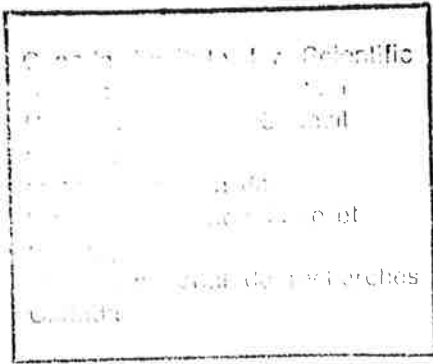


OCCUPATIONAL HEALTH AND SAFETY RESOURCE CENTRE

TESTS OF AIR QUALITY IN
THREE LONDON (ONTARIO) HOMES



THE UNIVERSITY OF
WESTERN ONTARIO



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ABSTRACT

This report describes an air quality study made in three homes in London, Ontario. The initial stimulus for the project was one home, where elevated formaldehyde concentrations had been measured for several months after urea-formaldehyde foam insulation (UFFI) had been removed from it. The owner of the home, identified as Home 1, had also complained about a continuing irritant in the air of the home. In both of the other two homes, included in the study, the occupants had voiced similar complaints, but the UFFI situation in each was different to Home 1. One of the two, (Home 2) had never contained UFFI, while the other, (Home 3) at the initiation of the project, had UFFI installed. Unfortunately, this was removed at the time testing actually started. However, it was retained in the study because it had not been assumed that the complaints were, necessarily, caused by formaldehyde.

For the study, tests were performed in the 3 homes for (1) carbon monoxide, (2) nitrogen dioxide, (3) nitric oxide, (4) total hydrocarbons and (5) formaldehyde. Total particulate matter, by a numerical counting method, was also measured in Homes 1 and 2.

None of constituents (1), (2), (3) and (4) were found in concentrations as high as standards accepted for outdoor air in the United States and Canada. Also, formaldehyde concentrations in Homes 2 and 3, were about the same or less than in many homes not containing UFFI and were well below recognized standards. Consequently, because high readings continued to occur in Home 1, the remainder of the project was devoted to it.

Throughout 1983, Home 1 had higher than expected formaldehyde concentrations, exceeding 0.3 parts per million in parts of the house during one period. After excluding other possible causes, it was found that the cause of the continuing formaldehyde was the presence of wood-ply panelling in the basement. To confirm this, a plastic chamber was placed over part of the basement wall and tests, taken from inside it, showed formaldehyde several times higher in concentration than the air of the house generally.

The basement, itself, initially, was not tested because UFFI had not been installed in it. When tests were done, there, they invariably showed the highest formaldehyde concentrations of the house.

Particulate levels, in Homes 1 and 2, were several times above outdoor concentrations nearby. These were attributed to household activities, smoking and cooking, but findings on this aspect were preliminary, only.

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AN INVESTIGATION OF AIR QUALITY IN THREE LONDON (ONTARIO) HOMES

INTRODUCTION

This project was initiated and proposed primarily because of vigorous complaints about health effects from the occupant of a home which had had urea-formaldehyde foam insulation (UFFI) removed. Prior to the removal of the foam, which had taken place in November 1982, elevated formaldehyde concentrations (above 0.1 ppm) had been reported by both the UFFI Centre (average 0.217 ppm) in August 1982, and the Ontario Ministry of Labour (average 0.13 ppm) in January 1982.

The Occupational Health and Safety Resource Centre (OHSRC) was first involved in December 1982, about a month after the foam had been removed. A test made at that time, by the NIOSH, P and Cam 125 method, by OHSRC, showed an average concentration of formaldehyde of 0.096 ppm. As far as could be ascertained, the tests done by the UFFI Centre and the Ontario Ministry of Labour had been done by the same method.

When the house was first visited by staff of OHSRC, the occupant complained of the existence of a choking odour and a persistent haze. It was intimated that fibre-glass insulation, installed when the UFFI was removed, was responsible. The three staff members, who went to the home, had varied responses to these statements. One person agreed that an irritant was present in the air but the others were uncertain. A haze was not readily discernible. Later, on other visits, when shafts of sunlight were present, a haze could be seen in them, but this occurs in many homes.

At the time the formaldehyde tests were performed, in December 1982 by OHSRC, it had been assumed that whatever was found was residual from the previously installed UFFI and that it would eventually dissipate. However, in the first two or three months of 1983, the householder continued to complain about the same problems. It was believed by OHSRC that these complaints could not be attributed to formaldehyde though, as eventually found, this assumption was not valid. However, it prompted the belief that the problem, if one existed, was the result of some other cause and, for this reason, the proposal submitted involved more than formaldehyde.

Coincidentally, in 1982, complaints had been received from another home-owner about irritating fumes. These were not attributable to formaldehyde as the home had never had UFFI installed and the indoor concentrations of formaldehyde were about the same as outdoors in the area (\bar{c} 0.02 ppm). Several occupants of homes containing UFFI had also complained about irritation and, therefore, the final proposal was based on three homes. These were the subject house, from which the foam had been removed, the one which had never contained UFFI, and another in which it was still installed and the owner had complained. In the third home, which still contained the foam, a test in September 1981, showed concentrations of formaldehyde ranging from 0.07 to 0.10 ppm.

Prior to making the proposal for this three-home study, the Occupational Health and Safety Resource Centre had not made more than a few residential air quality studies except for formaldehyde assessment in UFFI homes. Others, which had been done, included a few homes investigated for specific contaminants such as ozone and carbon monoxide. In addition, air quality tests had been conducted in several London office buildings. The Centre has sensitive equipment for measuring various gases in urban air where the concentrations are comparable to non-industry indoor air. As some of the equipment is automatic and continuous it is suited to real-time monitoring.

RESIDENTIAL AIR QUALITY

Background

Ventilation of many places of public congregation has been regulated to ensure adequate supplies of fresh air to protect public health and comfort. It was not suggested, until recently, that specific toxic substances need be considered except in workplaces such as industries, mines and similar. Air quality regulations have commonly applied to such locations but not to buildings such as homes, schools, offices, stores, places of entertainment and others.

When the question of indoor air pollution first arose, it was mainly considered in terms of potential ingress of urban air pollution for which standards (United States) and objectives (Canada) were developed. It was formerly believed that indoor air quality was not likely to be inferior to outdoors. Later, it was reported^[1] that higher levels than acceptable outdoor standards can occur in homes. To some degree, the comparative lack of regulatory interest in residential air quality was formerly influenced by attitudes based on concepts in the workplace where the levels of contaminants, which often occurred, were much higher. Therefore, until comparatively recently, even guidelines were not available for offices and homes.

Early examples of indoor air quality concerns, at least in offices, largely resulted from fears of respiratory disease cross-infection. This was stimulated by the increased use of air-conditioned sealed buildings. Complaints about respiratory infections in offices rarely received much attention and it was generally believed to be an inconsequential problem. However, the outbreak of respiratory disease, involving several deaths, from a specific organism in a Pennsylvania hotel in 1976 did much to change former attitudes.

The disease was quickly named Legionnaire's Disease, because of the occasion on which it occurred and was first thought to have been caused by some exotic agent. This belief soon changed, particularly when other outbreaks of the disease were reported^[2]. It is now known that the causative organism has been active for many years. The same organism and probably others are now considered potentially responsible for a recently recognized

syndrome described as "humidifier disease" or "humidifier fever"^[3]. This could be encountered in homes as well as offices.

Concern over air pollution by chemical or physical agents in offices and residences was almost non-existent a few years ago except for specific problems, such as ozone from photocopying machines in offices. Apart from such issues, there was little conception of a general problem nor real concern. This change towards current awareness was almost certainly stimulated by concerns which arose over specific contaminants such as asbestos and urea-formaldehyde foam insulation (UFFI). In the case of UFFI, this new concern was directed first towards formaldehyde but recently attention has moved to other potential contaminants. Another stimulus towards more serious attitudes to indoor air pollutants, both in homes and offices, has been reduced air infiltration in buildings accompanying greater energy conservation objectives.

Overview of Indoor Air Pollution

Numerous contaminants may occur in residences. They can include a few common ones and a much larger number that are rarely considered. Airborne substances can originate from the outgassing of installed materials, of which formaldehyde, from UFFI or bonded timber products, is an example. They may also be caused by the use of various types of equipment and materials. One published summary^[4] of the products used in homes, which may lead to air contamination, lists bleaches, floor polishes, and general purpose and glass cleaners. To this list may be added various personal products such as cosmetics, particularly when used in spray form.

Activities which may produce significant air contamination include cooking and the use of other kitchen equipment, drying clothes, especially in non-vented dryers, vacuum cleaning and various hobbies. Household pets and indoor plants and their care can also introduce other agents to the air. Few references are available which cover any more than the common air contaminants.

An extensive, and relatively recent review of indoor air pollution particularly applicable to residential circumstances, has been published by the United States National Research Council^[5]. The report treats many aspects of the problem and describes some sources and types of contaminants which occur in indoor air pollution. Some of the following sections of the present report are based on the U.S.N.R.C. publication, but it is not directly quoted.

INDIVIDUAL AIR CONTAMINANTS

Some types of contaminants occur frequently in outside air pollution and will then inevitably gain entry to buildings except, perhaps it may be reduced where air purification equipment is installed. Generally, air treatment is limited to particulate matter removal and gas treatment systems are very uncommon. Recommended standards for outdoor air supplied to buildings have been published by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)^[6]. Any contaminants resulting from indoor sources would be additive. Table 1 presents some of the more common air pollutants which may occur in outdoor and/or indoor air. A few of the many possible sources of the contaminants are also shown in Table 1.

Table 1Air Pollutants and Typical Sources

<u>Pollutant</u>	<u>Common Sources</u>
Sulphur oxides	Power plant and smelter stacks, negligible indoors;
Nitrogen oxides	Fuel burning, outside and inside;
Carbon monoxide	Automobiles, fuel heating, gas cooking equipment;
Ozone	Photochemical reactions (outdoors) photocopying machines and electronic air cleaners (indoors);
Carbon dioxide	Metabolic activity and fuel combustion;
Formaldehyde	Indoor significance, only, from insulation bonded boards, tobacco smoke, furnishings;
Acrolein	Cooking, combustion and tobacco smoking;
Radon	Indoor significance, only, from mineral based construction materials, ground water;
Other organics	Automobiles, oil refineries and industrial processes. Indoor sources - cooking, solvents, cleaners, etc.
Particles	Industrial processes, windblown dust, condensation of vapour and combustion;
Lead, manganese	Automobiles;
Asbestos, other fibres	Automobiles, building demolition (outdoors), insulation (indoors);
Pollens	Outdoor and indoor plants;
Spores	Fungi and moulds in dust, plant waste;
Bacteria	Human cross-infections, animals;
Allergens	House dust, animal dander;

Radon

According to the report by the United States National Research Council^[5], it is known that, in some geographic areas, large populations are being exposed to radon gas and radon progeny particles in their residences. Although the concentrations to which they're exposed are much lower than those in uranium mines, they are substantially higher than those in most residences. The report advocated a well-funded national survey of radon concentrations in residential buildings to estimate the exposure of the total population to radon and its progeny. Various other needs such as the development of inexpensive instruments to measure radon, studies of radon emanation, transport and transformation and strategies for abatement were also identified.

In a report by Cohen^[7], reviewing current information on present radon exposures, it was estimated that 10,000 fatal lung cancers per year would occur in the United States. It was also predicted that, with current views on energy conservation and the consequent additional insulation, the number of annual deaths would double.

Formaldehyde

In recent years, methods of measuring formaldehyde, including the development of simple and reliable dosimeters have reached an adequate state of development. However, monitoring formaldehyde still presents difficulties because of the influences of temperature, humidity and, sometimes, interfering substances.

Considerable knowledge exists on typical concentrations in homes. On the other hand, knowledge of the variables such as building construction, ventilation and the breakdown properties of foam is incomplete. The currently available information on the health effects of low level concentrations of formaldehyde is also uncertain and controversial.

Combustion Generated Contaminants

As listed in Table 1, combustion, of outdoor and indoor origins affects the quality of indoor air. Among the indoor sources of combustion which are probably significant are cooking, gas, oil or kerosene heating, tobacco smoking and wood fires. According to the U.S.N.R.C. report, previously cited, the combustion contaminants that deserve special attention are nitrogen dioxide, carbon monoxide, respirable particles, nitrosamines and polynuclear aromatic hydrocarbons. To these, could be added aldehydes, especially acrolein and formaldehyde and possibly organic acids, but there would be, no doubt, others still to consider.

It is relatively simple, at any given time, to measure general species of contaminants or single components. However, existing knowledge is scanty on individual members of species or on the temporal and other variations which occur in homes. Unfortunately, the acquisition of the necessary knowledge is hampered by inadequate information on rates of emission and chemical reaction data. Other problems are the present difficulties and time requirements needed to obtain the necessary information on air quality and the effects of contaminants.

Aeropathogens and Allergens

At present, little is known about the sources, concentrations and effects of biological organisms and allergens in the domestic environment. They occur generally and the extent of the potential problems are normally assessed in terms of concentrations existing in any specific situation. As indicated, earlier in this report, air humidifying and air-conditioning systems deserve special attention.

Limited sampling by OHSRC of the air in offices for biological organisms has, so far, revealed only low concentrations. In most cases, they have been classified of satisfactory air quality for hospital operating rooms.

Indoor Air Pollutant Effects and Standards

It is not practicable in this report to review fully the details of the known effects of all types of contaminants which occur in homes. Information is available in the literature but is not specifically useful for residential problems. On the other hand, on the basis of current medical knowledge, various standards have been introduced by which acceptable human exposures can be judged. These standards are normally based upon specific populations or groups and for general purposes can be regarded as bench marks. However, it is important to recognize that they are not hard and fast rules. They apply to the majority of people but exceptions occur because of special susceptibilities in some and because of differences in health status of others. The standards, which have been set in the past, by official government and non-official organizations, have varied with time according to changing knowledge.

The earliest standards were introduced to regulate exposure of employees in industrial plants and mining. These went through many stages of development but, now, most developed countries use tables of contaminant concentrations to regulate workplace exposures. Typical examples include the Designated Substances Regulations or exposure criteria tables under the Ontario Occupational Health and Safety Act and the Permissible Level Tables under the United States Occupational Safety and Health Act. Where official standards do not include certain contaminants or where authorities have not established exposure limits, a comprehensive table, published as threshold limit values (TLVs) by the American Conference of Governmental Industrial Hygienists, is widely used instead^[8].

At the time of major redevelopment, in the early 1970s, of legislation to control outdoor air pollution, the concept of air quality regulation for the atmosphere was introduced. Under the 1970 Clean Air Act, the United States Government introduced Air Quality Standards with legal standing. The following year, the Canadian Government adopted the same philosophic approach and introduced Air Quality Objectives with the same intent as standards but without the same legal connotation.

These approaches incorporated the relatively new principle of basing standards or recommendations on the needs of receptor populations. For many years prior to this, most standards were based on engineering practicability without reference to human receptors with no special consideration for those below normal health norms. Sometimes occupational health criteria were used but when the epidemiology of diseases in large populations exposed to air pollution was studied in more detail, it was clear that workplace standards were inappropriate. As a result, when ambient air quality standards, objectives or similar approaches were adopted for urban pollution they were based on concentrations much lower than the equivalent workplace limits.

The limits for outdoor air were designed to protect people in their homes. However, no legislation or regulatory attention has been specifically directed towards indoor generated pollution in homes or in many public occupancy buildings. These include educational institutions, offices, hospitals, stores and similar places. On an unofficial level, but one which is widely used in practice, the American Society for Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has recommended^[6] standards for acceptable outdoor air supply. For the purpose, ASHRAE adopted the U.S. National Ambient Air Quality Standards but, in addition, proposed a comprehensive list of other air quality standards for substances not in the official list. The list of U.S. and the additional ASHRAE ambient air quality standards are given in Tables 2 and 3. Levels recommended in Table 3 were selected, by ASHRAE, from current practice in various states in the U.S., provinces of Canada and other countries.

Acceptable outdoor air supply for ventilation purposes, according to ASHRAE, is air which does not exceed the concentrations laid down in the two tables. If the air is believed to contain any contaminants not listed in Tables 2 and 3, an approximate indication of acceptability can be obtained by adopting one-tenth of the standards used for occupational health purposes. This may not result in acceptable limits for some substances, and in such cases, individual judgement would be required. As an example, the acceptable workplace standard for hydrogen sulphide is 10 parts per million. A concentration of one-tenth of that would represent an intolerable

TABLE 2

NATIONAL AMBIENT AIR QUALITY STANDARDS

(Adopted by ASHRAE for Acceptable Ventilation Air.)

Contaminant	Long Term		Short Term	
	Level	Time	Level	Time
Carbon Monoxide			40mg/m ³	1 Hr
			10mg/m ³	8 Hrs
Lead	1.5µg/m ³	3 Mo		
Nitrogen Dioxide	100µg/m ³	Yr		
Oxidants (Ozone)			235µg/m ³	1 Hr
Particulates	75µg/m ³	Yr	260µg/m ³	24 Hrs
Sulfur Dioxide	80µg/m ³	Yr	365µg/m ³	24 Hrs

Note: Pertinent local regulations may be more restrictive than those given here, and additional substances may be regulated.

TABLE 3

ADDITIONAL AMBIENT AIR QUALITY GUIDELINES
FROM OTHER THAN U.S. NATIONAL STANDARDS*

(Adopted by ASHRAE for Acceptable Ventilation Air.)

Contaminant	Long Term		Short Term	
	Level	Time	Level	Time
Acetone-0**	7mg/m ³	24 Hrs	24mg/m ³	30 Min
Acrolein-0			25µg/m ³	C***
Ammonia-0	0.5mg/m ³	Yr	7mg/m ³	C
Beryllium	0.01µg/m ³	30 Days		
Cadmium	2.0µg/m ³	24 Hrs		
Calcium Oxide (Lime)			20-30µg/m ³	C
Carbon Disulfide-0	0.15mg/m ³	24 Hrs	0.45mg/m ³	30 Min
Chlorine-0	0.1mg/m ³	24 Hrs	0.3mg/m ³	30 Min
Chromium	1.5µg/m ³	24 Hrs		
Cresol-0	0.1mg/m ³	24 Hrs		
Dichloroethane-0	2.0mg/m ³	24 Hrs	6.0mg/m ³	30 Min
Ethyl Acetate-0	14mg/m ³	24 Hrs	42mg/m ³	30 Min
Formaldehyde-0			120µg/m ³	C
Hydrochloric Acid-0	0.4mg/m ³	24 Hrs	3mg/m ³	30 Min
Hydrogen Sulfide-0	40.50µg/m ³	24 Hrs	42µg/m ³	1 Hr
Mercaptans-0			20µg/m ³	1 Hr
Mercury	2µg/m ³	24 Hrs		
Methyl Alcohol-0	1.5mg/m ³	24 Hrs	4.5mg/m ³	30 Min
Methylene	20mg/m ³	Yr	150mg/m ³	30 Min
Chloride-0	50mg/m ³	24 Hrs		
Nickel	2µg/m ³	24 Hrs		
Nitrogen Monoxide	0.5mg/m ³	24 Hrs	1mg/m ³	30 Min
Phenol-0	0.1mg/m ³	24 Hrs		
Sulfates	4µg/m ³	Yr		
	12µg/m ³	24 Hrs		
Sulfuric Acid-0	50µg/m ³	Yr	200µg/m ³	30 Min
	100µg/m ³	24 Hrs		
Trichlorethylene-0	2mg/m ³	Yr	16mg/m ³	30 Min
	5mg/m ³	24 Hrs		
Vanadium	2µg/m ³	24 Hrs		
Zinc	50µg/m ³	Yr		
	100µg/m ³	24 Hrs		

* Unless otherwise specified, all air quality measurements should be corrected to standard conditions of 25°C (77°F) temperature and 760mm. (29.92 inches) of mercury pressure, (101.3 kPa).

** Those materials marked "0" have odors at concentrations sometimes found in outdoor air. The tabulated concentration levels do not necessarily result in odorless conditions.

*** Ceiling, or maximum allowable concentrations.

stench. Even at a level of one-hundredth or one-thousandth of the workplace standard, it would still be unacceptable for normal building occupancy. The same applies to other odourous compounds such as mercaptans. Therefore, any fixed dilution amount would be only a very approximate guide and new indoor air quality criteria necessitate knowledge of the contaminants concerned.

Where air is recirculated in a building, an air cleaning system of sufficient efficiency to provide an indoor air quality equivalent to outdoor air as specified in Tables 2 and 3 is recommended by ASHRAE. In homes, this would probably be impracticable as the cost of air cleaners for most contaminants would be beyond the resources of home owners. For nitrogen oxides and carbon monoxide, the removal technology is probably too sophisticated and expensive for most office building owners to install required equipment. Consequently, if excess contaminants were produced in a building, it would be necessary to have some marginal capacity of outdoor air supply to receive further impurities from indoors without exceeding indoor air quality to the recommended standards.

Ventilation and Carbon Dioxide

It is a popular misconception that poor ventilation in buildings can lead to sufficient oxygen depletion to cause breathing problems or even asphyxiation. Though it would no doubt be possible to construct a building where this could occur, it is inconceivable in the average house or office building. In occupied normal buildings, the change in oxygen concentration is invariably insignificant. However, any occupied area will show a measurable increase of carbon dioxide from human metabolism. The concentration of the gas can be used to calculate the fresh air supply in office and similar buildings by the following relationship:

$$Q = \frac{0.55}{(CO_2\%) - 0.03} \text{ litres/second/person}$$

where 0.55 represents the CO_2 production l/sec by one person
0.03 is the background percentage of carbon dioxide in the atmosphere.

According to occupational health standards, a concentration of carbon dioxide not exceeding 0.5 percent^[8] is acceptable but this would rarely, if ever, be approached in commercial or office buildings. In private homes such a level would be inconceivable unless some large unvented fuel consuming equipment were present. In the study of the 3 homes, reported here, carbon dioxide was not used to measure air supply although tracer gas measurements were used to determine the rate of air change.

SURVEY PROGRAM

General Design

As stated in the introduction to the report, this survey was partly prompted by complaints from an occupant of a home in London, Ontario which had contained UFFI but from which it had been subsequently removed. These complaints persisted for long after the foam had been removed. A test by the Occupational Health and Safety Resources Centre (OHSRC) had also shown elevated concentrations of formaldehyde after the removal.

In addition to the complaints made by the owner of the above home two other residents of London had asked OHSRC to investigate contaminants in their homes. One of the homes had never had UFFI installed in it but the owner-occupants considered that it contained contaminants which caused respiratory irritation and affected their health. The third home was one in which UFFI was still installed when the owner told OHSRC that he and his family were suffering health effects. They attributed these to the UFFI.

Unfortunately, after the proposal had been accepted by NRC but just before the series of tests started, the owner of the home containing the UFFI decided to have it removed. However, because OHSRC already had test data for the home, it was decided to retain it in the survey. At a later stage, the owner lost interest in the project and declined to

co-operate further. Consequently, the results for that home were incomplete.

For identification purposes the three homes in the survey were given numbers, as follows:

Home 1 : This was the home which had contained UFFI which, though it had been removed, continued to contain significant formaldehyde.

Home 2 : This home has never contained UFFI but the owner complained of irritants and health effects;

Home 3 : This home contained UFFI at the time of the proposal and the owner complained of health effects. The foam was removed shortly before testing could begin.

The survey started with initial measurements, at each home, of carbon monoxide, nitrogen dioxide, nitric oxide, total hydrocarbons, ozone and formaldehyde. To conduct these tests, three days or more at each home was required. The particulate measurements were conducted later and, because of the withdrawal of the Home 3 owner, only included two homes. Also, an evaluation of the air change by the use of a tracer gas was made, only, in these two homes. The methods by which all tests were made are described in the next section.

Soon after the survey was initiated, the occupant of Home No. 1 began to complain bitterly that the irritation and respiratory effects were as severe as ever. As the result of this and some publicity about the home following a public meeting in London, arranged by the UFFI Centre, an air to air heat exchanger was installed by a local supplier on a no-cost basis. As a result, about 12 sets of further tests were done. This large number included tests before and after the heat exchanger was installed. Because of some unusually high readings, measured after the heat exchanger was installed, additional tests were made to try and explain what had taken place. Details of these tests are given in the results section. Other

tests were done in an attempt to identify the cause of the continuing high concentrations of formaldehyde in Home No. 1. These included measurements of formaldehyde concentrations in the wall cavities and a number of tests to assess rates of emission from various surfaces such as carpets and walls. For this purpose, a plexiglass chamber was constructed and placed over each surface at the time it was tested. Air was sampled from the chamber.

More extensive tests for other constituents were also made in Home 1. For example, on the occasion that the series of tests for CO, NO₂, NO, O₃ and hydrocarbons were made, it was found that the hydrocarbons were unusually high. Consequently, hydrocarbons were repeated twice and charcoal tube samples were collected for more detailed analysis. These were subjected to gas chromatographic and combined gas chromatography - mass spectroscopy (GC-MS) analysis.

ANALYTICAL METHODS

With the exception of formaldehyde other air measurements were made mainly by recording instruments. These were of the type used for urban air pollution and had sensitivities of about 10 parts per billion or less. The methods used are described individually in the following sections.

Formaldehyde

Air samples were collected and analyzed by the NIOSH chromotropic acid method at approximately 4 locations in each house. The usual assembly consisting of a pump, adjusted to operate at 1 litre per minute, connected to an all glass impinger, containing one percent sodium bisulphate, was used. Collection times were 3 to 3½ hours. After return to the laboratory, the samples were subjected to the standard NIOSH chromotropic analytical procedure. For the wall cavity tests, collected in Home No. 1, Draeger detector tubes were used.

Carbon Monoxide

For carbon monoxide (CO) measurements in room air, Draeger detector tubes were used. A Beckman non-dispersive infrared (NDIR) Model 215A continuous analysis was also used but the levels present were all lower than the detection level of both the infrared instrument and the detector tubes. If appreciable concentrations had been present, the NDIR would have been useful because it was capable of continuous recording. The NDIR analyzer consisted of a fixed-wavelength infrared spectrophotometer, mounted with the source and detector at opposite ends of a gas chamber, through which the air being sampled was continuously drawn by a pump. An attached chart recorder would have provided a continuous reading had CO been present. The instrument is very useful for detecting and analyzing changing concentrations. Normally, it will respond to concentrations of about 3-5 ppm and higher. Other, more sensitive, chemical methods for carbon monoxide are available but as the detection limit for the Draeger tube, using multiple passes (16) through the tube, is 2 ppm or less, it was not considered necessary to use other alternatives.

Nitrogen Oxides

Nitric oxide and nitrogen dioxide were analyzed by chemiluminescence by a Thermo Electron Corporation, Model 14 B/E, analyzer. The principle of the method depends upon the emission of photons emitted by excited molecules of nitrogen dioxide (NO_2) which are produced when nitric oxide (NO) is oxidized by ozone (O_3). In the operation of the instrument, air which may contain both NO_2 and NO is drawn into a chamber where it is mixed with ozone. Ozone (O_3) is produced electronically by the instrument.

On contact with the O_3 , any NO is converted to NO_2 (excited state). The mixture takes place in a reaction chamber which also contains a light sensor, connected to a photomultiplier for measurement of light emission. If NO_2 is present in the air being sampled, it exists in the ground state and therefore does not emit photons. Thus, in the appropriate mode, the reading indicates nitrogen monoxide only.

Sequentially, the instrument changes to the NO_2 mode. In this case, NO_2 is electrically reduced to NO . The resultant gas stream, containing NO from the reduction of NO_2 as well as the NO present in the air, then passes to the O_3 gas reactor chamber and light photons are again measured. This gives the total nitrogen oxides in the sampled air and the NO_2 can be calculated by difference. In practice, the recorder of the instrument provides a reading of nitrogen monoxide, total nitrogen oxides and nitrogen dioxide in sequence. The results were continuously recorded. The limit of sensitivity of the instrument is about one part per billion and it is suitable for continuous operation.

Total Hydrocarbons

Total hydrocarbons were analyzed by a Beckman Total Hydrocarbon analyzer, Model 109A. In this instrument, air is drawn in by an inbuilt pump and is then analyzed by a flame ionization detector. All hydrocarbons present in the air are detected simultaneously and therefore the result of the analysis is not specific for any particular hydrocarbon. Actually, the instrument measures total organics rather than hydrocarbons, and it is not possible to differentiate species or individual compounds. The instrument will respond to concentrations of hydrocarbons at about 10 parts per billion although it would be probably impossible to find air so free of hydrocarbons. In cities, huge amounts still escape from automobiles and even in remote areas or over the ocean, large quantities are produced by natural decay.

Ozone

This gas was measured by a Bendix Model 8002 ozone analyzer which is also based on chemiluminesce. This is the present definitive air pollution measurement method for ozone and the instrument has a sensitivity of one part per billion. The light emission occurs from excited molecules of ethylene gas, which is simultaneously introduced from a cylinder, while air is being sampled. Photons occur in proportion to the excited ethylene molecules produced and are proportional to the ozone in the sampled air.

This instrument is equipped with a recorder for continuous monitoring.

Particulates

The only home, in which visible pollution was complained of, was No. 1 where complaints about haze in addition to irritating odours had been made. A haze was not readily apparent to the investigative groups, but some members of the team believed they could see a suggestion of it on occasions. Cigarette smoking, which took place, could have been responsible for any haze.

The method for measuring air-borne particles employed a Bausch and Lomb Aerosol Counter, Model 40-1. In this instrument, air in the home samples was drawn through a chamber containing a light source and photometer which measured particle concentrations by light scattering. It is designed so that several particle size ranges from a median of 0.3 micrometres to 10 micrometres can be differentiated. The instrument is automatic, continuous and equipped with a print-out attachment which makes it very convenient to use. Its output is numerical and the results are expressed in particles per cubic foot. These have been converted to metric for this report.

It is important to recognize that particle mounting instruments are designed on many different principles. One instrument may give very different results to another, and often there is only approximate consistency between methods. This is caused by idiosyncrasies between instruments rather than operators. The light photometer, used in this survey, prints out a result and there is no room for operator misinterpretation. On the other hand, other light beam scattering instruments would be likely to give differing results, although each one might be adequately consistent in itself.

Some methods of evaluation include manual particle sampling followed by counting by an operator with the aid of optical or electron microscopy. Sampling methods based on many principles such as filtration, impingement in liquids, impaction on solid surfaces, electrostatic

precipitation, thermal precipitation, sedimentation in closed cells and others have been used. In most cases, operators using any single method will obtain reasonably consistent particle counts ($\pm 10-20\%$) but attempts to obtain precise consistency between different methods are usually unsuccessful.

One main disadvantage of the photometric method is that no information, other than size, can be obtained about the particles. In order to characterize particles, it is necessary to collect samples for examination by microscope or physical or chemical analysis. It was not possible to include these in the present study although work is currently in progress to develop techniques. Some samples collected in Home 1, by filtration through cellulose ester filters, were examined by optical microscopy but very little information on the particles seen could be obtained. The techniques required are time-consuming and useful work could not be accomplished within the scope of the project.

RESULTS

The tests, reported here, were done under normal home occupation conditions. That is, the householders were not asked to make any changes in ventilation or normal domestic operations. They were not asked to refrain from smoking or from cooking while the tests were in progress. The reason for this was that, as stated in an earlier section, indoor air quality is influenced by activities as well as materials of construction. As shown later in this section, results for hydrocarbons, particularly, varied widely when cooking operations were in progress.

Materials of construction and age were somewhat different for the three homes. Home No. 1 was timber frame and covered on the outside with vinyl siding, installed when the UFFI was removed in 1982. The home is at least thirty years old although a new section was added a few years ago. Both of the other two homes are brick. Floor plans and photographs of the homes are shown in Figures 3 to 8 after the results section.

Carbon Monoxide and Hydrocarbons

Table 4 gives the readings obtained in the three houses for carbon monoxide and hydrocarbons. The tests for carbon monoxide produced no readings on the non-dispersive infrared spectrophotometer (NDIR) nor with the detector tubes in Homes 2 and 3. In Home No. 1, the infrared analyzer did not show a reading but a slight change in colouration at the 2 ppm level occurred on the detector tube. As stated previously, the limit of detection for the infrared instrument is about 5 ppm. For the Draeger tube test, at least 16 pump strokes were used, routinely, which provided a lower detection limit of about 1-2 ppm.

All three homes showed appreciable levels of total hydrocarbons but, as the instrument used was non-specific, it could more accurately be described as a volatile organics analyzer. In an attempt to determine the constituents actually present, charcoal tube samples were also collected. However, beyond determining that multiple components were present, no compounds could be identified. Further analyses were also attempted by combined mass spectroscopy - gas chromatography but the amounts were too small to be analyzed. Unfortunately the charcoal tube samples were collected during the May 3 series when the hydrocarbon concentrations were much lower than during the March 25 tests. However, the hydrocarbons present in the home may have been too low in molecular weight to be collected by activated carbon.

During the tests in Home No. 3 on April 22, the hydrocarbon concentration remained at a reasonably uniform level of about 8.6 ppm shown in the Table 4, until the occupant started cooking a spaghetti dish on the top of an electric stove. Almost immediately, the concentration increased rapidly to around the 20.8 ppm level also shown on Table 4. Transient peaks were higher including one over 95 ppm when the mixture started to burn slightly. The reading of 120 ppm in Home No. 1 was also measured when cooking was in progress. In that case, both the top of the stove and the oven of an electric stove were in use. A gas heating furnace was also in operation at the time.

TABLE 4

CONCENTRATIONS OF CARBON MONOXIDE AND HYDROCARBONS IN THE 3 HOMES (1983).

	Carbon Monoxide*	Total Hydrocarbons		
	PPM - CO	PPM (as CH ₄)		
Home No. 1	March 25	March 25	May 3	October 25
Living Room	~2	35.0-120.0	3.0-3.6	-
Dining Room	~2	-	3.0-3.4	-
Bedroom	~2	24.0	1.8	-
Kitchen	-	25.0	1.6	-
Basement	-	-	-	1.9-8.4
Outside	<2	<0.5	<0.5	<0.5
Home No. 2	March 28	March 28		
Living Room	<2	2.6-7.6		
Dining Room	<2	1.6-9.6		
Bedroom	<2	4.0-7.5		
Basement	<2	-		
Outside	<2	<0.5		
	<			
Home No. 3	April 22	April 22		
Living Room	<2	8.6-20.8		
Dining Room	<2	8.6-20.8		
Bedroom	<2	-		
Outside	<2	<0.5		

*All tests for carbon monoxide given above were done by Gastec extra low range 1LL detector tubes. None of the concentrations found could be measured by the Non-Dispersive Infrared Detector.

There are no published standards for unspecified hydrocarbons, although workplace threshold limit values (TLV) have been recommended, by the American Conference of Governmental Industrial Hygienists (ACGIH), for individual compounds. No hydrocarbon standards or objectives exist for urban air nor in the additional guidelines published by the American Society of Heating, Refrigeration and Air-Conditioning Engineers. For the workplace, some hydrocarbons such as methane, acetylene, propane, etc. are only significant as simple asphyxiants or possible explosion potential. Such concentrations rarely occur except in confined spaces. Others have more specific toxic properties. Hexane, which has been reported as a neurotoxic agent is one example. The TLV recommended for hexane by ACGIH is 50 ppm. The range of other organics to which the hydrocarbon analyzer could respond is virtually limitless and to analyze them would require more exhaustive sample collection and chromatographic analysis.

Ozone and Nitrogen Oxides

The results for ozone and nitrogen oxides are shown in Table 5. Ozone is not a likely contaminant in a private home except in the presence of a specific source such as an electronic air cleaner. In some urban areas, relatively high concentrations of the gas occur as the result of photochemical reactions, induced by sunlight, between hydrocarbons and nitrogen oxides. The air quality standard, for one hour, adopted in the United States is $235 \mu\text{g}/\text{m}^3$ (0.12 ppm) and the tolerable ambient air quality objective, No. 3, (amendment 26 October, 1978) for Canada is 160 to $300 \mu\text{g}/\text{m}^3$ (0.08-0.15 ppm). Also, in Canada, the acceptable objective for ozone on a 24 hour basis, is 0.025 ppm while a desirable limit is 0.015 ppm. These are likely to be exceeded frequently in any city area, and in locations near the United States, for most of the warmer months.

The highest ozone reading obtained in the survey was 0.015 ppm in Home No. 1. This is equivalent to the Canadian desirable objective. The outdoor concentrations in Ontario, at monitoring stations range up to values of 0.14 ppm, in Toronto and 0.11 ppm, in London^[9]. Natural background has been reported as 0.01-0.04 ppm^[10].

The nitrogen dioxide (NO_2) values, shown in Table 5, were also very low when compared to the U.S. ambient air quality standard (used by

ASHRAE) of 0.1 mg/m^3 , (0.05 ppm) on an annual average. This same value is also the current acceptable ambient air quality objective, for NO_2 , in Canada, although, there is also a desirable objective, in Canada, of 0.06 mg/m^3 (0.03 ppm).

There are no national air quality standards or objectives for nitric oxide(NO) in the U.S. or Canada but the additional ASHRAE list recommends 0.5 mg/m^3 (0.4 ppm). Compared to this recommendation, as a limit for air supply, the values obtained in all three homes in the survey were insignificant.

Formaldehyde

The initial stimulus for this 3 house study arose from complaints relating to House 1 about the continuing presence of an irritating odour and haze after the UFFI was removed from the walls. In fact, the occupant has frequently stated that the problem either was no better or even became noticeably worse, after the foam was removed. The other two homes were added to the survey because the owners had complained about symptoms attributed to air pollutants. The background concerning these two homes has been described earlier in the report.

A summary of all of the tests done in the three homes, in terms of the means, maxima and minima, is given in Table 6. It is evident from the table that Homes 2 and 3 were within the limits normally experienced in non-UFFI homes. Home 2 had never had foam installed and it had been removed from Home 3. The owner was satisfied that a marked improvement had resulted. On the other hand, despite the removal of the UFFI, about 6 months before the survey started, tests in Home 1 continued to show high concentrations of formaldehyde. These are discussed, in more detail, later in this section.

There are no national ambient air quality standards or objectives for formaldehyde, but the additional ambient air quality guide-lines listed by ASHRAE [6] give a ceiling limit of 0.12 mg/m^3 (0.1 ppm). No justification

TABLE 6

RESULTS OF FORMALDEHYDE TESTS FOR THE 3 HOMES

<u>Locations</u>	<u>Home 1</u>	<u>Home 2</u>	<u>Home 3</u>
Living Room			
Average Formaldehyde Concentration(ppm)	0.15	0.031	0.040
Number of Tests	13	2	1
Highest Value (ppm)	0.290	0.045	-
Lowest Value (ppm)	0.045	0.016	-
Dining Room			
Average Formaldehyde Concentration(ppm)	0.088	0.028	<0.003
Number of Tests	2	2	1
Highest Value (ppm)	0.130	0.046	-
Lowest Value (ppm)	0.046	0.009	-
Master Bedroom			
Average Formaldehyde Concentration(ppm)	0.170	0.027	0.044
Number of Tests	12	2	1
Highest Value (ppm)	0.230	0.040	-
Lowest Value (ppm)	0.064	0.014	-
Other Bedroom			
Average Formaldehyde Concentration(ppm)	0.150	0.022	-
Number of Tests	10	2	-
Highest Value (ppm)	0.280	0.022	-
Lowest Value (ppm)	0.060	<0.003	-
Family Room			
Average Formaldehyde Concentration(ppm)	-	0.009	-
Number of Tests	-	1	-
Highest Value (ppm)	-	-	-
Lowest Value (ppm)	-	-	-
Basement			
Average Formaldehyde Concentration	0.230	-	-
Number of Tests	12	-	-
Highest Value (ppm)	0.380	-	-
Lowest Value (ppm)	0.120	-	-

Dates of Testing:

Home 1 - Mar. 25, June 3, 13 & 22, July 13, 14, 15, 18, 21, 25 & 29
 Aug. 5 & 8, and Oct. 25, 1983

Home 2 - Mar. 28 and May 9, 1983

Home 3 - Apr. 22, 1983

for offering this figure was given by ASHRAE except that it had been taken from the recommendations of other jurisdictions. Presumptively, ASHRAE offers it as a satisfactory standard for formaldehyde. The Canadian Department of Health and Welfare also suggested the same value as a tentative standard for homes containing UFFI.

Both Home 2 and Home 3 had concentrations of formaldehyde typical of homes tested by OHSRC that never had UFFI installed or where there was no other source of the gas. As a general guide, most homes not containing UFFI or another source of the gas, such as urea-formaldehyde bonded wood product, would not be expected to contain more than 0.05 ppm formaldehyde.

Those homes which do contain wood paneling and particle and chip boards, in large amounts, often have relatively high formaldehyde concentrations. These can be comparable to UFFI homes. One house tested by OHSRC (not one of those in the 3-home study) containing no UFFI but considerable shelving made of particle board, had a formaldehyde in air concentration of 0.2 ppm. Other homes also had elevated concentrations above 0.1 ppm. In one new home, a formaldehyde concentration of 7 ppm was found inside a kitchen cabinet, constructed of particle board.

The results shown in Table 6 were unremarkable except for those found for Home 1. Because of this, as well as the lack of interest of the owner of Home 3, tests for formaldehyde in Homes 2 and 3 were discontinued in May and were only done in Home 1 for the rest of the period. Because of the unusual conditions and some subsequent changes which were made in Home 1, the survey was later extended and continued for longer than originally intended.

One change which was made, in Home 1, was the installation of an air/air heat exchanger, which was connected to the furnace distribution system. At the time of this installation, summer, 1983, the fan was operated to enable the additional outside air to be distributed to the upstairs rooms. The amount of additional outside air, introduced, and indoor air, extracted, by the new system was about 80 cubic feet per

minute (cfm), when measured by OHSRC, though it was said to be rated at 130 cfm. This unit was installed without charge by Enerco Energy Systems of Exeter, Ontario, following a discussion between the home owner and the proprietor of the Company. They met at a public meeting in London organized and held by the UFFI Centre, Department of Corporate and Consumer Affairs, Ottawa, Canada. The installation of the air exchanger had no connection with this project though it did stimulate a reason for further study.

The period between the start of the 1983 survey in March and the following October indicated a marked seasonal difference in formaldehyde concentrations. In the period from March to early June, 1983, the formaldehyde concentrations increased from approximately 0.05 ppm to 0.13 ppm. Although it had been planned originally to complete the three-home study by April, 1983, it was decided to extend the project to October, 1983, so that additional information on formaldehyde concentrations in Home 1 could be obtained in the summer period.

During the period from March to June, when the formaldehyde increased, as noted in the previous paragraph, the temperatures on the test days increased from 0.5°C to 18°C. Later in June and in the first week or two of July, the temperature increased to near 30°C, but there was no substantial change in formaldehyde concentration. The results for this period and the ensuing summer and autumn are shown, in detail, in Table 7. In the middle of July, 1983, the temperature rose to above 30°C and remained at that level for a few days.

On July 14, the indoor/outdoor air exchanger became operational. A test for formaldehyde was made on that day and found to average 0.25 ppm. The outdoor temperature on July 14, during the period of the test, averaged 31.7 ppm. On the next day, when the outdoor temperature was 34°C, the highest reading in the house was 0.38 ppm which occurred in the basement. Prior to June 13, when preparations were being made to install the indoor-outdoor air exchanger, the basement had never been tested. It had been assumed that, as it contained no UFFI, concentrations

TABLE 7
RESULTS OF FORMALDEHYDE, TEMPERATURE AND HUMIDITY MEASUREMENTS
FOR HOME NO. 1, IN ROOM LOCATIONS DESCRIBED, DURING 1983

<u>Date, 1983</u>	<u>Locations</u>	<u>Formaldehyde ppm</u>	<u>Outdoor Temp. °C</u>	<u>Outdoor Rel. Hum. %</u>
March, 25	Living Room	0.05	0.5	62
	Bedroom	0.06		
	Dining Room	0.05		
June, 3	Living Room	0.14	17.6	76
	Bedroom	0.13		
	Dining Room	0.13		
June, 13	Living Room	0.14	30.1	70
	Bedroom	0.14		
	Backroom	0.17		
	Basement	0.20		
June, 22	Living Room	0.12	27.0	60
	Basement	0.19		
July 13	Living Room	0.17	28.5	62
	Bedroom	0.15		
	Backroom	0.14		
	Basement	0.20		
July, 14	Living Room	0.21	31.7	66
	Bedroom	0.25		
	Backroom	0.23		
	Basement	0.30		
July, 15	Living Room	0.29	34.0	63
	Bedroom	0.31		
	Backroom	0.28		
	Basement	0.38		

TABLE 7 (CONT'D.)

<u>Date, 1983</u>	<u>Locations</u>	<u>Formaldehyde ppm</u>	<u>Outdoor Temp. °C</u>	<u>Outdoor Rel. Hum. %</u>
July, 18	Living Room	0.16	29.5	69
	Bedroom	0.12		
	Backroom	0.09		
	Basement	0.28		
July, 21	Living Room	0.15	25.5	78
	Bedroom	0.17		
	Backroom	0.10		
	Basement	0.28		
July, 25	Living Room	0.12	28.5	65
	Bedroom	0.13		
	Backroom	0.06		
	Basement	0.17		
July, 29	Living Room	0.20	25.5	84
	Bedroom	0.18		
	Backroom	0.18		
	Basement	0.22		
August, 5	Living Room	0.08	25.0	78
	Bedroom	0.23		
	Backroom	0.16		
	Basement	0.27		
August 8	Living Room	0.11	31.0	54
	Bedroom	0.11		
	Backroom	0.12		
	Basement	0.18		
October, 25	Living Room	0.09	9.0	87
	Basement	0.15		

Note: The heat exchanger was operated, for the first time on July 14, but was switched off on July 17. It was switched on again, on July 19, and remained Operational until August 7 when it was turned off prior to the test on August 8.

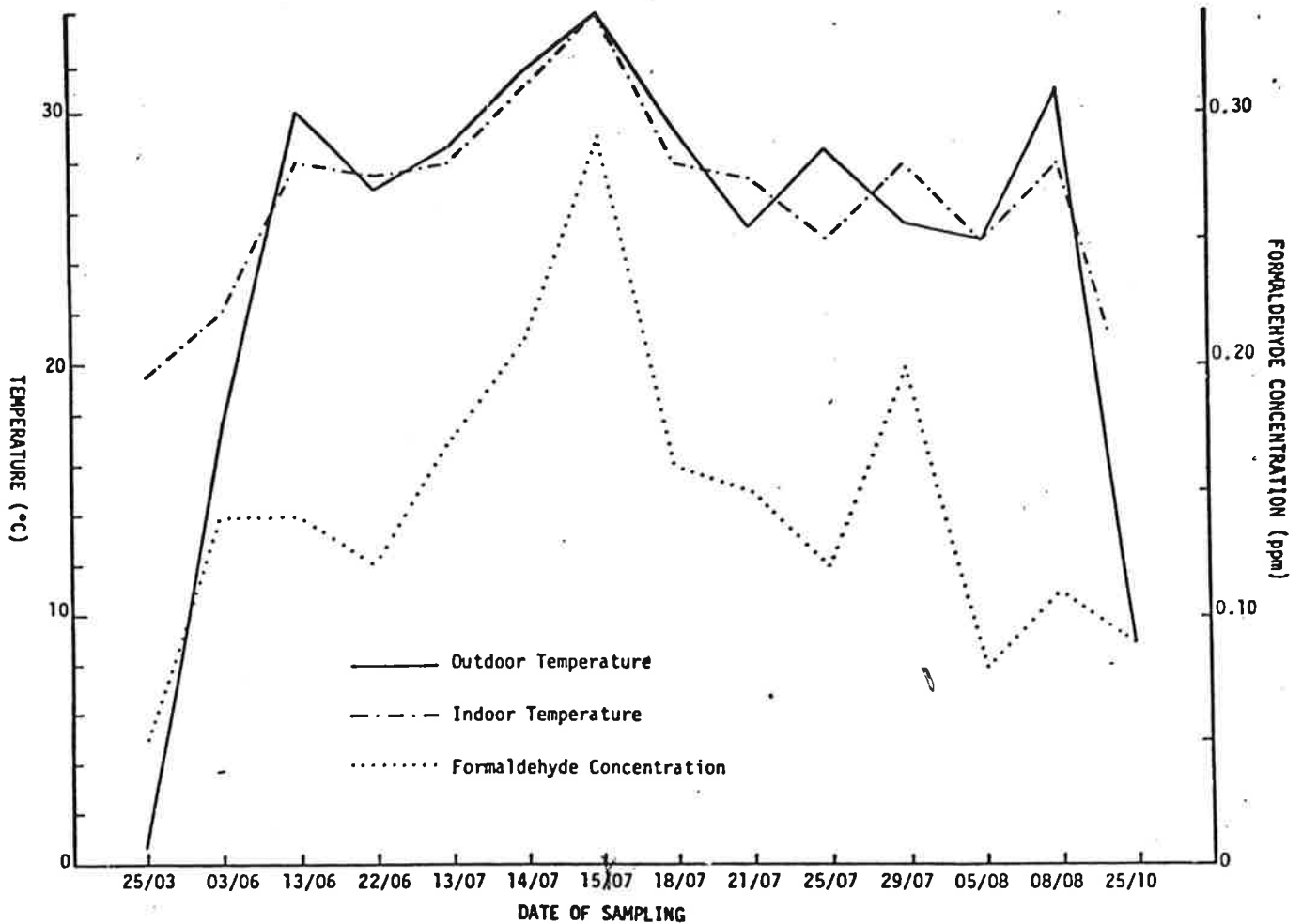
of formaldehyde would be negligible compared to the rest of the house. However, the basement was routinely included after that date and, on every occasion in 1983, it showed the highest concentrations of the house.

It was likely that the unusually high concentrations, measured on July 15, were the result of the high temperature on that day. However, another possibility, considered, for the elevated readings, in the living room etc., was the transfer of the high concentrations from the basement by the operation of the main fan on the heating system. For this reason, it was suggested to the occupant that the operation of the air distribution system be discontinued temporarily. The next test, on July 18, revealed a substantial drop in formaldehyde (average 0.16 ppm) and the air exchanger and house distribution systems were re-activated. For the rest of the summer, the concentrations remained at about the July 18 level and then dropped in October. In general, the average formaldehyde concentrations in the house were clearly related to outside temperatures. A significant correlation ($p < 0.01$) was found for the results given in Table 7. The same data are also shown in Figure 1.

Discussion of 1983 Results

On several occasions, during 1983, OHSRC staff had conducted wall cavity tests for formaldehyde in Home No. 1. The results of these were all below the minimum detection limits (0.5 ppm) of the Draeger detector tubes used. Because of this negative indication, as thorough a search as possible, was made for any UFFI which might have been lodged in any part of the walls or ducting. A further search was also made by the engineering company which installed the air exchanger. In both cases, no evidence of any UFFI was found.

FIGURE 1 - VARIATION OF FORMALDEHYDE CONCENTRATIONS IN HOME NO. 1, LIVING ROOM COMPARED TO INDOOR AND OUTDOOR TEMPERATURES.



As there seemed to be no possibility that UFFI was the cause of the continuing high concentrations of formaldehyde, a search for other potential sources was made. This easily led to the conclusion that a considerable amount of ply-wood panelling and some chip and particle board were responsible.

Prior to reaching this conclusion, various other surfaces in the house had been examined by fastening a 170 litre Lucite chamber over them and then sampling from it. These were all done on the main floor of the house, where the problem was believed to be. The surfaces sampled for formaldehyde included various parts of the walls and floors but all proved negative. Tests for formaldehyde were done by the NIOSH method.

The realization of the potential contribution of the wall-boards in the basement only occurred at the time of the preparation of the first draft report. It was not possible, because of this, to conduct confirmatory tests in 1983 and the report was submitted on November 2, 1983.

In the report, it was stated that the only potential source of formaldehyde, in the house, was the wall-boarding in the basement. It was therefore concluded that this was the cause of the continuing problem. The householder was very skeptical about this suggestion and pointed out that the wooden partitions had been in the basement since before the UFFI was installed. No problem similar to that which had caused the initial complaint had been noticeable until the installation of the UFFI.

Because of the incomplete nature of the study, it was proposed by OHSRC and supported by NRC that the survey be continued to attempt to identify, finally, the source of the formaldehyde. This was started in spring, 1984, and is described in the following section.

Basement Wall-Panelling Emission Tests

In order to determine whether emissions of formaldehyde from the wall-panelling, were occurring, the 170 litre Lucite box was placed tightly against the wall in the basement. The portion of the wall covered was about 0.56 m² (6 ft²). Although the box was held tightly against the wall, no sealing compound or tape was used so as to avoid possible adventitious contamination. It was assumed that any leakage could be tolerated.

The results of the room-air and the chamber measurements are shown in Table 8. However, in spring 1984, a larger capacity air exchanger was installed by the contractor who had supplied the small unit the previous year.

Probably because of the larger exchanger, as shown in the table, all of the room air results were markedly lower in 1984 than in 1983. No concentration of formaldehyde equal to or higher than 0.1 ppm was found after February, 1984. On the other hand, all of the tests done

TABLE 8

RESULTS OF FORMALDEHYDE AND TEMPERATURE MEASUREMENTS FOR HOME NO. 1,
IN ROOM LOCATIONS DESCRIBED AND INSIDE CLOSED BOX IN BASEMENT DURING 1984

<u>Date, 1984</u>	<u>Locations</u>	<u>Formaldehyde (ppm)</u>	<u>Outdoor Temp. °C</u>
Feb. 23	Living Room	0.17	-13.0
	Basement	0.08	
March 12	Basement	0.07	-11.0
	In Box	0.13	
April 13	Basement	0.05	15.0
	In Box	0.47	
May 11	Basement	0.07	15.0
	In Box	0.30	
June 5	Living Room	0.05	26.0
	Backroom	0.05	
	Basement	0.08	
	In Box	0.33	
July 27	Living Room	0.09	30.5
	Backroom	0.08	
	Basement	0.10	
	In Box	0.58	
Oct. 18	Living Room	0.05	8.0
	Bedroom	0.07	
	Backroom	0.03	
	Basement	0.05	

inside the Lucite box gave much higher results than the corresponding room-air samples. The days on which the tests were taken were all comparatively cool compared to those which occurred in 1983. Generally, the number of very hot days in 1984 appeared to be comparatively few. Nevertheless, the results obtained in the box confirmed, clearly, that the wall-board in the basement was exuding considerable formaldehyde. At the time of the tests, it was several years old.

Finally, because of reasons other than a possible formaldehyde problem, the wood-panelling and all similar boarding was removed from the basement of the house in September, 1984. The last test, shown in Table 8 for October 18, 1984, was made about a month after the removal of all wall boards in the basement.

Particulates

Whether the haze, repeatedly described by the occupant of Home No. 1, actually existed, was very difficult to determine. One member of the staff of OHSRC agreed that a haze could be seen, on occasions but three others doubted its existence. Particles, of course, can be seen by light-scattering in most homes.

The results of the tests by the Bausch and Lomb Aerosol Counter, described earlier, are shown in Table 9. This instrument operates on the principle of light scattering and, therefore, would be indicative of haze. The table shows the results for the same type of rooms in Houses 1 and 2 as well as the adjacent outdoor atmosphere in each case. The outdoor readings are shown in the right-hand column. Unfortunately, the owner of Home 3 had decided to withdraw from the study before the particle measurements were started and no results were available for it.

Most of the literature on particles in homes is described in mass units but, during the operational part of the study, collection of gravimetric samples was omitted. This could have been done, easily, but it was decided to count rather than weigh samples because of the concerns about haze which is a light-scattering effect.

TABLE 9

PARTICLE CONCENTRATIONS IN HOMES AS IDENTIFIED

particles $\times 10^6 / m^3$ particles / cm^3 Home No. 1

<u>Size Range(μm)</u>	<u>Living R.</u>	<u>Main Bed R.</u>	<u>Basem't</u>	<u>Outside</u>
≤ 0.3	388.3	406.0	194.2	58.2
0.3-0.5	127.1	222.4	120.0	38.8
0.5-1.0	127.0	26.8	44.1	10.6
1.0-2.0	113.0	68.8	29.3	8.8
2.0-3.0	21.2	17.6	1.4	0.2
3.0-5.0	1.7	9.9	0.25	0.1
5.0-10.0	0.2	0.3	0.05	0.05

Home No. 2

<u>Size Range(μm)</u>	<u>Living R.</u>	<u>Bed R.</u>	<u>Basement</u>	<u>Outside</u>
≤ 0.3	279.8	209.0	164.1	30.0
0.3-0.5	135.0	111.2	97.1	21.2
0.5-1.0	67.1	41.3	30.7	4.6
1.0-2.0	76.6	59.0	35.3	3.9
2.0-3.0	0.4	0.35	0.35	0.2
3.0-5.0	0.4	0.45	0.45	0.1
5.0-10.0	0.2	0.1	0.25	0.05

Few studies, based on non-specific indoor particulates occur in the literature apart from those concerned with industrial workplaces. Most of those which have been conducted in residences have directed their attention towards specific chemical classes or compounds. The one report^[1], cited earlier, was of non-specific particulate matter but on a mass concentration basis. Although it is possible, by making assumptions on the density of particles, to compare mass concentrations with numerical particle counts, it usually needs more information than could be obtained in this survey.

However, one previous study of numerical particle concentrations, was published, coincidentally, on work done by the same instrument used in the present survey. This work was also done in London, Ontario, in three homes, by Lefcoe and Inculet^[11&12]. Their main purpose was to determine the effect of a central electrostatic air cleaner on indoor particle concentrations.

In their study, the two workers found concentrations of total particulates, with the precipitator off, as follows:

<u>Particle Size</u>	<u>Particles per cubic metre</u>
≥ 0.3 μm	85,000,000
≥ 0.5 μm	35,000,000
≥ 1.0 μm	1,000,000
≥ 4.0 μm	35,000

Generally, they found, unlike the present study, that outdoor particle concentrations were higher than those measured indoors. On the other hand, they found, as was the case in the present survey, that certain activities in the house had a marked effect on concentrations. Smoking one cigar, for example, was enough to raise the base concentrations by up to 100 times. Certain dusting operations were also enough to overwhelm the dust counting analyzer. The vacuum cleaner, when in use, also increased particle concentrations by 100 percent.

In addition to the particle measurements, the same workers measured sulphur dioxide, nitrogen dioxide and ozone, but all concentrations found were below detectable levels which were about 0.01 ppm.

Ventilation

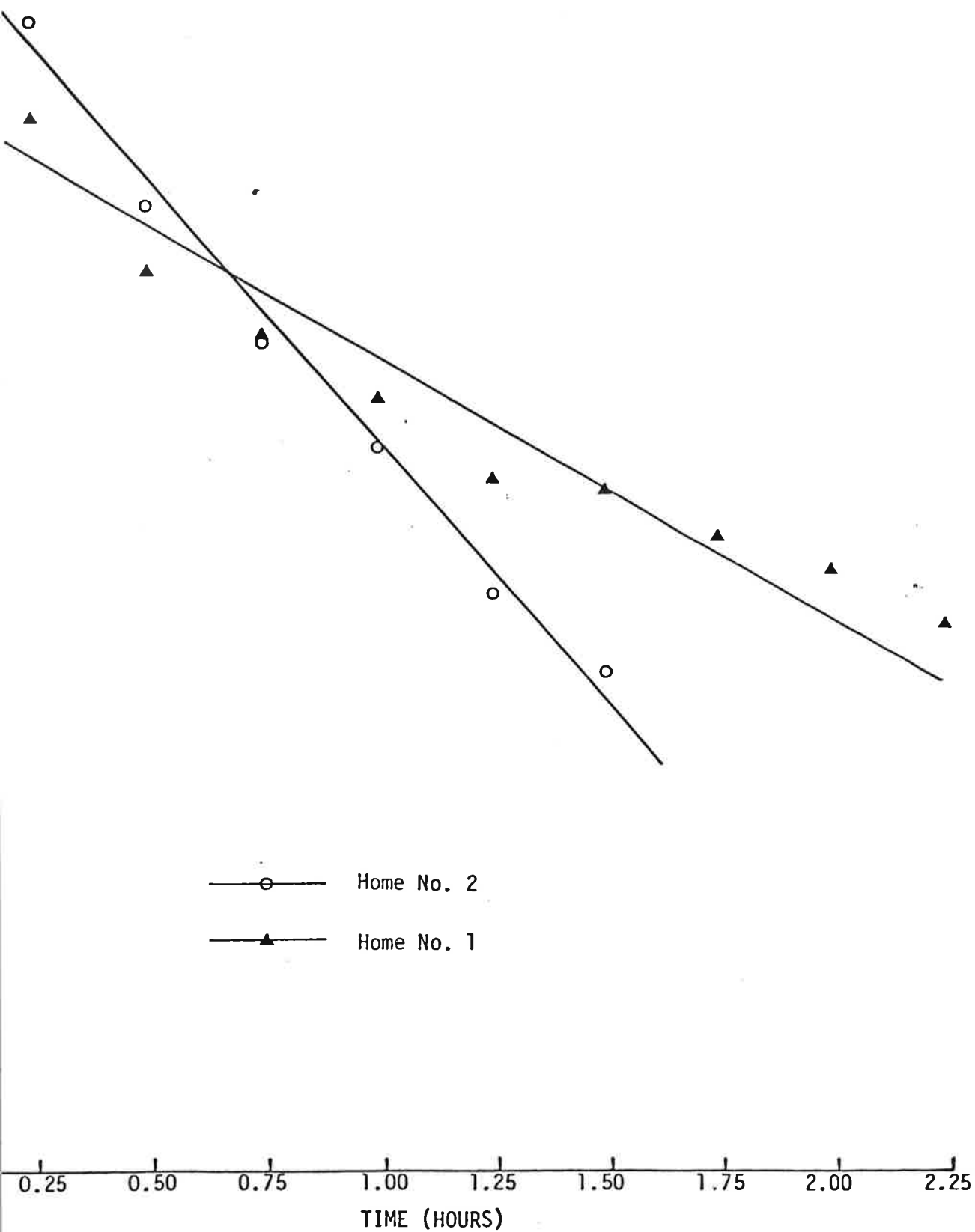
Air leakage studies, using sulphur hexafluoride, (SF_6) as a tracer gas, were also carried out in Homes 1 and 2. In preparation for the test, all exterior doors, windows, fireplace dampers were closed and interior doors and closets were opened. The furnace fan was left running.

The SF_6 was transferred to a 30 cm^3 syringe, outside and downwind of the house, and then injected into the cold air plenum of the forced air system. Samples were collected in the same location every 15 minutes. From the syringe, the samples were injected into vacutainers and returned to the laboratory for chromatographic analysis.

From these results, a decay curve was produced by plotting the results of the natural logarithms of the SF_6 analyses for the two homes on regular linear graph paper. From the two decay lines plotted, the slopes of the linear regression lines provided the air changes for the homes. The plots for the two houses are shown on Figure 2. From the slopes of the two lines, it was determined that the air changes were 0.25 per hour, in Home 1 and 0.45 per hour in Home 2.

SUMMARY AND CONCLUSIONS

This survey was conducted for the purpose of examining possible causes for complaints about health effects and discomfort made by the occupants of three homes in the London area. By chance, the three homes had different characteristics. One, which was identified as No. 1 in this report, had had UFFI installed in it but it had been removed in the year before the study, reported here, started. Despite this removal, the occupant continued to complain strongly, about the presence of an irritating gas. Formaldehyde concentrations also continued to be well above expected levels. The home described as No. 2, in the study, had never had UFFI installed and had no more than outdoor levels of formaldehyde. In the third one, UFFI was installed and the owner had health problems

FIGURE 2 - DECAY RATES FOR SF_6 IN HOMES 1 and 2.

which were attributed to the foam. Unfortunately, this owner decided to have the insulation removed while the tests were still in the planning stages, but it was included in the study, nevertheless.

As the objective of the study was to determine any possible causes of ill-health, all predictable and possibly harmful contaminants were included in the measurement program. However, no medical investigations were undertaken. In addition to formaldehyde, the potential contaminants sampled and analyzed were carbon monoxide (CO), nitrogen dioxide (NO₂), nitric oxide (NO), ozone (O₃), general hydrocarbons and particulates. A ventilation or air-leakage test was done on two of the homes (Nos. 1 and 2) by means of an innocuous tracer gas.

With the exception of formaldehyde, which continued to exist in an elevated concentration in Home No. 1, no gaseous contaminants were found above accepted outdoor (ambient) standards. Carbon monoxide, the two nitrogen oxides and ozone were all well below Canadian federal air quality objectives and U.S. air quality and ASHRAE recommendations referred to in the report. Hydrocarbons, collectively, are not subject to standards or recommendations as their effects are only relevant in terms of specific compounds. Most which occur in homes, except when particular products are being used, have negligible toxicity. Tests for specific hydrocarbons in the home did not reveal any of the compounds known to produce health effects. Most of the hydrocarbons measured appeared to be produced by cooking. However, though most members of the group are either harmless or generally occur in negligible concentrations, hydrocarbons and other organic compounds represent an important aspect of indoor air quality research requiring further investigation.

For the three-home study, therefore, the only gaseous constituent which warrants further discussion is formaldehyde in Home No. 1. No formaldehyde, above outdoor levels, was found in Home No. 2 and the level in Home 3, where it had been recently removed, was very low. In that home, the removal had clearly achieved the desired effect.

In Home 1, formaldehyde continued to be found well above the recommended level for homes. Throughout most of 1983 even though the

previously installed UFFI had been removed in 1982, sometimes very high concentrations were found. It was only in the cold months that it fell below 0.1 ppm and, in summer, 1983, it exceeded 0.3 ppm in one day's test. It was therefore indisputable that, during 1983, the house had formaldehyde concentrations which would be considered excessive.

At the beginning of 1983, when the survey first started, it was believed that some of the UFFI had not been completely removed and the continuing high formaldehyde levels were attributed to this. Consequently, extensive wall-cavity tests for formaldehyde were made but no concentrations equivalent to minimum detection levels of detector tubes (0.5 ppm) were found. It had, therefore, to be concluded that residual UFFI in the house was not the cause of the formaldehyde. Additional tests to determine whether out-gassing of formaldehyde was occurring from carpets, walls or other surfaces, in the living areas of the home, also proved negative.

Subsequently, it was found that the probable true cause of the formaldehyde in the house was a large quantity of wood-panelling in the basement. This was found during summer, 1983, when the first tests in the basement were done. Prior to then, the basement had always been considered of no significance because the UFFI was only installed in the two upper floors. However, when tests were done in the basement, during the 1983 summer and autumn, it was found that the highest concentrations in the house occurred there repeatedly.

This led to the conclusion that off-gassing from the wood-panelling was occurring. Though, such a possibility had been considered previously, it had been rejected because the panelling had been installed before the UFFI and the occupants had not noticed any problems. To test the possibility of formaldehyde out-gassing from the panelling, a portion of it was sealed under a plastic box and formaldehyde tests were done from that enclosure. These tests, which were done during 1984, confirmed that off-gassing from the surface of the panelling was occurring. The panelling and small amounts of particle and chip boards were removed during September, 1984, and a test done in the following month showed concentrations of about 0.05 ppm formaldehyde. It would appear that the entire cause of formaldehyde in the house, following the removal of the UFFI, could be

attributed to the wood-panelling. On the other hand, the concentrations were much lower in summer 1984, compared to 1983, even before the panelling was removed. This was the result of the installation of a larger indoor/outdoor air exchanger in early spring, 1984.

Particle concentrations in the two homes tested, Nos. 1 and 2, were considerably higher than the outdoor air in their vicinities. However, although the concentrations looked high, they were not actually unusual. This part of the study was somewhat exploratory and more work requires to be done on the significance of residential air-borne particles in relation to activities.

The general conclusion of the study of the three homes was that no unusual conditions nor any health factors were identified, other than, perhaps, formaldehyde in Home No. 1. It is clear that much more work on indoor air quality, in homes, is required before realistic responses to the concerns of some occupants can be given.

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PICTURES AND FLOOR PLANS
OF THE 3 HOMES

TABLE 10

SUMMARY OF HOUSE CHARACTERISTICS
OF THREE HOMES SURVEYED

HOME 1

Originally built	1930s
UFFI installed	1977 (October)
Location of UFFI	Main and upper floors, exterior walls
Exterior walls at that time	Brick covered with vinyl siding
UFFI removed	1982 (October)
Exterior walls when replaced	vinyl siding

HOME 2

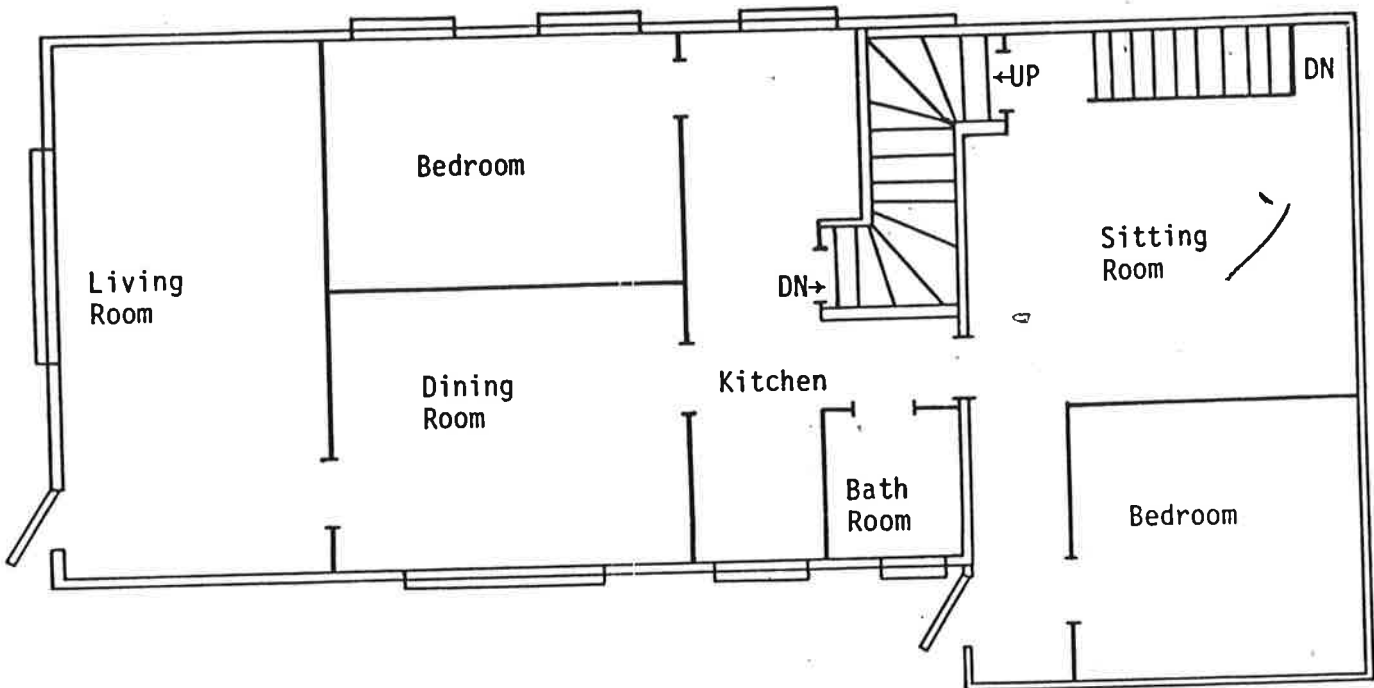
Originally built	about 1970
Exterior walls	Mixed brick and timber
UFFI installed	Never

HOME 3

Originally built	1956
UFFI installed	1979 (Spring)
Exterior walls	Brick
UFFI removed	1983 (May)
Exterior walls when replaced	Brick

FIGURE 3' - FLOOR DIAGRAM OF HOME NO. 1

USED IN THE STUDY. 1cm = .85 m



4

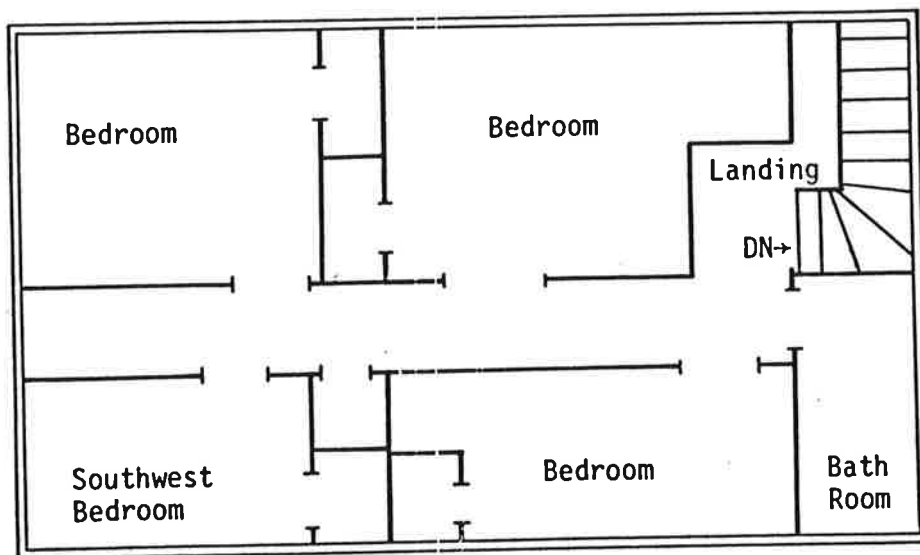


FIGURE 4 - FRONT VIEW OF HOME NO. 1

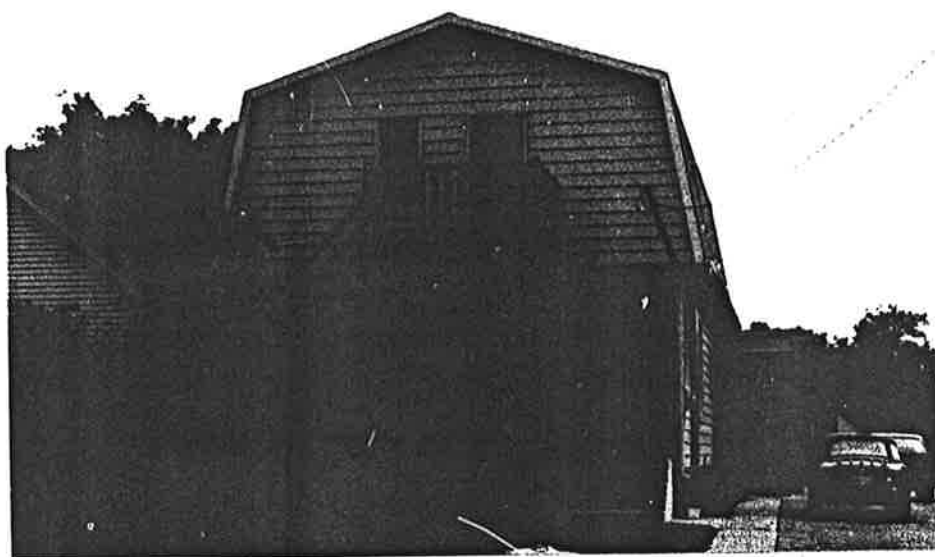


FIGURE 6 - FRONT VIEW OF HOME NO. 2

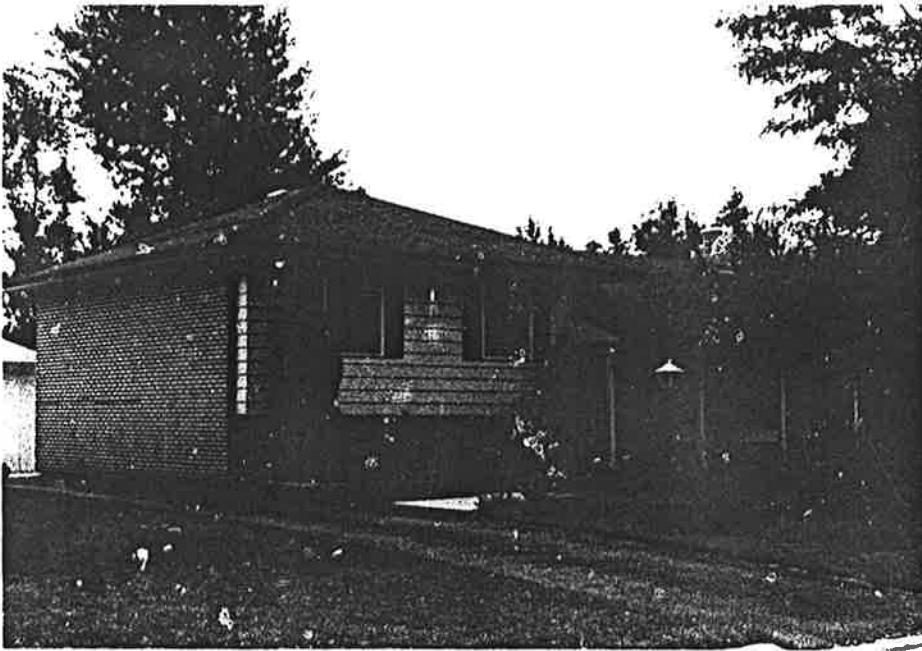


FIGURE 7 - FLOOR DIAGRAM OF HOME NO. 3
USED IN THE STUDY. 1cm = 0.96 m

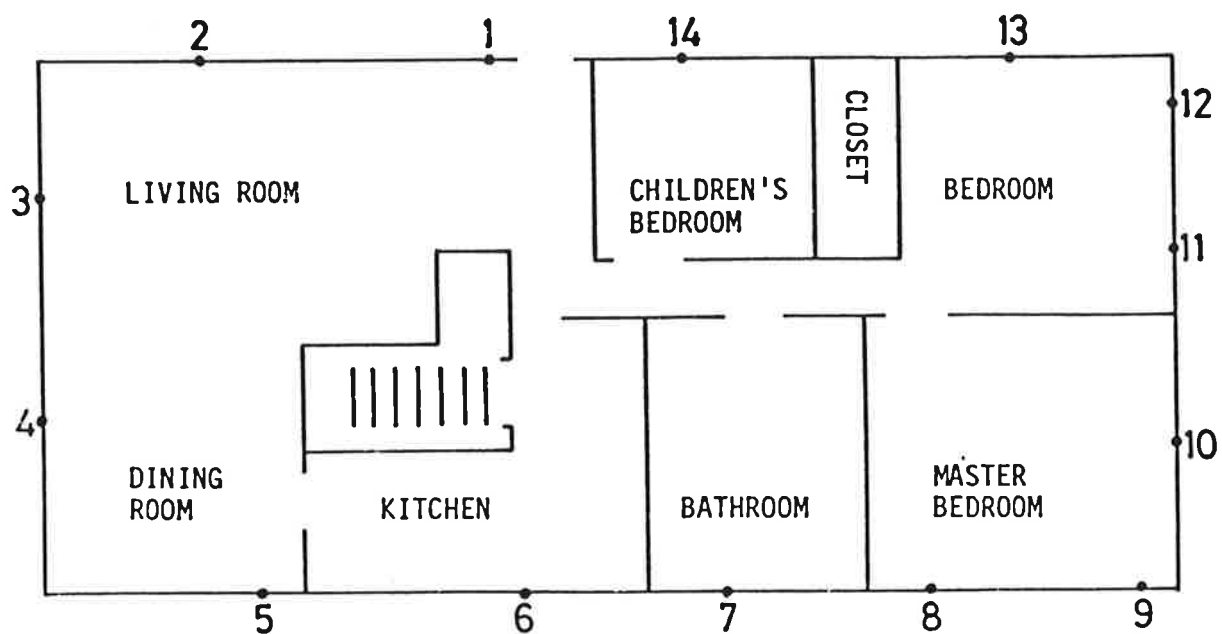


FIGURE 8 - FRONT VIEW OF HOME NO. 3

