability?
- Energy Do heaters save energy? How do dilution of concentrations, usage pattern, fuel and heater type affect savings? How great are savings compared to those of other space heater types (e.g., electrical heaters)?
- Overall Economy Are kerosene heaters cost-effective compared to other space heaters? What nationwide impacts (savings versus costs) do heaters make?
- Usage Pattern How long, when, and by whom are heaters used? Where and how are they placed? How are they fueled and what type fuel is used? How often, how, and by whom are the heaters serviced?

1.5 Purpose of Pilot Study on Kerosene Heaters

The main purpose of this pilot study was to compile information for a subsequent comprehensive study which would address the question: "Is a kerosene heater safe to operate and is it possible to achieve acceptable indoor air quality, thermal acceptability, and energy savings simultaneously when using the kerosene heater?"

Special objectives of the pilot study were:

- to develop a test procedure and measuring technique for further studies
- to evaluate the performance and effects of a kerosene heater in a single family residence
- to obtain preliminary data for questions concerning air quality and thermal acceptability
- to examine the transient nature of combustion products
- to survey the potential effects of water vapor condensation on building materials

1.6 Advisory Committee

To consider various viewpoints for the need of this pilot study and establish research guidelines, a meeting of an advisory committee was convened on December 9, 1982. The group was composed of representatives of the kerosene industry; energy-, fire-safety-, ventilation-, combustion-, and housing-specialists; utility companies; and state agencies. The members of the committee are listed in Appendix 1.

One of the results of the Advisory Committee meeting was the approval of a protocol for comparing results of kerosene and electric in-space radiant heaters in the ISU Energy Research House. This protocol is attached in Appendix 1.

Later on the same day, a seminar "Indoor Air Quality, Safety, and Energy Conservation Aspects of In-Space Kerosene Heaters" was held (see Appendix 1). In this seminar, important aspects concerning the application of heaters were expressed both in the presentations and in the discussions. These aspects were considered in conducting the tests.

2. Experimental Procedure

2.1 Revision of Protocol

Before the tests were run, changes were made in the protocol. NO_2, CO and SO_2 concentration measurements were not included in the revised protocol (compare with 4.4 in Appendix 1) due to the unavailability of the instrumentation.

Instead of measuring the electric consumption of the furnace and that of the electric radiant heater (see 4.2 in Appendix 1), the total electric consumption of the house and the electric consumption of the instrumentation were measured.

Measurements of apparent air exchange rates (see 4.5.2 in Appendix 1) and relative exposure index (see 4.5.4 in Appendix 1) were obtained. Measurements of local air exchange rates and nominal air exchange rates (see 4.5.1 and 4.5.3 in Appendix 1) were omitted in the protocol since they require an uniform initial tracer gas concentration which cannot be provided without affecting other measurements.

To purge all analyzers thoroughly, the switching mechanism was set to change the zone every 90 seconds. Data were recorded 75 seconds after each switch (compare to 5.0 in Appendix 1).

2.2 ISU Energy Research House

The experiments were conducted in the Energy Research House (ERH) of Iowa State University). The ERH is a single family house with three levels (the lowest level is partially underground). The volume of the house is 558 m^3 (19,700 ft^3) and room area 180 m^2 (1,930 ft^2). The ERH has three bedrooms (upper level), a living room and a kitchen (middle level) and a family room (lower level). The living room, kitchen and family room are open to the staircase which connects all three levels. A greenhouse also connects the three floors and is separated from the rooms by sliding windows and curtains. The floor plans for this house are shown in Figure 2. The house is equipped with an electric forced air furnace.

The ERH is considered to be energy efficient. Its specific heat power requirement is about 1.33 W/m^2 C (0.23 BTU/hr ft^2 F) when the outdoor air flow rate is minimized (24).

Infiltration of the house is low. From previous studies, the local air exchange rates of rooms are in the range of 0.10 ACH - 0.33 ACH when outdoor temperatures are -4.8 C - +6.6 C (23 F - 44 F) and wind velocity 0.4 m/s - 5.8 m/s (0.9 mph - 13 mph) (21).

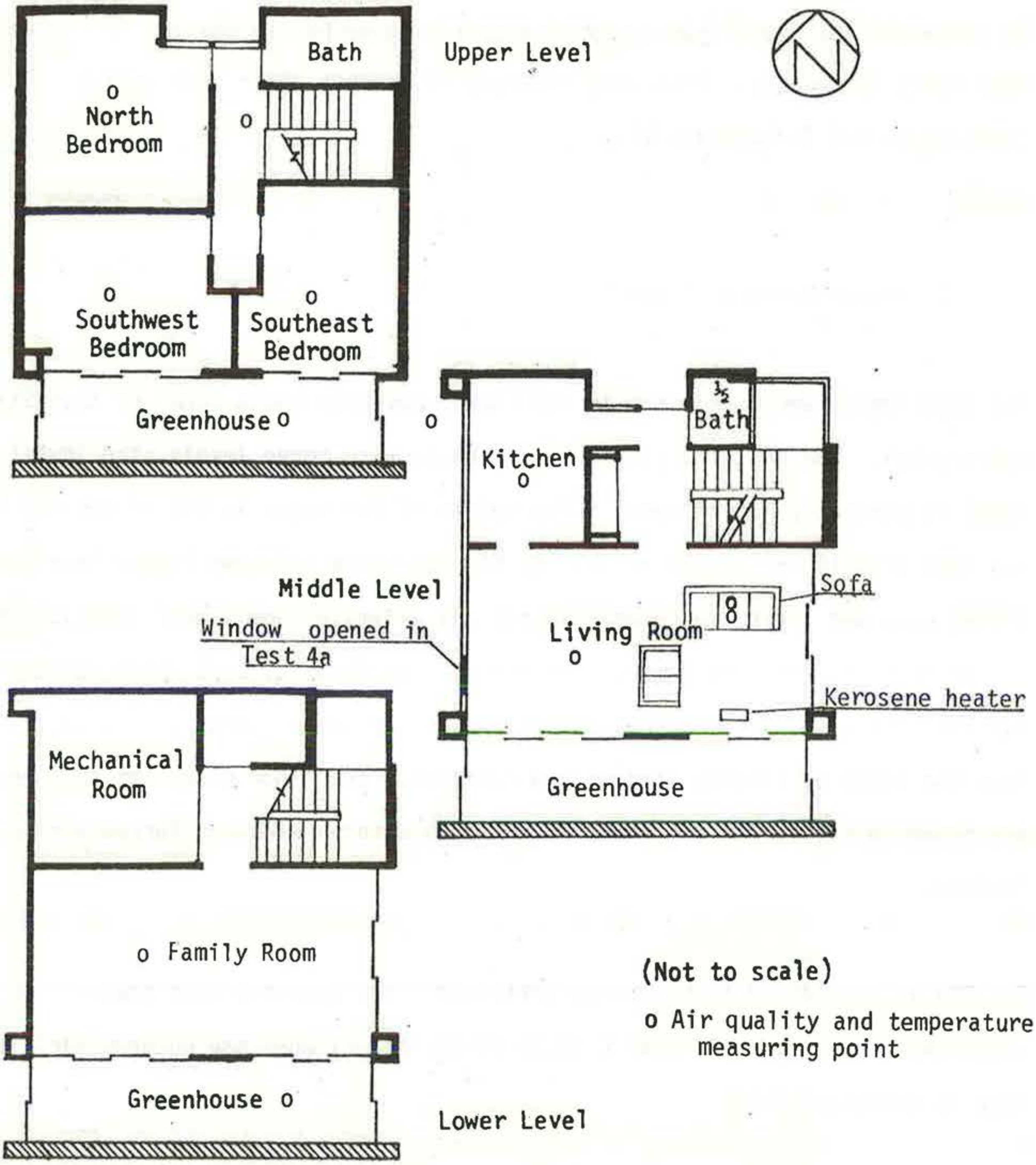

Figure 2. Floor plan of the Iowa State University Energy Research House and the locations of the measuring points.

2.3 Kerosene Heater, Room, and Fuel Specifications

The heater used in the study was the Radiant 8 model of Kero-Sun, Inc.. Its total rated (sensible + latent) heat output was 2400 W (8200 BTU/hr). The sensible heat output was 2230 W (7600 BTU/hr), according to the manufacturer's literature.

This model and its companion model, the Radiant 10, are the most popular types sold by Kero-Sun, which is the largest distributor of kerosene heaters in the United States.

A typical room size that can be heated by this kerosene heater is approximately 25.5 m^2 (274 ft^2) (the heated area varies with outdoor temperature, insulation R-factor and square footage of the windows) when the heater is the only heat source for the room (18). For this pilot study, the heater was placed in the 33 m^2 (357 ft^2) living room in front of the sofa (see Figures 3 and 5).

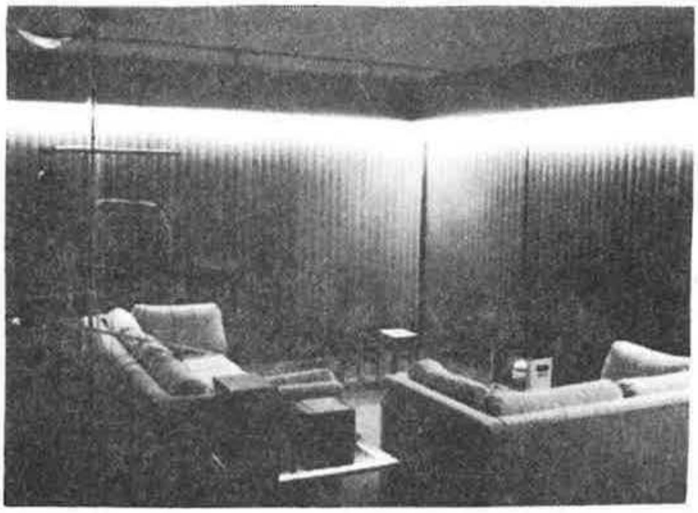

Figure 3. The kerosene heater was placed in the living room in front of the sofa.

The heater and kerosene used in this study were provided by Kero-Sun, Inc. The result of the analysis of the kerosene is shown in Appendix 2.

The heater was placed and operated according to the instructions by the manufacturer, and as recommended by the fire safety specialists of the Advisory Committee.

2.4 Evaluation Criteria

2.4.1 Acceptable Air Quality

For purposes of this study, the objective part of ASHRAE Standard 62-1981 definition of Acceptable Air Quality was used:

> "ACCEPTABLE AIR QUALITY. Air in which there are no known contaminants at harmful concentrations..."

The subjective part of the definition in the Standard 62-1981 states:

> "Air...with which a substantial majority (usually 80 %) of the people exposed do not express dissatisfaction."

This subjective part was not addressed in this study.

The measured values in this study were compared to the following air quality standard guidelines:

Contaminant	Concentration	Time	Source
Nitrogen Dioxide NO_2	100 $\mu g/m^3$ (0.05 ppm*)	yr	ASHRAE Standard 62-1981
Nitrogen Monoxide NO	0.5 mg/m^3 (0.41 ppm)	24 hrs	"
Carbon Dioxide CO_2	4.5 g/m^3 (2500 ppm)	Continuous	"
Oxygen O_2	19.5 %	Continuous	

*ppm = parts per million

Due to technical reasons, total nitrogen oxides NO_x (=$NO+NO_2$) were measured in this study.

Since no standard guidelines exist for NO_x concentration, the ASHRAE NO_2 guideline, 0.05 ppm (100 $\mu g/m^3$), was used when assessing air quality in terms of NO_x concentrations. This criterion was chosen based on the following:

- laboratory tests show that radiant kerosene heaters emit several times more NO_2 than NO (7,10)
- NO tends to oxidize to NO_2 (28)

2.4.2 Thermal Acceptability

Ranges for thermal acceptability variables for this study were taken from ASHRAE Standard 55-1981 (Thermal Environmental Conditions for Human Occupancy).

The winter range, as shown in Figure 4, was used to define acceptable operative temperature and humidity. The operative temperature was calculated as the mean value of the radiant and dry-bulb temperatures, which were measured at the 60 cm (24 in) level above the sofa.

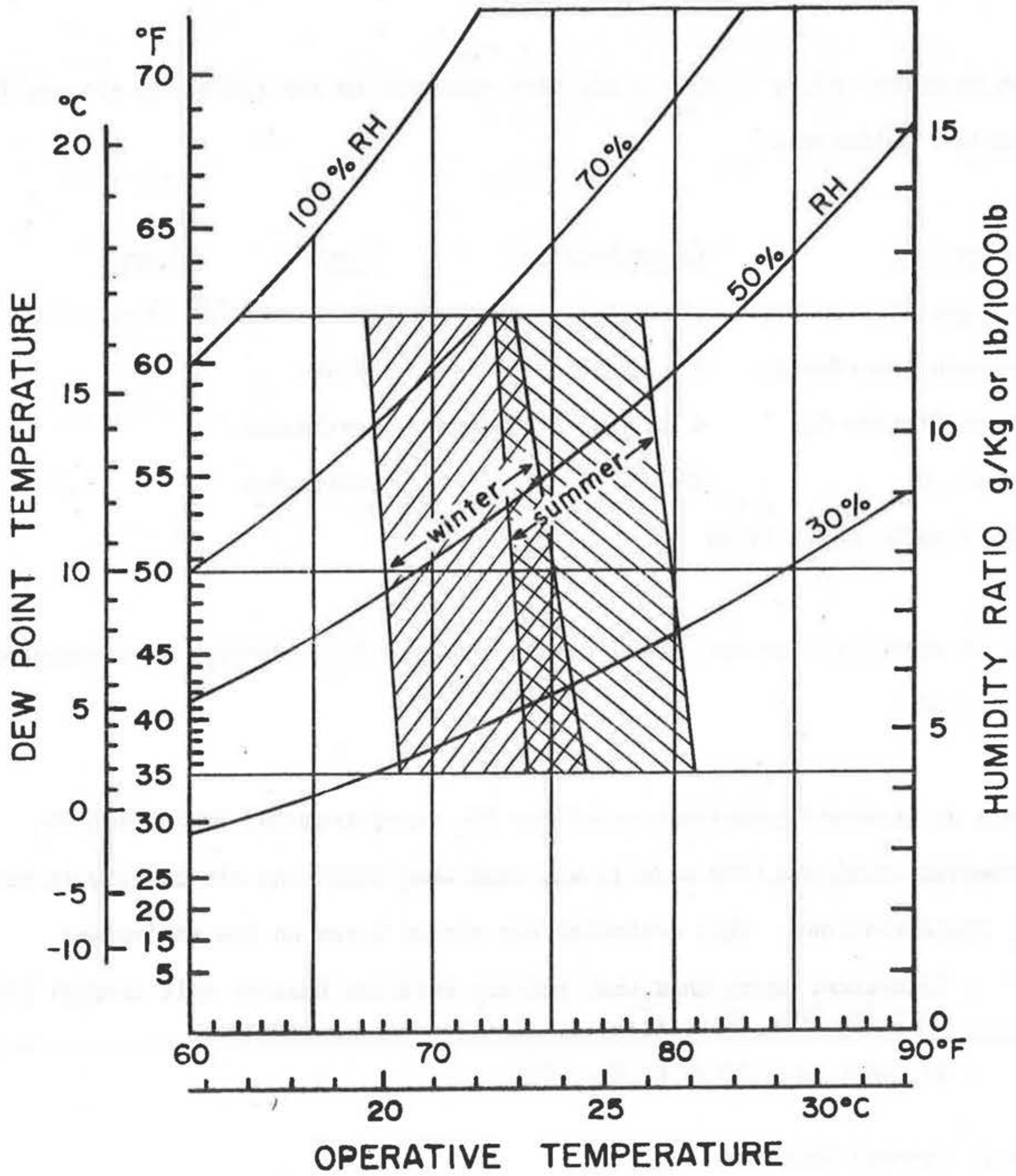

Figure 4. (Figure 2 in ASHRAE Standard 55-1981). Acceptable ranges of operative temperature and humidity for persons clothed in typical summer and winter clothing, at light, mainly sedentary, activity (≦1.2met). (met=metabolic rate, see reference 20)

The following constraints, which were adopted from ASHRAE Standard 55-1981, were also used in defining thermal acceptability:

- air movement less than 0.15 m/s (30 fpm) at the level of 110 cm (43 in) above the sofa
- radiant temperature asymmetry in the horizontal direction less than 10 K (18 F) at the level 110 cm (43 in) above the sofa
- vertical operative temperature difference between 10 cm (4 in) level and 110 cm (43 in) level in the sofa area less than 3 K (5 F)

2.4.3 Energy Consumption

Energy consumption of the electric furnace and instrumentation was measured in kWh. Kerosene consumption of the heater was measured in ml/hr which was converted to kWh by using the heat value 38 MJ/l (= 47.5 MJ/kg = 13.2 kWh/kg at 15.5 C (60 F)) (25).

2.4.4 Cost-Effectiveness

Cost-effectiveness of the use of the kerosene heater compared to the use of the electric space heater (both used in conjunction with the electric forced air furnace) and to the use of the electric furnace depends upon the following factors:

- the prices of the electricity and the kerosene
- the electrical consumption of the furnace and the electric space heater and the kerosene consumption
- the useful ages or expected life of the electric space heater and the kerosene heater
- the initial cost of the electric space heater and the kerosene heater
- miscellaneous costs (e.g., maintenance, repair) of the space heaters
- the effect of the use of the space heaters on the useful age, maintenance, and repair of the building structures (e.g., walls, windows), movables (e.g., furniture, drapes), and equipment (e.g., furnace, plumbing)

Cost-effectiveness was not investigated in this pilot study.

2.5 Characteristic Numbers

To evaluate and compare the behavior and dispersion of different gases, the following characteristic numbers were calculated from concentration measurements:

Apparent Air Exchange Rate was calculated from the decay curves of tracer gas concentrations using the equation:

$$n_i = \frac{\ln C_i(t_1) - \ln C_i(t_2)}{t_2 - t_1}$$

n_i = Apparent Air Exchange Rate in the measuring point i, ACH or 1/hr

C_i = Gas concentration at the measuring point i, ppm

t = Time, hr

Relative Exposure Index was calculated from the equation:

$$E_i = \frac{\int_0^\infty C_i(t)\, dt}{\int_0^\infty C_1(t)\, dt}$$

E_i = Relative Exposure Index at the measuring point i, dimensionless

C_1 = Gas concentration at the reference point in the living room at 110 cm (43 in) level above the sofa, ppm

When calculating relative exposure indices for CO_2, outdoor air CO_2 concentration was subtracted from indoor air concentrations.

Average Concentration was calculated from the equation:

$$\bar{C}_i = \frac{\int_0^t C_i \, dt}{t}$$

$\bar{C}_i$ = Average concentration in the measuring point i, at the period 0-t.

If gas concentrations had not decayed to the level before the test when data acquisition was turned off, decay curves were assumed to follow the curve:

$$C_i = C_o + (C_{off} - C_o)\, e^{-n_i t}$$

C_o = Concentration in the beginning of the test, ppm

C_{off} = Concentration when data acquisition was turned off, ppm

2.6 Measurements

2.6.1 Air Quality

Air sampling points were situated in the middle of each room at the height of 110 cm (43 in) (see Figure 2). Two additional sampling points were placed in the living room above the sofa at the heights of 110 cm (43 in) and 170 cm (67 in) (see Figure 5). One point was outdoors. The total number of the points was 12.

The following air quality parameters were monitored:

- NO_x concentration
- CO_2 concentration
- O_2 concentration
- dew point temperature

2.6.2 Thermal Acceptability

Variables used to evaluate thermal acceptability were monitored in the sofa area. Moreover, dry-bulb and dew point temperatures were measured at all air quality measuring points. As a whole, 14 dry-bulb temperatures, 12 dew point temperatures, 4 directional radiant temperatures, 1 globe temperature and 1 air velocity were monitored.

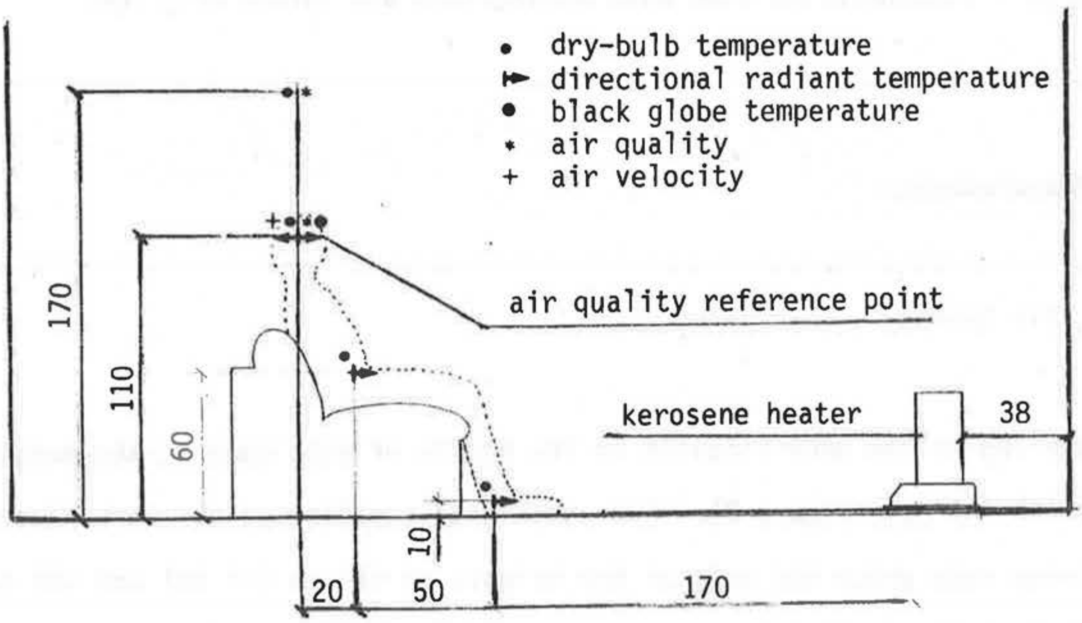

Figure 5. Sketch of sofa area, showing dimensions and the locations of the measuring points. All dimensions are in centimeters.

2.6.3 Energy Consumption

The following variables were measured:

- total electric consumption
- electric consumption of instrumentation
- kerosene consumption

2.6.4 Tracer Gas Concentration

Tracer gas (SF_6) concentrations were monitored at the same points as air quality.

2.6.5 Meteorological Measurements

The following meteorological parameters were monitored:

- outdoor dry-bulb temperature
- outdoor air dew point temperature
- wind speed and direction
- solar radiation on horizontal surface

2.7 Instrumentation

Air samples from each air quality measuring point were taken through Tygon 1/4" plastic hoses by means of a 12 channel sampling device, as shown in Figure 6. It consists of 24 solenoid shutoff valves, a switching mechanism for the valves, an air pump, a filter for solid particles and two flow meters (21).

Sampling air was passed through the analyzers which were connected in parallel. Total sampling air flow rate was 20 l/min (0.7 cfm). Sampling air was returned to the same zone it was taken from through a diffuser to avoid disturbing room air flows. The diffuser is shown in Figure 7.

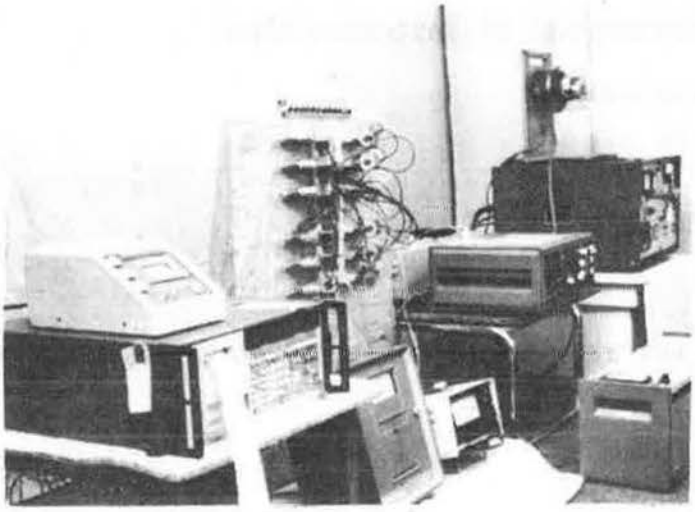

Figure 6. Instruments were placed in the family room. Sampling air was passed through the analyzers by means of a sampling device (in the middle of the figure). Data were recorded on a magnetic tape (datalogger and tapedrive on the left).

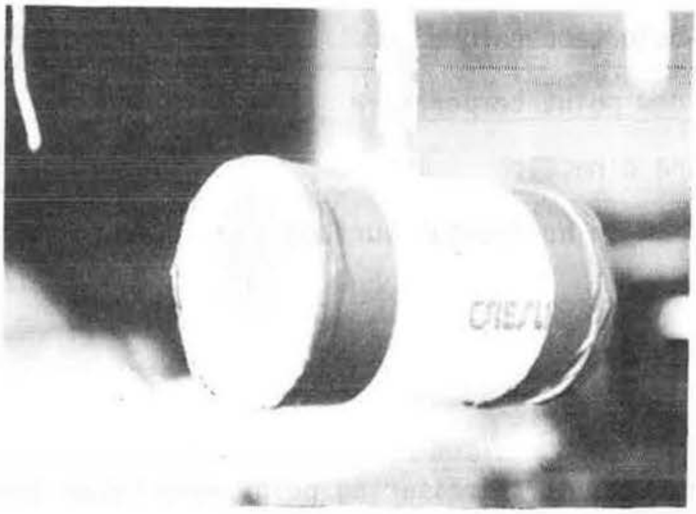

Figure 7. Sampling air was returned to the rooms through diffusers 5 cm (2 in) in diameter.

Sampling pressures in all analyzers were maintained higher than atmospheric pressure. This was taken into account either in the adjustments of analyzers or in the calculations of results.

Temperatures were measured with Cu-Cn thermocouples. Directional radiant temperatures were calculated from the temperatures of 5 cm (2 in) flat black aluminum plates (see Figure 8) and air temperatures (see Appendix 3 for calculation method). The analyzers used in the study are summarized in Table 1.

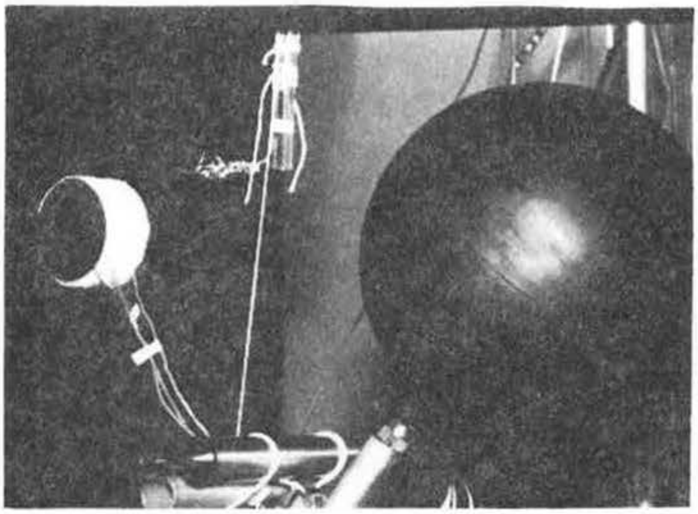

Figure 8. Measuring points above the sofa at the 110 cm (43 in) level.

Instrumentation

Measurement	Analyzer	Analyzer Principle
NO_x	Thermo Electron Corporation, Model 10A	chemiluminescent
CO_2	Anarad, Model 101	infrared
O_2	Beckman Oxygen Monitor, Model 7003	amperometric
SF_6	Wilks Miran 103	infrared
H_2O	EG & G, Model 880	thermoelectric

Table 1. The analyzers and their principles.

3. Measurement Procedure

3.1 General

In all tests, the heater was placed in the living room. The doors of the bedrooms, bathooms, and mechanical room were closed. Window coverings and curtains were closed to minimize the effect of solar radiation.

One researcher stayed in the house during the first eight (8) hours of each test. He was in the family room most of the time.

The room thermostat for the electric furnace was in the stairwell on the lower level. It was set to 13°C (55°F) before each test.

The heater, which was located in the living room, was operated for 6.2 hours in accordance with consumer use surveys (16). The heater was ignited and adjusted according to the "Owner's Guide" provided by Kero-Sun for the Radiant 8 heaters (see Appendix 4).

The schedule of the tests was the following:

Time (hours)	Activity
00.0	Data aquisition on
00.5	Kerosene heater on
00.6	Tracer gas release by the heater
06.7	Kerosene heater off
12.4	Data aquisition off

3.2 Tests Conducted

Tests were conducted from Feb. 24, 1983 to March 12, 1983. During the tests, 86 hours (over 80,000 single measurements) of data were recorded.

Time and weather constraints limited the number of tests that could be accomplished during the 1982 - 1983 heating season. Therefore, only tests 3 and 4a in the protocol were conducted.

Test 3, Windows Closed

In this test, the outdoor air flow rate was minimized by keeping the windows closed. Thermal acceptability, as defined in section 2.4.2, was maintained in the sofa area. If minimum thermal acceptability was not achieved in one hour after igniting the heater, the setpoint of the room thermostat was increased (the furnace was turned on). Test 3 was repeated five times. In two of these tests, the setpoint had to be increased.

Test 4a, Window Opened

In this test, the west window in the living room (see Figure 2) was opened as required to reduce the concentrations of combustion products in the sofa area to those defined in section 2.4.1. The reference point (see Figure 5) was above the sofa at the height of 110 cm (43 in).

The openable window was the horizontal sash type and 50 cm (20 in) high. It was in the upper part of the west wall of the living room (see Figure 2). The window was closed immediately after extinguishing the heater. Thermal acceptability in the sofa area was maintained by the same procedure as in test 3. Test 4a was repeated twice. In both of these the setpoint of the room thermostat had to be raised to achieve thermal acceptability.

4. Results

4.1 Evaluation of the Protocol and the Conduction of Tests

Even though both the scope of the protocol and the conduction of the tests were limited (see 2.1 and 3.2) enough data were gathered to evaluate the protocol in Appendix 1.

The main features of the test procedure (see 6.0 in Appendix 1) are appropriate. Tests 3 and 4a were conducted repeatedly without major problems caused by the test procedure. Since tests which were not conducted resemble tests 3 and 4a in major features, it is obvious that all tests in the protocol can be conducted.

The objectives of the protocol are realistic (see 2.0 in Appendix 1). Since weather conditions have a significant effect on heating energy consumption and since individual tests are conducted on different days and weather conditions, several test sets are needed to make a reliable energy consumption comparison between the heating methods (see 2.1 in Appendix 1). Thus in this pilot study, no reliable comparisons of energy consumption could be made.

Weather conditions and the heating method used affect the infiltration (dilution) and hence indoor concentrations. It is not possible to separate these two effects completely in a single test set and, hence, several test sets are needed to make reliable indoor concentration comparison between the heating methods (see 2.2 in Appendix 1). No comparison was made in this pilot study.

The major problems in this pilot study were conducting the measurements and the data processing. Measurements could not be conducted in the scope presented in the protocol (see 2.1 Revision of Protocol) because suitable analyzers could not be obtained. Mechanical and electrical connections of instrumentation were complex. The nitrogen oxides analyzer was not able to monitor NO and NO_2 simultaneously. Therefore, only NO_x was measured. Due to the sensitivity of the NO_x analyzer, readings below 0.03 ppm were unreliable. Moreover, the calibration of NO_x analyzer tended to float. Therefore the analyzer was calibrated before each test and the calibration was checked after each test by using a permeation tube. In data processing, outdoor NO_x readings were subtracted from indoor readings. The CO_2 analyzer had minor calibration difficulties. The O_2 analyzer had an electric connection problem in one test. The sample pump broke in the beginning of the test series. The repairing of the pump postponed the conduction of the measurements to late February and early March.

Due to the large number of air quality measuring points (12) and the monitoring time of one point needed, the same point was monitored only every 18 minutes. This, along with the sensitivity of NO_x analyzer, limited the analysis of transient behavior of the pollutants to only a qualitative examination (see 2.3 in Appendix 1).

The Energy Research House was suitable for the site of the pilot study. However, it cannot be considered a "typical" U.S. house due to its energy-efficient construction and configuration. Because of the large size of the house, a large number of measuring points were needed to monitor all parts of the house. This hampered acquisition, processing and analyzing of the data. Some of the data could not be analyzed because of acquisition and processing problems, and only one test set was completely analyzed. The data in this test set were complete except temperature data in two tests could not be plotted (however, these temperatures were printed and followed during the test).

4.2 Results of Test 3, Windows Closed

4.2.1 Furnace off during the Whole Test

Results of the test 3 were dependent on the operation of the forced-air furnace.

When the furnace was off during the whole test, CO_2 and NO_x concentrations increased rapidly in the living room, kitchen and upper staircase after igniting the heater (see Appendix 5).

NO_x concentrations in these rooms exceeded the ASHRAE value for continuous NO_2 exposure (0.05 ppm) in half an hour. Concentrations achieved almost constant levels in three hours.

Concentrations in the bedrooms and in the family room rose more slowly and continued to rise until the heater was shut off. NO_x concentrations in these rooms exceeded the ASHRAE NO_2 value in about two hours after igniting the heater.

The maximum CO_2 levels were slightly above the ASHRAE standard value 2500 ppm for continuous exposure. Maximum NO_x levels exceeded ASHRAE NO_2 value by the factor of four and were about half of the ASHRAE NO value, 0.41 ppm.

Average CO_2 levels, during the time when the heater was on, were at or below the standard CO_2 value in the whole house. Average NO_x concentrations at the same time were 1.4 - 3.2 times higher than the standard NO_2 value.

Average 24 hours CO_2 levels were well below the ASHRAE CO_2 value. Average 24 hours NO_x concentrations were around the standard NO_2 value.

The decay rate of NO_x was higher than that of CO_2 and SF_6 after the heater was turned off. This can be seen in the decay curves in Appendix 5. No exact numbers could be calculated due to differences in the initial concentrations of the gases and fluctuations in the NO_x measurement at low concentrations. The rapid decay rate of NO_x implied degradation by chemical reactions, absorption, or diffusion.

Relative exposure indices indicated that exposure in the kitchen and in the upper staircase was higher than that in the living room where the heater was placed. Exposure in the bedrooms was about equal to that in the living room. This resulted from the lower decay rates of pollutants in the bedroom than in the living room.

NO_x removal processes were also indicated from the relative exposure indices. NO_x indices, compared to CO_2 indices, are relatively lower in the bedroom and family room than in the living room. Thus, NO_x had decayed as it was transported to the bedrooms and the family room.

The dew point temperature increased almost linearly until the heater was shut off. Afterwards, it decreased slowly. These results were probably due to the increasing outdoor air dew point temperature which rose from -2.9°C (26.8°F) to +1.9°C (35.4°F) during the period when the heater was in operation. The maximum dew point temperatures were 6.6°C (43.9°F) in the living room and 5.9°C (42.6°F) in the bedroom (i.e., 50 % relative humidity). There appeared to be no condensation on the structure.

Oxygen levels decreased about 0.3 % (i.e., from 20.9 % to 20.6 %) in the living room, kitchen and staircase. In the other parts of the house, the decrease was about 0.2 %.

The living room air temperature at the height of 110 cm (43 in) above the sofa rose from 17.7°C (63.9°F) to 21.1°C (70.0°F) during the time when the heater was on. Temperatures in the bedrooms stayed almost constant 15.4°C - 16.3°C (59.7°F - 61.3°F) during the entire testing period.

Thermal acceptability within the sofa area was achieved in less than one half hour after igniting the heater and was maintained during the time the heater was on. The radiant temperature asymmetry above the sofa at the height of 110 cm (43 in) was 5.0°C (9.0 F). The operative temperature difference between the feet (at 10 cm level) and the face (at 110 cm level) of a sedentary person on the sofa was 1.0 C (1.8°F). Room air velocities in the sofa area were lower than 5 cm/s (10 fpm) on the average.

Kerosene consumption was 233 ml/hr. Average rate of total electrical consumption of the house was 2.55 kW during the time when the kerosene heater was on. This reflects the consumption rate for instrumentation of 0.75 kW and miscellaneous consumption 1.8 kW (lighting, pumps, etc.).

Outdoor temperature rose from -2.0 C (28.4°F) to 6.3°C (43.4°F) during the time when the heater was in operation. Outdoor CO_2 concentrations varied from 350 ppm to 800 ppm. The average level was about 500 ppm.

4.2.2 Furnace on Occasionally

In this test, the outdoor air temperature was lower and heat loss of the house was greater than in the test described above. To achieve thermal acceptability in the sofa area, the setpoint of the room thermostat was increased to 15.5°C (60°F) one hour after the heater was ignited. The electric furnace then operated in cycles during most the time the kerosene heater was on. This can be seen distinctly from the temperature curves in Appendix 6.

The operation of the furnace increased the apparent air exchange rates from about 0.2 ACH in the previous test to about 0.4 ACH because of the leaking outdoor air dampers (the furnace was set at 100 % recirculating mode). This decreased the concentrations compared to the test where the furnace was off. However, the maximum NO_x levels were about two times higher than the ASHRAE standard NO_2 value.

Average NO_x concentrations during the time when the heater was on exceeded standard NO_2 value about by the factor 1.6 in the living room, kitchen and upper staircase. Those in the bedrooms and in the family room were slightly lower than the standard value. All average 24-hour NO_x concentrations were below the standard NO_2 level.

All CO_2 concentrations including maximum concentrations were lower than the standard CO_2 value.

Relative exposure indices were closer to each other than in the previous test, due to the equalizing effect of the furnace on the room air concentrations. The dew point temperature stayed below 0°C (32°F) in the whole house.

Oxygen levels decreased about 0.1 % throughout the house.

Thermal acceptability parameters were about the same as in the previous test.

Kerosene consumption was 244 ml/hr. The average rate of total electrical consumption of the house was 3.87 kW during the time the kerosene heater was on.

The outdoor temperature was -6.4°C (20.5 F) at the beginning of the test and -2.7°C (27.1°F) at the time the heater was turned off. The outdoor air dew point temperature rose simultaneously from -9.5°C (14.9°F) to -5.5°C (22.1°F). The average outdoor CO_2 concentration was about 500 ppm.

4.3 Results of Test 4a, Window Opened

In this test, the CO_2 concentration was kept below 2500 ppm and the NO_x concentration below 0.05 ppm at the reference point in the living room while the thermal acceptability was maintained in the sofa area. It appeared that NO_x concentration was the dominating criterion.

Since opening a window made the situation dynamic, constant concentrations were difficult to maintain. The NO_x concentrations rose rapidly to the 0.08 ppm - 0.10 ppm level after igniting the heater. The CO_2 concentration increased simultaneously to about 1800 ppm. Concentrations began to drop after the window was opened. When the heater was turned off, NO_x levels were 0.04 ppm - 0.06 ppm and CO_2 levels 1400 ppm - 1600 ppm.

The window was opened one half hour after igniting the heater. First, the window was opened to 0.05 m^2 (0.54 ft^2). However, the open window area was further increased to about 0.5 m^2 (5.9 ft^2) to maintain acceptable indoor air quality. During this test, the wind direction was not directly into the window. The window was closed immediately after the heater was turned off.

The setpoint of the room thermostat was increased to 17.2°C (63°F) one hour after igniting the heater because thermal acceptability was not achieved. This started the electric furnace which continued to operate occasionally during the whole test. Thermal acceptability excluding humidity was achieved 15 minutes after turning on the furnace.

Average NO_x concentrations in the living room, kitchen and upper staircase during the time the heater was on were slightly higher than the standard NO_2 value. Those in the bedrooms and in the family room were lower than the standard NO_2 value.

All 24-hour average concentrations were well below the standard values.

SF_6 decay rates were rather high (0.42 ACH - 0.60 ACH) when the window was open and very low (0.10 ACH) after the window was closed. As seen in Appendix 6 and 7, the apparent air exchange rate increased by 50 % in the living room, but only by 30 % in the north bedroom when the window was opened. After the window was closed (Appendix 7), the apparent air exchange rates were again similar to those in the previous test (Appendix 6).

Dew point temperatures stayed below 0°C (32°F) in the whole house when the heater was on and the window open. It was lowest in the living room, about -1.3°C (29.7°F). Dew point temperatures began to rise after the heater was turned off and the window closed.

Oxygen levels decreased 0.03 % - 0.1 % throughout the house.

The living room air temperature was 14.8°C (58.6°F) in the beginning of the test. It increased to 17°C - 19°C (63°F - 66°F) when the heater was on. In the bedrooms, temperatures were almost constant 13°C - 15°C (55°F - 59°F) during the whole test. The operative temperature varied 20°C - 22°C (68°F - 72°F) above the sofa at the 60 cm (24 in) level when the heater was on. Room air velocities were below 10 cm/s (20 fpm) in the sofa area.

Kerosene consumption was 194 ml/hr. Average total electricity consumption of the house was 3.83 kW during the period when the heater was on.

The outdoor air temperature rose from -4.2°C (24.4°F) to -1.7°C (28.9°F) and outdoor dew point temperature from -8.5°C (16.7°F) to -6.5°C (20.3°F) during the heater operation time. Outdoor CO_2 concentration was 500 ppm on the average.

4.4 Summary of the Results

The notable results of the study were as follows:

- the main features of the test procedure were appropriate
- the scope of the protocol was too broad to be conducted in this pilot study
- major problems in the tests resulted from data acquisition and processing
- maximum NO_x concentrations in the house were four times higher than the ASHRAE standard NO_2 level for continuous exposure and about half of the ASHRAE standard NO value for 24-hours exposure
- the highest average 24-hour NO_x concentrations were at the standard NO_2 value
- acceptable air quality and (minimum) thermal acceptability were achieved simultaneously in the living zone when the window was opened
- when NO_x concentrations were diluted to the standard NO_2 value, average 24-hour NO_x concentrations were well below the standard NO_2 level
- the highest CO_2 concentrations were slightly above the ASHRAE standard CO_2 value 2500 ppm for continuous exposure
- average CO_2 concentrations were below the standard value in all tests
- NO_x decay due to other processes than dilution was noticed
- moisture generation of the heater was significant. However, minimum acceptable indoor air humidity was not achieved in all tests.

- no condensation on the structures was noticed
- decrease in the oxygen levels was not substantial
- the kerosene heater provided thermal acceptability in the sofa area when temperatures in the rest of the house were significantly lower than the operative temperature in the sofa area
- thermal acceptability was achieved only in the radiant envelope of the heater
- no reliable energy consumption comparisons could be made
- the kerosene heater worked faultlessly during the whole study

5. Discussion

In this study, a radiant kerosene heater was operated in a room which was open to several other rooms. However, if a radiant heater were applied in a closed room, concentrations could rise significantly higher than in this study. Moreover, as the convective kerosene unit has been reported to emit significantly more NO_x than the radiant unit (6,22), the concentrations in a closed room should be even higher if the convective unit is used.

When the outdoor temperature is low, artificial humidification is often needed to maintain proper indoor air humidity. Moisture generation of the kerosene heater can decrease this need. An increased wet bulb temperature slightly increases the thermal sensation, too. However, if a window is opened to dilute other combustion products, the benefits of moisture generation are partly lost. On the other hand, moisture generation can be redundant. A recent study indicates SO_2 and moisture emitted by a kerosene heater may degrade building materials (23).

In the Energy Research House, the average air exchange rate had to be increased from 0.2 ACH to about 0.6 ACH to achieve acceptable indoor air quality. This corresponds to an increase of 50 l/s (106 cfm) in outdoor air flow. If the outdoor temperature were 0°C (32°F), 1.0 kW (3400 Btu/h) heating power would be required to heat this 50 l/s to 17°C (63°F) which is almost half of the rated sensible heat output of the heater. This rough example shows that the overall thermal efficiency of the heater (25) is low in a tight house if the heating power needed to heat the additional diluting outdoor air flow is taken into account when calculating the thermal efficiency. In a house with substantial air leakage, this additional diluting air flow may be smaller and the thermal efficiency may be higher. In other words, the kerosene heater may be more effective in housing with substantial air leakage, if air quality is considered. However, this example is unrealistic since users do not know without instrumentation how much dilution is needed to achieve acceptable air quality.

Although fire and other safety issues were not addressed directly in this research, no fire hazard was noticed. Careful attention was paid to the placement and operating of the kerosene heater, in strict accordance to manufacturer's and advisory committee's instructions.

6. Conclusion

The results of this study were consistent with the study made at Lawrence Berkeley Laboratory (1). In that study, a kerosene heater was used in a 240 m^2(8470 ft^2) house and concentrations of different pollutants were measured.

The results of our study showed that both average and maximum concentrations of the combustion products depended, to a great extent, upon the air exchange rate of the house. Results indicated also that NO_x decayed at a rate which was higher than the decay rate for the inert tracer gas (SF_6) used to determine the air exchange rates. These results, in conjunction with different usage patterns, create a wide variety of possible exposures an individual can experience.

Combustion products of the kerosene heater dispersed quickly throughout the house. Hence, the exposure was of about the same magnitude in all rooms. However, concentrations in the basement were lower than in the rest of the house due to stratification.

A comparison of the tracer gas test results in this study to the tracer gas tests made earlier without a kerosene heater in the same house (21) shows that tracer gas dispersed more quickly when the kerosene heater was used. Tracer gas decayed at significantly different rates in different rooms when a kerosene heater was not used, whereas there was little difference in decay rates when the kerosene heater was utilized. This indicates that the kerosene heater has an effect on ventilation efficiency by generating convective air flows.

Thermal effects of the radiant kerosene heater were beneficial. Operative temperature in the radiant envelope of the heater was substantially higher than the room air temperatures. This means that potentials for energy savings exist if indoor air quality is controlled by low energy means.

7. Recommendations

Due to the nationwide importance and the multiplicity of the kerosene heater question, further studies are needed to obtain reliable information from all factors (see 1.4) related to it. Of special importance is the need for further study of the transient nature of pollutants, especially that of NO and NO_2, and the effects of those pollutant concentrations on human exposure.

The effects of kerosene heaters on ventilation efficiency and on air distribution patterns by natural convection should be investigated to explore how human exposure to combustion products varies in different areas of single family houses.

8. Acknowledgments

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We thank the members of the advisory committee for their comments and guidance. In addition, a special thanks is due to Mr. John Janssen, Mr. Jeffrey R. Parkin, Mr. Eimund Skåret, and Mr. Delmar B. Van Meter for their valuable contributions to the study.

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Table of Appendices

KEROSENE HEATER PILOT STUDY IN ISU ENERGY RESEARCH HOUSE

Research Protocol

1.0 Introduction

Ventless kerosene heaters have become popular heating appliances in residences. It has been estimated that at the end of this heating season there will be over 10 milj. units in U. S. homes, and more than 92% of Japanese residences have kerosene heaters.

Reports concerning health and safety aspects of kerosene heaters are conflicting. Some calculations and tests indicate that concentrations of indoor pollutants may be extremely high (1, 2, 3, 4, 5)*; other reports state that significant amounts of energy can be saved and that no noticeable increase in indoor pollutants result (6, 7, 8). The former contentions are based on assumptions or test conditions related to a single room of a house, while the latter contentions are based on whole-house assumptions.

2.0 Objectives

The main objective of this study is, unlike the former tests, to evaluate the performance and effects of a typical kerosene heater in a single family residence.

The special objectives are:

2.1 To compare the energy consumption of a typical kerosene heater to the consumption of a forced air resistance heater system (furnace), and to the consumption of an electric radiant heater, when the same level of thermal comfort is maintained in the living room of the Energy Research House.

* See references in Appendix 1.

2.2 To compare the concentrations in the living room and in other rooms when using a kerosene heater, or a furnace or electric heater, and when the same level of thermal comfort is maintained. These tests will be conducted first at minimum outdoor air exchange rate, and followed by tests in which the outdoor exchange rate will be increased as necessary to achieve the same indoor quality as that measured when the electric furnace was operated.

2.3 To examine the transient nature of indoor pollutants affected by the kerosene heater, the absorption of contaminants, especially NO_2, in building materials and furnishings will be studied.

2.4 To evaluate the effects of the products of combustion produced by the kerosene heater. The capacity of the kerosene heater will be compared to that of the in-space electric radiant heater in terms of sensible and latent heat components. Also, the potential effects of water condensation on building materials will be addressed.

2.4.1 The potential effects of CO_2 generation will be discussed.

2.4.2 The potential effects of NO_X generation will be discussed.

2.4.3 The potential effects of CO generation will be discussed.

2.4.4 The potential effect of SO_2 generation will be discussed.

3.0 <u>Advisory Committee's Meeting and Kerosene Heater Seminar</u>

3.1 To consider various viewpoints for the need of this study, a meeting of an advisory committee was convened on the 9th of December, 1982 at 8:30 a.m. The members of the committee are listed in Appendix 2.

This meeting was held in the Building Energy Utilization Laboratory with Professor Woods as chairman. Later, the participants moved to the ISU Energy Research House, the proposed site for this project. In the meeting, the following points were agreed upon:

3.1.1 The overall test procedure was approved.

3.1.2 Tests will be conducted until steady condition of the air throughout the house has been demonstrated for at least an hour.

3.1.3 The room air thermostat for this project will be located on an interior wall of the lower level of the Energy Research House.

3.1.4 The setpoint of the room air thermostat will be set at 70°F (21°C) for the reference test.

3.1.5 In the other tests, the initial setpoint will be 55°F (13°C)

3.1.6 The kerosene heater for this project will be of the radiant type with a rated heating capacity of 8,200 BTU/h (2.4 kW). This heater is the most popular model of Kero-Sun, Inc.

3.1.7 Kero-Sun, Inc. will provide an analysis of the fuel used in the tests. Another analysis will also be conducted by ISU personnel.

3.1.8 The locations of the heater and the sofas in the living room of the ERH were determined.

3.1.9 The electric heater will be of the radiant type. Only one heater will be used and its capacity will be 1.5 kW so that compliance with electrical safety can be maintained.

3.1.10 The window treatments will be closed during the tests.

3.1.11 The researchers may adjust the test procedure if it is necessary, but the advisory committee will be notified beforehand, if possible.

3.1.12 The results of the pilot study will be made available to the advisory committee on a confidential basis. Results of the pilot study will not be released publicly until the more detailed followup study has been published.

3.2 In the afternoon of the 9th of December, 1982, a seminar "Indoor Air Quality, Safety and Energy Conservation Aspects of In-Space Kerosene Heaters" was held (see Appendix 3). In this seminar, important aspects concerning the application of heaters were expressed both in the presentations and in the discussions. These aspects will be considered in conducting the tests.

Professor Earl Morris, Department of Family Environment, agreed to participate in these studies and has been added to the advisory committee.

4.0 Measurements

4.1 Air temperatures, pollutant concentrations, and tracer gas concentrations will be measured continously in the middle of each room at the height of 43 in. (110 cm). In the living room, the measuring points will be in the occupied zone at the heights of 43 in (110 cm) and 67 in (170 cm). One sampling point will be located outdoors. Thermal comfort parameters will be monitored in the living room.

4.2 Energy Consumption

- electric furnace
- kerosene heater
- electric radiator

4.3 Temperatures

- air temperatures in each zone
- radiant temperatures in the living room

4.4 Concentrations of pollutants

- NO_x, NO_2, CO_2, CO, SO_2, O_2, H_2O

4.5 Tracer Gas Measurements

Measurements will be carried out by using SF_6. Several methods will be studied:

4.5.1 <u>Local Air Exchange Rate</u>. A fixed amount of SF_6 will be supplied and mixed uniformly in the house. Decay curves will be plotted on the basis of real time measurements. The air exchange rate will then be calculated from the formula:

$$n_i = \frac{C(o)}{\int_0^\infty C_i(t)\,dt}$$

n = air exchange rate

C = concentration of SF_6

i = room number i

4.5.2 Apparent Air Exchange Rate. Measurements will be conducted in the same way as in the point 4.5.1. However, uniform starting concentration is not necessary. Tracer gas may be supplied in any way without artificial mixing. Exchange rate will be calculated from the formula:

$$n_i = \frac{\ln C_i(t_1) - \ln C_i(t_2)}{t_2 - t_1}$$

4.5.3 Nominal Air Exchange Rate. This method is the same as 4.5.1. In addition, complete mixing will be maintained during the whole measurement period (forced air fan will run continuously).

4.5.4 Relative Exposure Index (REI). The tracer gas will be supplied in the living room above the heater as a pulse. The response as a function of time will be monitored at each measuring point. The REI will be determined from the formula:

$$E_i = \frac{\int_0^\infty C_i(t)\,dt}{\int_0^\infty C_1(t)\,dt}$$

E = relative exposure index

i = room number i

1 = living room

4.6 Meteorological Measurements

- outdoor air temperature
- outdoor air dew point
- wind speed and direction
- solar radiation on horizontal surface

5.0 Instrumentation

Tracer gas and pollutant gas samples from each room will be taken through plastic hoses by means of a 12 channel sampling device, which consists of 24 solenoid shut-off valves, a switching mechanism for the valves, an air pump, a filter for solid particles and two flow meters (rotameters). Sampling air will be passed through the analyzers. Total sampling air flow will be 0,7 cfm (20 l/min). Each zone will be monitored for 60 sec. Data will be recorded 45 sec. after the opening of a valve. Sampling air will be returned through a diffuser to the same room where it was taken from. The instruments used in the tests are summarized in Appendix 5.

6.0 Test Procedure

Five tests will be conducted. Each test will take approximately 6-8 hours. The summary of the test procedure is in Appendix 4.

6.1 Test 1.

- reference test
- outdoor air exchange rate is minimized by closing the outdoor dampers.
- the setpoint of the thermostat of the central heating system (furnace) is 70°F (21°C).
- furnace is the only heater in operation.

6.2 Test 2.

- like test 1, but the setpoint of the thermostat is 55°F (13°C)
- this test should result in the maximum saving potential in the energy consumption of the furnace.
- to ensure that tracer gas and pollutant gas analysis sampling has no effect on results, this test will be repeated when sampling is de-energized.

6.3 Test 3.

- minimum outdoor air flow
- kerosene heater in operation
- the setpoint of the thermostat is 55°F (13°C)
- the objective of this test is to get basic data from the emission and dispersion of pollutants, to measure maximum energy savings from kerosene heater, and to evaluate the thermal comfort provided at the sofa area in the living room.

6.4 Test 4a

- kerosene heater in operation
- the setpoint of the thermostat is 55°F (13°C)
- a window in the living room will be opened so that ASHRAE minimum air quality will be achieved when maintaining (minimum) thermal comfort in the living room sofa area.
- if the thermal conditions fall below the thermal comfort envelope, the setpoint of the thermostat will be increased.
- the objective of this test is to find out the saving potential in total energy consumption (kerosene and electricity) in a real operating situation when minimum air quality and (minimum) thermal comfort are maintained.

Test 4b

- like 4a, but the goal is to achieve the same air quality and thermal comfort as in the reference test.
- the objective of this test is to compare the total energy consumption of the reference case when the same indoor conditions are maintained.

6.5 Test 5

- like Test 4, but kerosene heater is replaced by an electric radiant heater.
- the objective of this test is to compare the total energy consumption when using electric heater to the total consumption when using kerosene heater.

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Advisory Committee

K. Baker	Engineering Extension - ISU
Lynn R. Forshee	Deputy State Fire Marshall
Laurent Hodges	Physics & Engineering Extension - ISU
Patrick Huelman	Energy Extension Service - ISU
John Janssen	Honeywell, Inc. - Minneapolis, MN
Bill Leech	Iowa Power & Light
Earl Morris	Dept. of Family Environment - ISU
Norm Olson	Iowa Energy Policy Council
George Oster	Fire Service Education - ISU
Jeffrey Parkin	Kero-Sun, Inc. - Kent, CT
Eimund Skåret	Norwegian Institute of Technology
Delmar Van Meter	Mechanical Engineering - ISU
Dick Vohs	Iowa Energy Policy Council

SEMINAR
Thursday, December 9, 1982
Pearson Hall Room 202
3:00 - 5:00 p.m.

INDOOR AIR QUALITY, SAFETY, AND ENERGY CONSERVATION ASPECTS OF IN-SPACE KEROSENE HEATERS

Sponsored by

Building Energy Utilization Laboratory
Department of Mechanical Engineering
Department of Architecture

Three aspects of the application of ventless kerosene heaters will be presented:

1. The nature and characteristics of In-space kerosene heaters will be introduced by Mr. Jeffrey Parkin, Counsel & Product Manager, Kero-Sun, Inc., Kent, Connecticut.

2. Fire and burn safety procedures for using kerosene heaters will be discussed by Mr. George J. Oster, Chief Instructor at ISU.

3. Indoor air quality and thermal comfort will be described in terms of ventilation efficiency by Dr. Eimund J. Skåret, Associate Professor of Heating and Ventilating at the Norwegian Institute of Technology, Trondheim, Norway.

Open discussion will follow these presentations. The objective of this seminar is to discuss, and modify as necessary, the scope and procedures being developed for a research project in the ISU Energy Research House.

Summary of the Test Procedure

Test No.	Outdoor Air	Thermostat	Heater
1	min	70°F (21°C)	furnace
2	min	55°F (13°C)	furnace
3	min	55°F (13°C)	kerosene
4a	window open	55°F (13°C)	kerosene (furnace)
4b	window open	55°F (13°C)	kerosene (furnace)
5	min	55°F (13°C)	electric radiator (furance)

Fuel Engineering Company of New York

Energy and Environmental Services

30 CLAIRMONT AVENUE • THORNWOOD, N.Y. 10594 • (914) 769-7900

RECEIVED ... 2 1983

Test Report # 344494 Pg. 1

Date Received 4/13/83

P.O. #

Sample Identification
Kerosene Sample
Iowa State University
Energy Utilization Lab

Sampled by: (You) (Us) Date:

CERTIFICATE OF OIL ANALYSIS

Approved by M. Camargo

Date Mailed April 20, 1983

Kero-Sun, Inc.
P.O. Box 549
Kent, CT 06757
Attn: Linda Ajello,
Product Liability Coordinator

Degrees API @60°F	45.5
Specific Gravity @60°F	0.7994
Flash Point °F	127
Bottom Sediment (incl water) %	
Sulfur %	0.02
BTU per pound	
BTU per gallon	
Viscosity @ °F	
@ °F	
@ °F	
@ °F	
Ash	%
Carbon	%
Hydrogen	%
Nitrogen	%
Oxygen	%
Sulfur	%
Water by Distillation	%
Sediment by Extraction	%
Pour Point	°F
Fire Point	°F
Freezing Point	°F

CHEMICAL ANALYSIS

Sodium	
Vanadium	
Potassium	
Iron	
Lead	
Nickel	
Copper	
Magnesium	
Calcium	
Manganese	

Saybolt Color = +25

Carbon Residue

FUEL ENGINEERING COMPANY OF NEW YORK EST. 1907

AMERICAN COUNCIL OF INDEPENDENT LABORATORIES

Fuel Engineering Company of New York *Energy and Environmental Services*

30 CLAIRMONT AVENUE • THORNWOOD, N.Y. 10594 • (914) 769-7900

Test Report # 344494 Pg.2

Date Received 4/13/83

P.O. #

Sample Identification
Kerosene Sample
Iowa State University
Energy Utilization Lab

Sampled by: (You) (Us) Date:

CERTIFICATE OF ANALYSIS

Approved by M. Camarro

Date Mailed April 20, 1983

Kero-Sun, Inc.
P.O. Box 549
Kent, CT 06757
Attn: Linda Ajello,
Product Liability Coordinator

Initial Boiling Point	334°F
5% Recovery	346°F
10% Recovery	352°F
20% Recovery	360°F
30% Recovery	370°F
40% Recovery	380°F
50% Recovery	395°F
60% Recovery	410°F
70% Recovery	426°F
80% Recovery	442°F
90% Recovery	460°F
95% Recovery	477°F
100% Recovery	–
End Point	486°F
% Recovered	96.2
% Residue	1.8
% Loss	2.0

CALCULATION OF RADIANT TEMPERATURES

Radiant temperatures were calculated from the energy balance on the surface of flat black aluminum plates, diameter 50 mm (2 in).

Energy Balance:

$$(1) \qquad \alpha\sigma T_r^4 - \varepsilon\sigma T_p^4 - h(T_p - T_a) = 0$$

α = absorptivity

ε = emissivity

σ = Stefan-Boltzmann constant

T_r = radiant temperature of the surroundings

T_p = temperature of the plate

T_a = dry-bulb temperature of air

h = convective heat transfer coefficient on the plate surface

Radiant temperature can be solved from (1):

$$(2) \qquad T_r = \sqrt[4]{\frac{h(T_p - T_a) + \varepsilon\sigma T_p^4}{\varepsilon\sigma}}$$

T_a and T_p were measured, $\sigma = 5.67\ W/(100K)^4 m^2$, $\alpha = \varepsilon = 0.92$ (Reference 26)

h was calculated from the equations for free convection (26,27) (room air velocities were very low (0.0 m/s - 0.1 m/s) in all tests):

$$Nu = 0.59(Gr \cdot Pr)^{0.25} \qquad h = \frac{Nu \cdot k}{L}$$

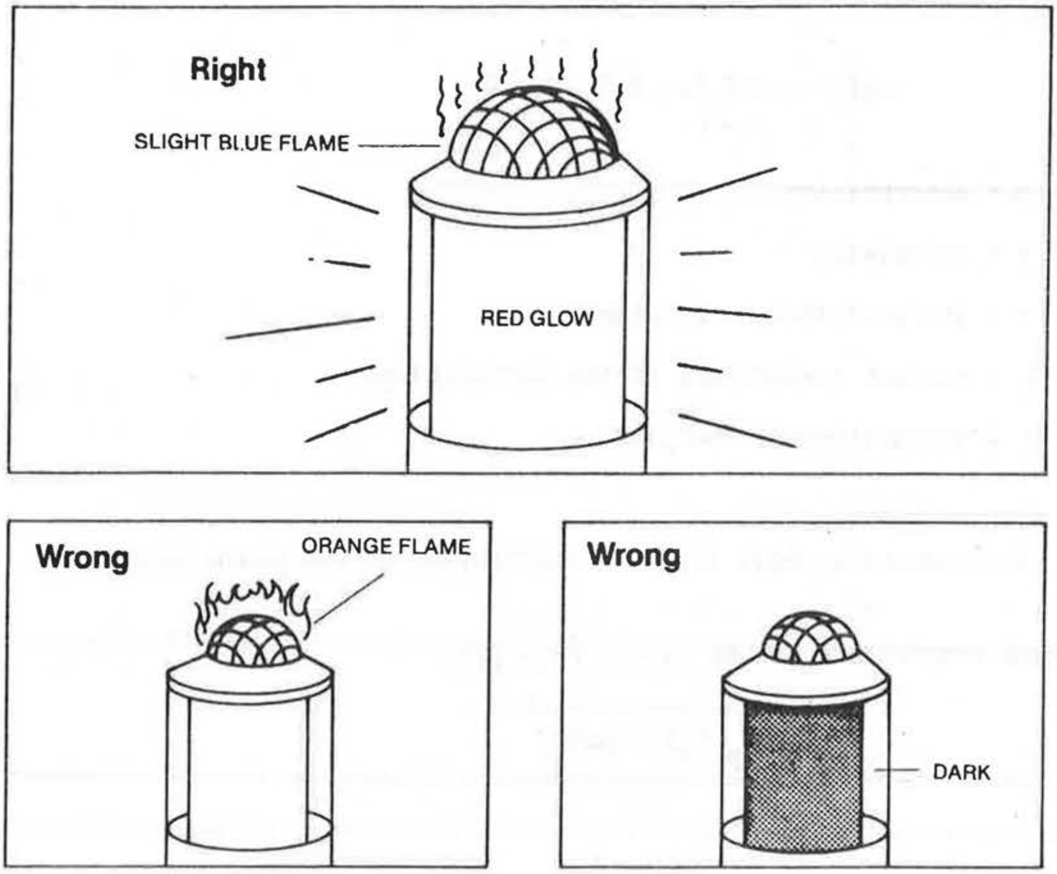
h varied from 4.1 W/m^2K to 4.8 W/m^2K. Average value 4.4 W/m^2K was used in the calculations.

Adjusting the Flame

(Reference 18)

1. Wait for the Heat Chamber to Reach Operating Temperature

Several minutes after lighting, heat will spread through the heat chamber. Then look for these signs of efficient operation:



WICK TOO HIGH

WICK TOO LOW

2. Signs of Correct Heating

About one minute after lighting, the flame should spread evenly around the entire heat chamber. In another two or three minutes the circular coil at the top will glow. After about five minutes, the entire chamber should be glowing red.

3. Wick Height Adjustment

If flames rise more than an inch above the top of the heat chamber, turn the flame regulator knob slightly counterclockwise.

The best wick setting causes the entire heat chamber to glow red, with a slight blue flame appearing at the top.

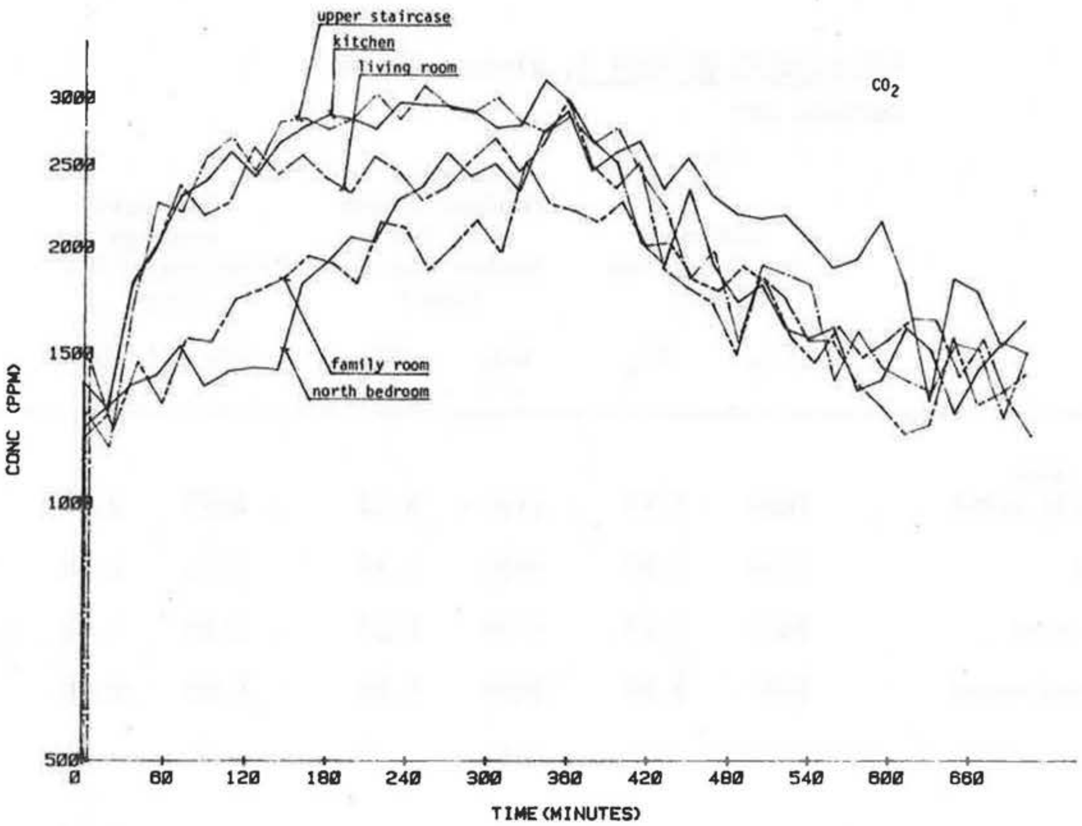
Raise or lower the wick to produce that ideal condition.

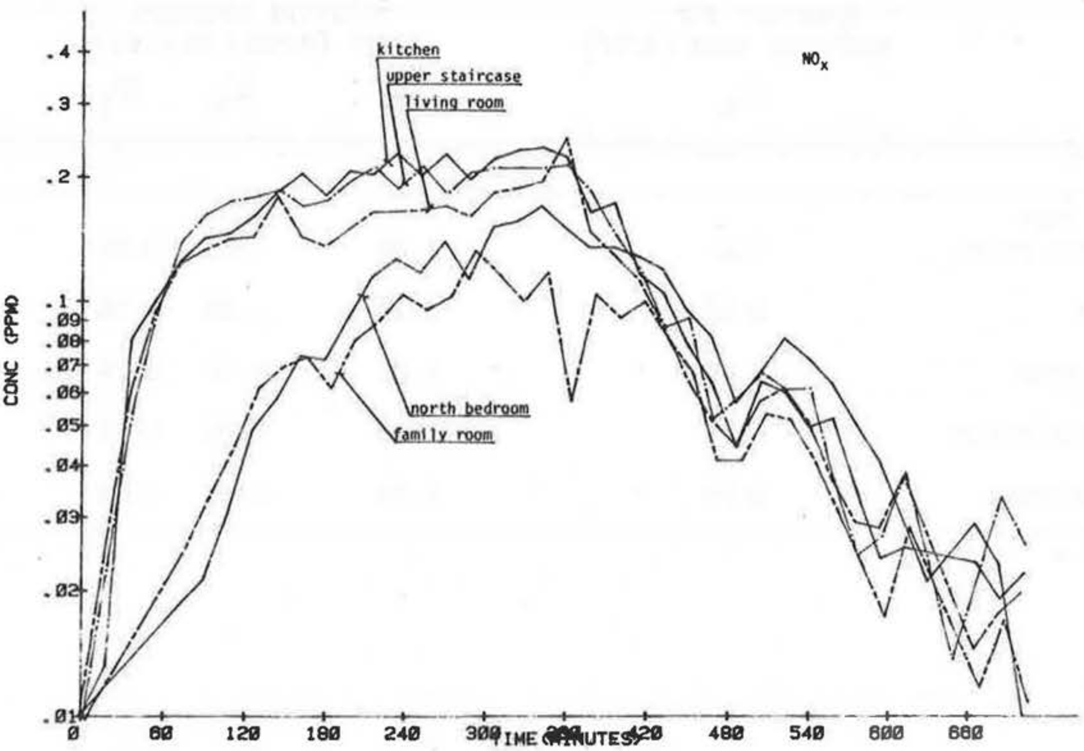
THE RESULTS OF TEST 3, Windows Closed

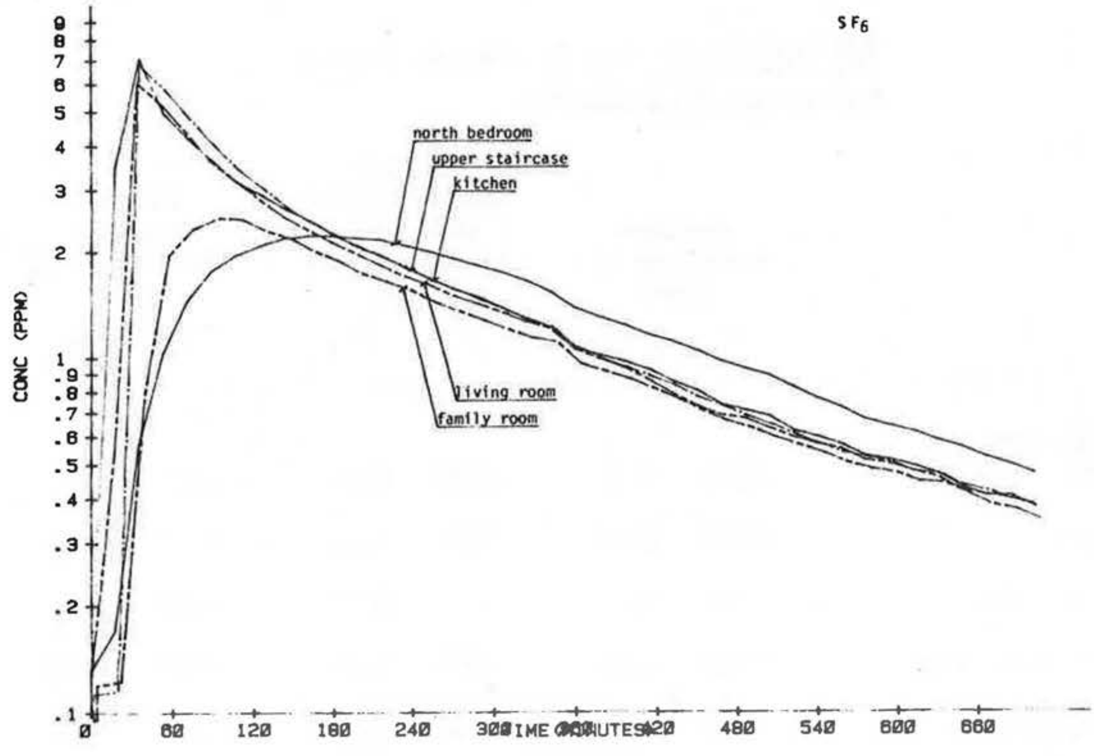
Furnace off

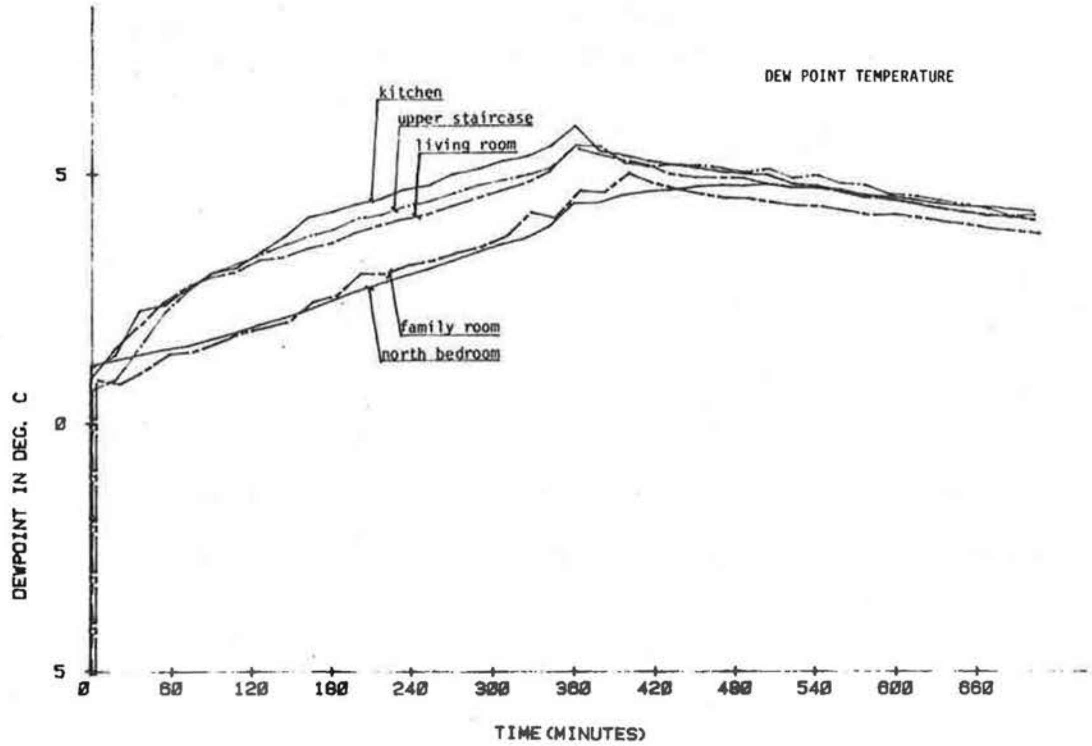
	maximum concentration [ppm]		average concentration when the heater was on [ppm]		24-hours average concentration [ppm]	
	CO_2	NO_x	CO_2	NO_x	CO_2	NO_x
living room reference point	2600	0.17	2190	0.13	1240	0.05
kitchen	2800	0.20	2450	0.16	1330	0.06
family room	2600	0.11	1790	0.07	1130	0.03
upper staircase	2800	0.20	2480	0.16	1340	0.06
north bedroom	2500	0.12	1830	0.07	1240	0.03

	apparent air exchange rate [1/hr]	relative exposure index [dimensionless]		
	SF_6	CO_2	NO_x	SF_6
living room reference point	0.22	1.00	1.00	1.00
kitchen	0.22	1.12	1.18	1.06
family room	0.22	0.86	0.56	0.74
upper staircase	0.22	1.13	1.15	1.07
north bedroom	0.19	1.00	0.72	0.85


upper staircase
kitchen
living room
CO_2
3000
2500
2000
1500
1000
500
CONC (PPM)
family room
north bedroom
0
60
120
180
240
300
360
420
480
540
600
660
TIME (MINUTES)


kitchen
upper staircase
living room
NO_x
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
CONC (PPM)
north bedroom
family room
0
60
120
180
240
480
540
600
660
TIME (MINUTES)

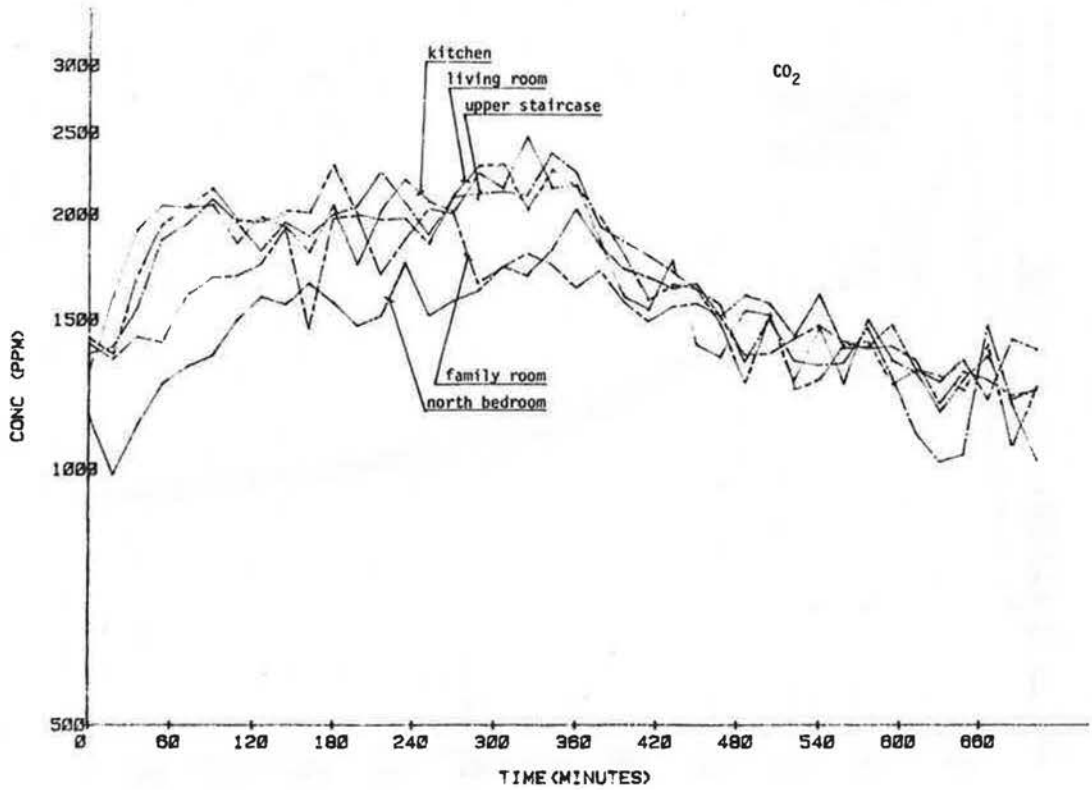

SF6
north bedroom
upper staircase
kitchen
living room
family room
CONC (PPM)
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
0
60
120
180
240
480
540
600
660

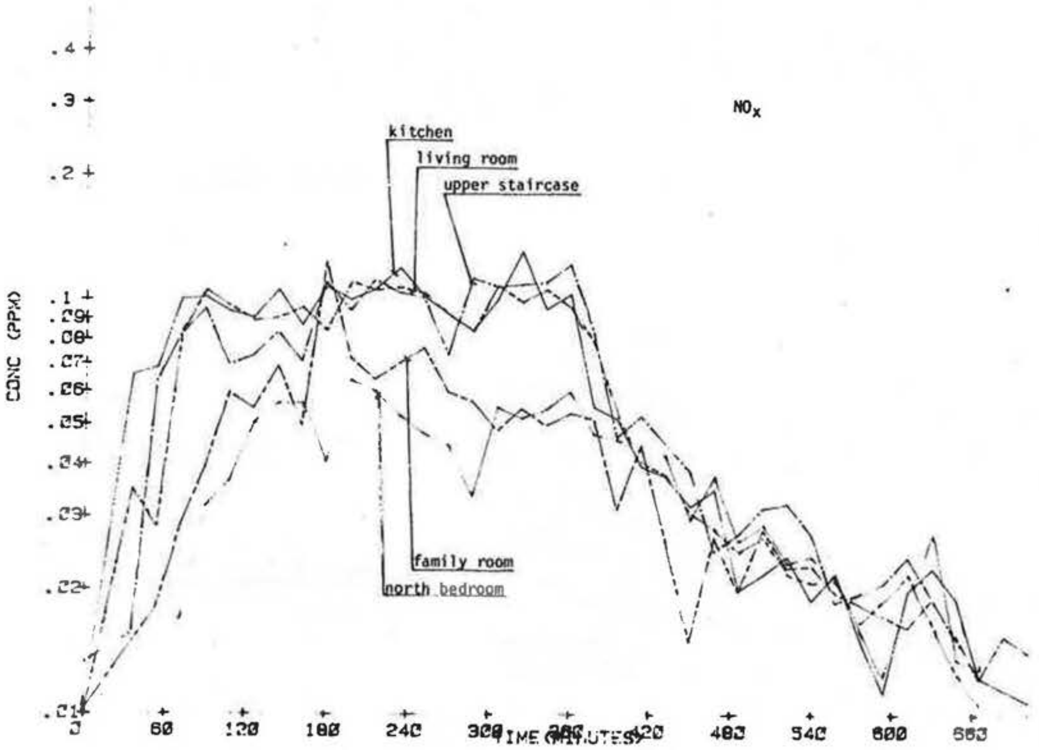

DEW POINT TEMPERATURE
kitchen
upper staircase
living room
family room
north bedroom
DEWPOINT IN DEG. C
5
0
5
0
60
120
180
240
300
360
420
480
540
600
660
TIME (MINUTES)

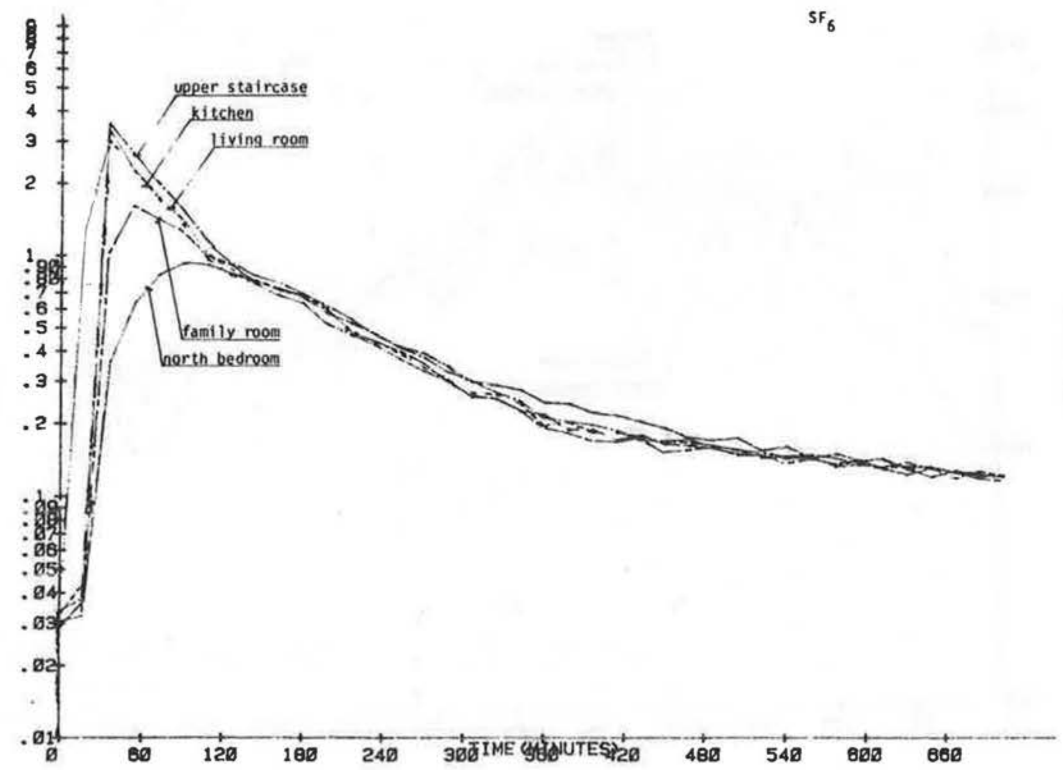
THE RESULTS OF TEST 3, Windows Closed
Furnace on Occasionally

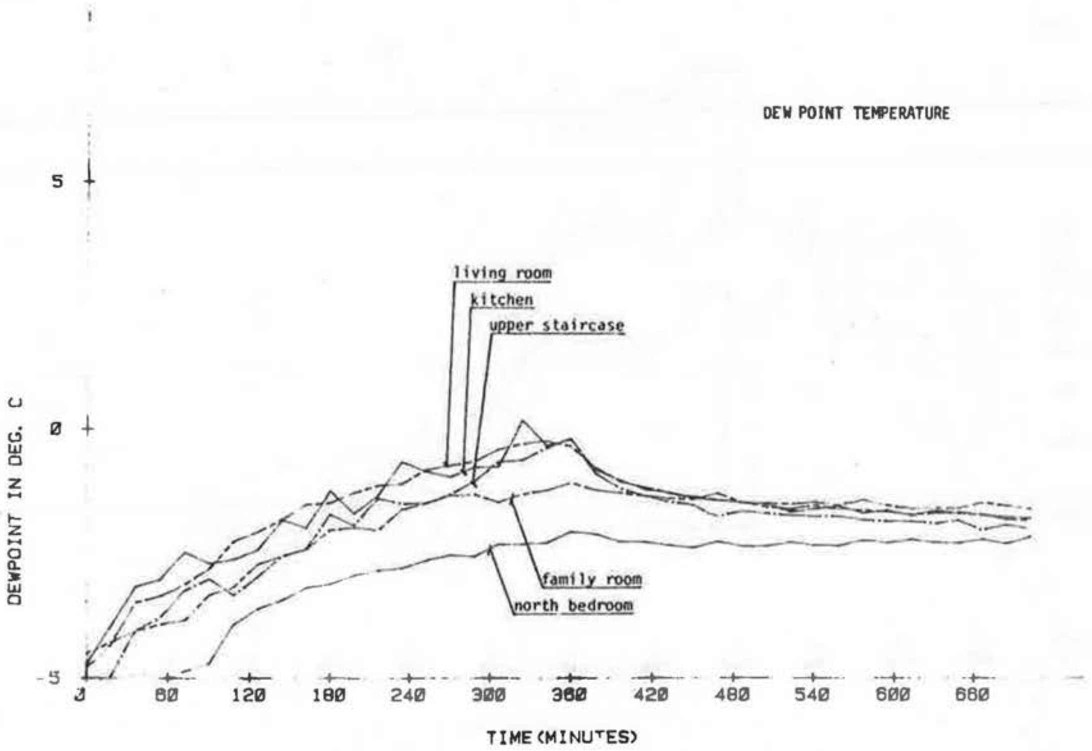
	maximum concentration [ppm]		average concentration when the heater was on [ppm]		24-hours average concentration [ppm]	
	CO_2	NO_x	CO_2	NO_x	CO_2	NO_x
living room reference point	2200	0.10	1930	0.08	1100	0.03
kitchen	2200	0.10	1930	0.08	1100	0.03
family room	1700	0.06	1610	0.05	1000	0.02
upper staircase	2200	0.10	1880	0.08	1090	0.03
north bedroom	1700	0.06	1450	0.04	1000	0.02

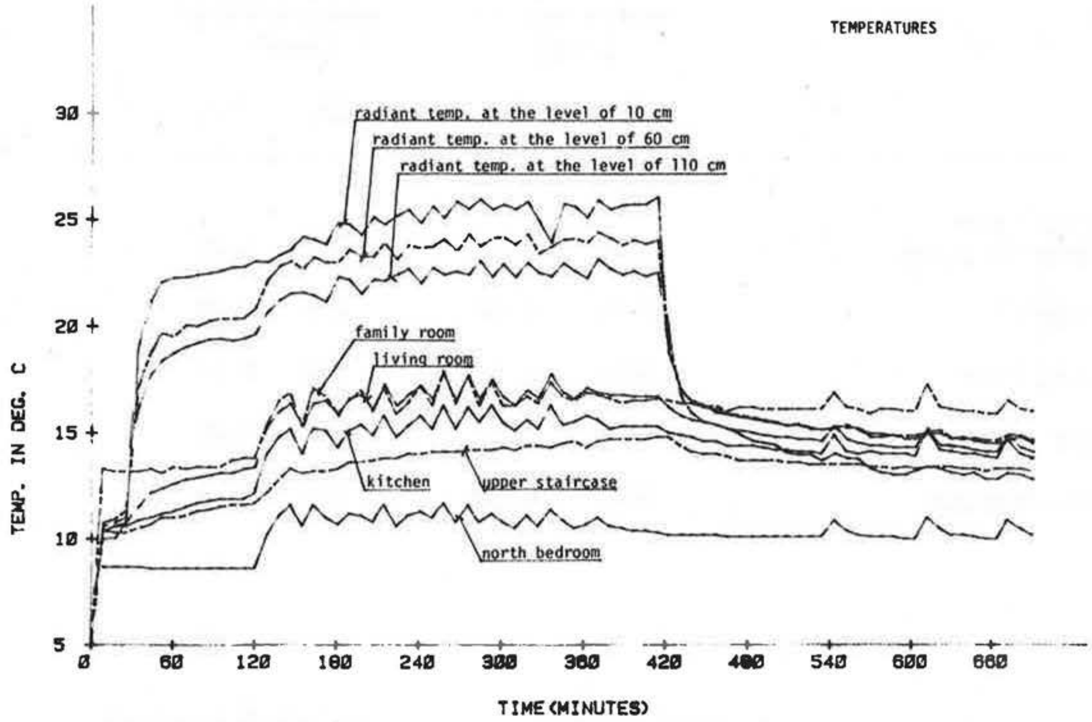
	apparent air exchange rate [1/hr]		relative exposure index [dimensionless]		
	SF_6 furnace on occasionally	SF_6 furnace off	CO_2	NO_x	SF_6
living room reference point	0.39	0.10	1.00	1.00	1.00
kitchen	0.40	0.12	1.00	1.04	1.05
family room	0.40	0.09	0.83	0.67	0.82
upper staircase	0.37	0.10	0.98	1.00	1.08
north bedroom	0.33	0.15	0.82	0.59	0.72


kitchen
living room
upper staircase
CO2
family room
north bedroom
CONC (PPM)
3000
2500
2000
1500
1000
500
0
60
120
180
240
300
360
420
480
540
600
660
TIME (MINUTES)


kitchen
living room
upper staircase
NOx
family room
north bedroom
CONC (PPM)
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
60
120
180
240
300
360
420
480
540
600
660
TIME (MINUTES)


SF6
upper staircase
kitchen
living room
family room
north bedroom
CONC (PPM)
TIME (MINUTES)
0
60
120
180
240
300
360
420
480
540
600
660

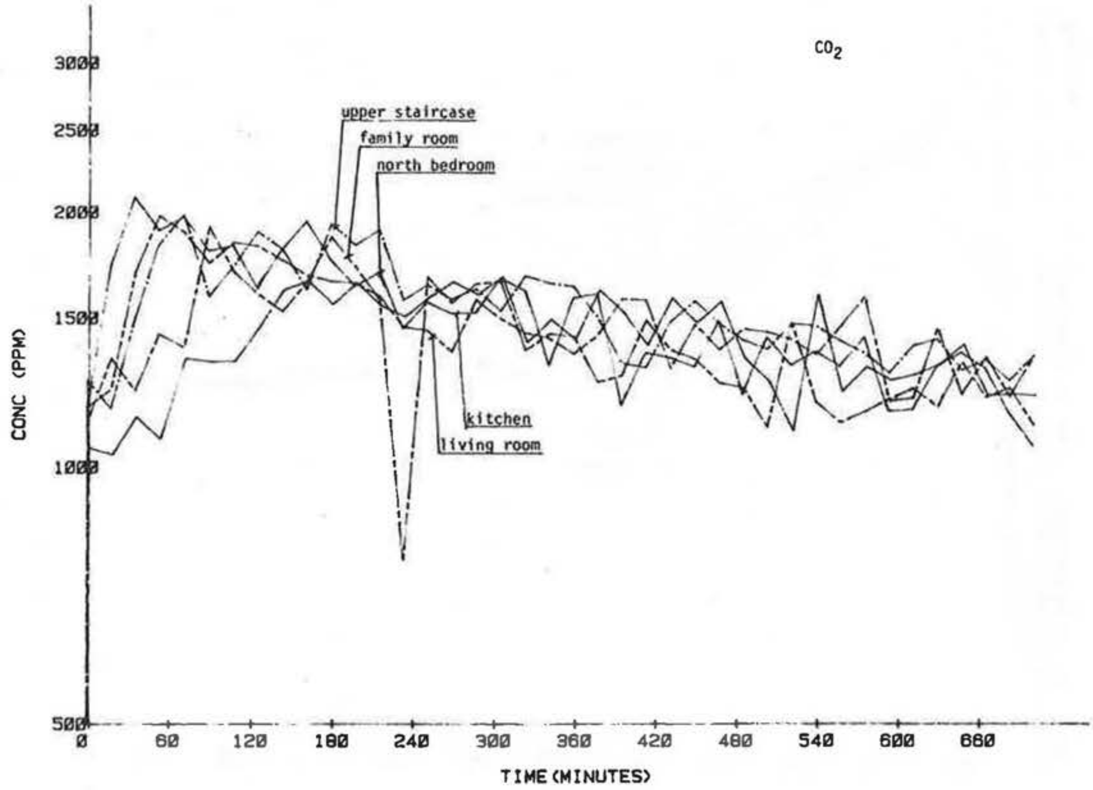

DEW POINT TEMPERATURE
living room
kitchen
upper staircase
family room
north bedroom
DEWPOINT IN DEG. C
5
0
-5
0
60
120
180
240
300
360
420
480
540
600
660
TIME (MINUTES)

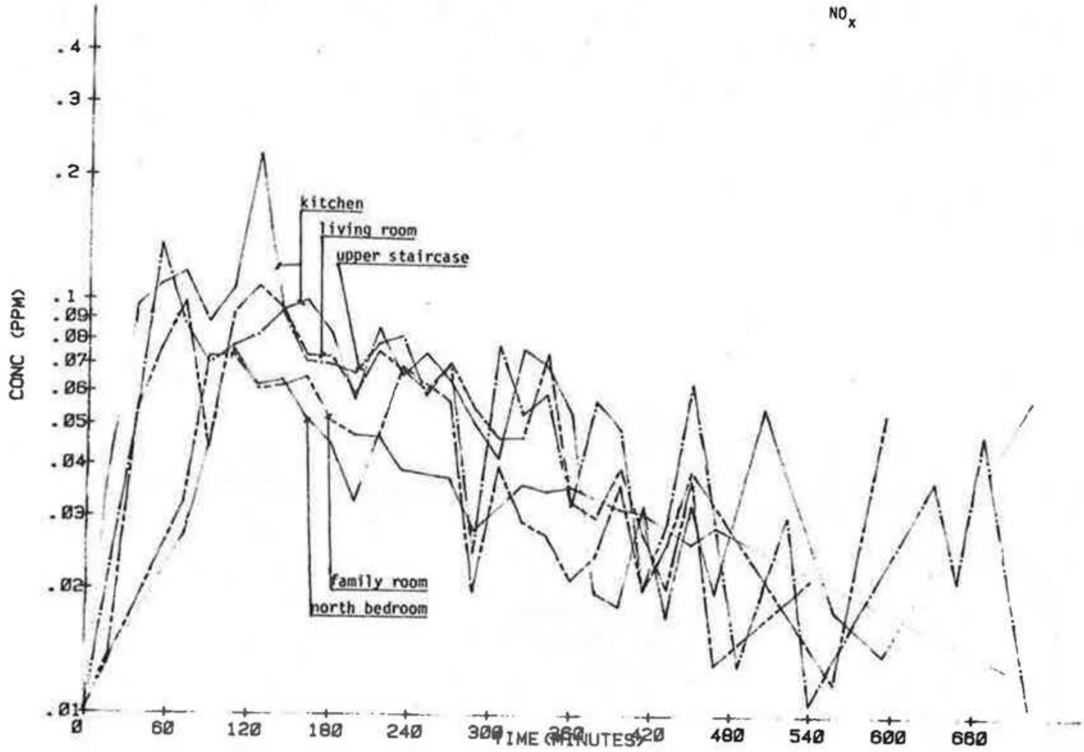

TEMPERATURES
radiant temp. at the level of 10 cm
radiant temp. at the level of 60 cm
radiant temp. at the level of 110 cm
family room
living room
kitchen
upper staircase
north bedroom
TEMP. IN DEG. C
30
25
20
15
10
5
0
60
120
180
240
300
360
420
480
540
600
660
TIME (MINUTES)

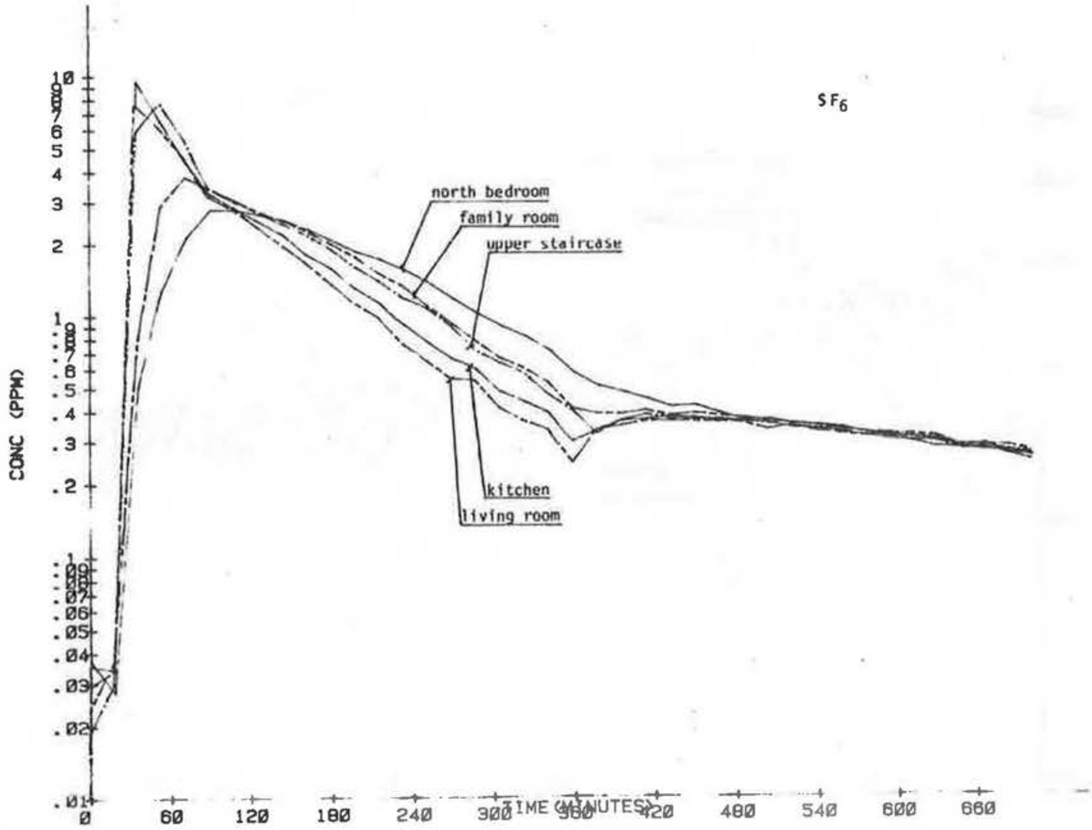
THE RESULTS OF TEST 4a, Window Opened

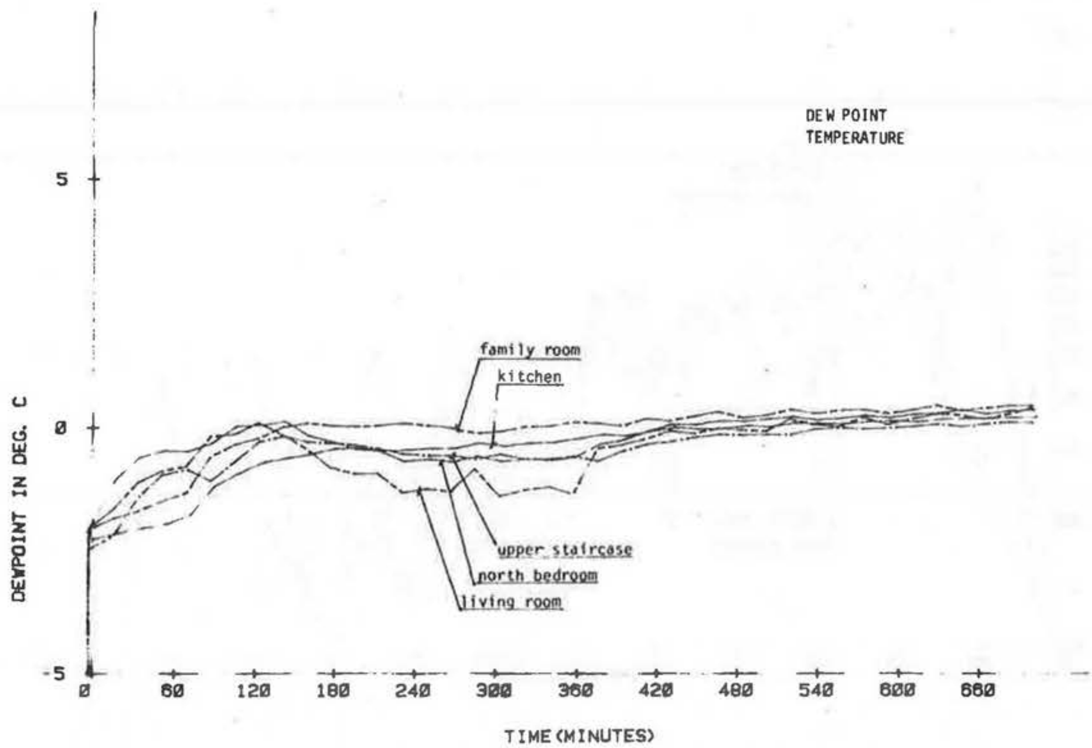
	average concentration when the heater was on [ppm]		24-hours average concentration [ppm]	
	CO_2	NO_x	CO_2	NO_x
living room reference point	1550	0.06	990	0.02
kitchen	1630	0.08	990	0.02
family room	1510	0.03	950	0.01
upper staircase	1600	0.06	1000	0.02
north bedroom	1400	0.03	940	0.01

	apparent air exchange rate [1/hr]		relative exposure index [dimensionless]		
	SF_6 window opened	SF_6 windows closed	CO_2	NO_x	SF_6
living room reference point	0.61	0.10	1.00	1.00	1.00
kitchen	0.54	0.10	1.01	1.01	1.02
family room	0.51	0.10	0.92	0.65	0.86
upper staircase	0.52	0.10	1.03	1.08	1.02
north bedroom	0.42	0.10	0.91	0.65	0.86


CO2
upper staircase
family room
north bedroom
kitchen
living room
CONC (PPM)
3000
2500
2000
1500
1000
500
0
60
120
180
240
300
360
420
480
540
600
660
TIME (MINUTES)


NOx
kitchen
living room
upper staircase
family room
north bedroom
CONC (PPM)
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
60
120
180
240
480
540
600
660


SF6
north bedroom
family room
upper staircase
kitchen
living room
CONC (PPM)
TIME (MINUTES)


DEW POINT
TEMPERATURE
family room
kitchen
upper staircase
north bedroom
living room
DEWPOINT IN DEG. C
TIME (MINUTES)