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CARBON MONOXIDE POISONING IN HOUSING:

CONTRIBUTING FACTORS AND REMEDIAL MEASURES

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As part of its mandate to improve housing quality, Canada Mortgage and Housing Corporation (CMHC) is pursuing a number of avenues of research into indoor air quality. This paper describes two phases of a project directed towards reducing carbon monoxide (CO) poisoning in housing, that is caused by hazardous heating and ventilation conditions.

The paper is in two sections. The first describes a survey, carried out by HATCH Associates on behalf of CMHC, Energy Mines and Resources and Health and Welfare Canada which looks at the incidences of hazardous conditions caused by CO. The second section describes the development and evaluation, by Sheltair Scientific Ltd., of a procedure to detect whether a house has a chimney which is vulnerable to backdrafting; one of the major causes of CO build-up in a house.

SECTION 1, SURVEY OF CARBON MONOXIDE EPISODES

Energy Conservation vs. Indoor Air Quality

For the past ten years, energy efficiency has been identified as a desirable feature in housing. New houses and retrofited existing houses are incorporating more insulation and more efficient and/or less oil-dependent sources of heat. Since air leakage can account for as much as 40% of heat loss, houses are being made more airtight. This can cause an increase in the levels of air contaminants from indoor sources and possible detrimental effects on the comfort, health and safety of the occupants.

Two of the steps that the homeowner can take to conserve energy may adversely affect indoor air quality:

1. Reduced air-leakage can contribute to high concentrations of air contaminants from indoor sources, and to draft reversal in the furnace or fireplace chimney, when the demand for air by fireplaces and/or furnaces and exhaust fans exceeds the air supplied by leakage area and supply ducts.

2. Converting from oil to gas, without taking steps to prevent chimney deterioration, can increase the risk of chimney blockage, draft failure and the associated release of combustion products into the house.

Although many products of combustion can cause discomfort and adverse health effects, it is CO which presents the greatest threat to life. Both reductions in air-leakage area and heating system conversions may have contributed to the incidence of these episodes.

Carbon Monoxide

When CO is inhaled it produces an effect which is referred to as chemical asphyxiation. Injury is due to the combination of CO with the available hemoglobin in the blood, to form carboxyhemoglobin (COHb), lowering the oxygen-carrying capacity of the blood. The body immediately attempts to compensate by increasing cardiac output and blood flow to critical organs.

The most common symptoms of CO exposure are: headache, dizziness, nausea, increased cardiac output, fatigue, flashes before the eyes, and ringing in the ears. The effects depend on: length of exposure, concentration, and activity of the person exposed. Levels of CO sufficient to cause these symptoms have been encountered in houses with inadequate exhaust of combustion products, (see Table I).

TABLE I. Effects of Carbon Monoxide

Symptoms of Carbon Monoxide (CO) Poisoning and Approximate Corresponding Concentrations	Percentage Carboxy-hemoglobin in blood by weight	Carbon monoxide parts per million in air by volume
Low concentrations;		
- shortness of breath on moderate exertion	10	50
- slight headache		
Higher concentrations;		
- severe headache	30	600
- mental confusion - dizziness		
- impairment of vision and hearing		
- collapse or fainting on exertion		
- nausea		
Extreme concentrations;		
- unconsciousness or death	50	1 000

Most of the symptoms attributed to CO are temporary. It is not clear at what point permanent damage might be sustained by a victim of asphyxia, but there is a relatively small factor of 20 between a concentration that is nontoxic for one hour (50 ppm) and one that may cause a fatality (1 000 ppm).

Survey Methods

In order to develop a comprehensive data-base, three types of information sources were utilized:

1. Statistics Canada data on deaths in Canada, by region, by year and by cause of death. Statistics Canada data are based on death certificate information from the Registrar in each province and territory. Causes

of death, as identified by the presiding physician are classified according to their International Classification for Disease number.

2. Descriptive reports of CO episodes, produced by investigators with varying technical ability and motivation. These reports may have already been summarized and incorporated into lists by different major sources, without the benefit of the uniform reporting and interpretation format employed by Statistics Canada. See Table II for types of contacts made.

3. Newspapers and radio were used as a means of soliciting information from the public, regarding experiences that may have been due to the inadequate exhaust of combustion products.

The data-base was analyzed for major contributing factors, regional differences, magnitude of risk and significant trends.

Recognized Contributing Factors

1. Collapsed, damaged or blocked chimneys or flues.
2. Reverse flow of exhaust in chimney or flues (down drafting).
3. Inadequate exhaust of space heaters, gas ranges or other combustion appliances.
4. Cracked or corroded heat exchangers, other equipment malfunctions.
5. Airtightness of house envelopes.
6. Other ventilation competing with normal combustion exhaust processes.
7. Lack of understanding of heating and ventilating system operation on the part of installers, users, etc.
8. Weather conditions.

A number of contributing factors were recognized at the outset of the survey: If CO is being released into the house by the heating system, at least one of the first four factors listed must apply. Many combinations of these eight factors may occur.

Results

Descriptive reports of 293 episodes of CO poisoning, due to hazardous heating and ventilating conditions in houses, were found for the ten year period from 1973 - 1982. Included were 145 deaths, i.e. 14 deaths per annum. Statistics Canada data show 238 deaths due to the incomplete combustion of domestic fuels, in the eight year period from 1973-81, i.e. 26 per annum. This higher figure may be an underestimate, since CO poisoning is difficult to diagnose and the episode reports involve more deaths than are accounted for by the Statistics Canada data. A conservative calculation of the Fatal Accident Frequency Rate (FAFR), based on the Statistics Canada data, results in a FAFR of 0.013. A FAFR of 0.001 has been proposed, by authors in the safety field, as acceptable for involuntary risks to the general public. The FAFR of 0.013 underlines the seriousness of the situation.

Table II Types of Information Sources

1. Government Organizations, Ministries, etc.
    - Federal energy
    - Provincial housing
    - Provincial health
    - Municipal health
    - Municipal building inspectors
    - Provincial environment
    - Provincial occupational health and safety
    - Provincial energy
    - Fire Marshall's office
    - Coroner's office
    - Hospital statistics
    - Statistics Canada

2. Public and Private Utilities
    - Hydro
    - Gas
    - Oil

3. Media Reports, Newspaper Clipping Files
    - Librarians
    - Science editors
    - Consumer advisors

4. Universities (Departments)
    - Building research, civil engineering, mechanical engineering and environmental studies
    - Occupational health and safety
    - Biostatistics
    - Law library

5. Associations - Professional, Business and Consumer
    - Air Pollution Control Association
    - Occupational Hygiene Association of Ontario
    - Housing and Urban Development Association of Canada
    - Consumers Association of Canada
    - Insurance companies

6. Technical Research Groups, Consultants, Laboratories
    - Saskatchewan Research Council
    - Centre for Research and Development in Masonry

7. Reports - Published and Unpublished

8. Persons with Established Reputations in the Field

Many combinations of factors contributed to these episodes. Each region of Canada has characteristics that have affected the occurence episodes, such as: condition of the housing stock, weather, type of heating equipment, fuel used, and a lack of awareness of potential problems.

Table III shows nine significant factors contributing to reported episodes. The first four include 70% of the identified causes. One should be aware that investigators of accidents may have had difficulty in pinpointing all significant causes. Whereas downdrafting alone may have been identified as the primary cause in one episode, downdrafting, airtigthness and weather conditions may have been identified in an equivalent accident. These results should therefore be treated cautiously.

There are two different populations at risk: occupants of private dwellings with combustion heating equipment (accounting for 82% of episodes), and users of combustion appliances in a recreational settings (accounting for 18%). The latter usually involve in most cases propane in mobile containers. See Table N.

The death of at least one occupant occured in 31 percent of reported episodes. There are two reasons for this level of severity. Firstly the episodes involving death are more likely to be reported and secondly, there is only one order of magnitude separating the carbon monoxide concentration which causes mild discomfort and the concentration which can be fatal.

As can be seen in Table V, an increase in the annual number of episodes is not demonstrated by the data. However, each of the following major contributing factors has the potential of increasing its influence:

1. Emergence of new technology with new equipment problems, e.g. improper use and maintenance of unvented kerosene space heaters.

2. Deterioration of existing chimneys.

3. Continuing steps towards airtightness in houses without ventilation systems.

4. Inadequate awareness of the potential for problems.

TABLE III Contributing Factors

NOTE: More than one factor can be implicated in an episode

		Number of Reference	Per Cent
1.	Equipment Problems, due to Defects, Poor Maintenance, Damaged Heat Exhangers	136	46
2.	Collapsed or Blocked Chimneys or Flues, Dislodged or Damaged Vents	90	31
3.	Downdraft in Chimneys or Flues	72	25
4.	Improper Installation of Equipment, Chimneys, Vents or Lack of Understanding of Operation	69	24
5.	Episodes in Recreational Settings (e.g. Cottages, R.V.'s, etc.)	52	18
6.	Airtightness of House Envelope/ Inadequate Combustion Air	51	17
7.	Inadequate Exhaust of Space Heaters, Appliances	34	12
8.	Exhaust Ventilation/Fireplace Competing for Air Supply	32	11
9.	Weather Conditions	4	1

Table IV Carbon Monoxide Episode Timing

Percentage of recorded episodes (1973-1982) vs. month of occurence

January	18	July	3
February	11	August	3
March	6	September	8
April	8	October	8
May	4	November	10
June	4	December	17

Table V Total Number of Reported Episodes by Year

In Regions that supplied significant numbers of episode reports

'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	TOTAL
30	25	24	24	25	33	26	25	24	34	270

SECTION 2. REMEDIAL MEASURES

The survey underlines an already unsatisfactory situation. In addition, recently verified trends in airtightness can be expected to make matters worse, unless appropriate measures are taken. This section deals with a test designed to reveal the probability of chimney backdrafting. So far, an assessment of the relationship between house airtightness and the likelihood of backdrafting has been carried out, and a method of detecting the possibility of backdrafting has been formulated, tested and evaluated. If the method can be made sufficiently reliable and simple, and if it can be widely adopted, it should reduce the incidence of CO build-up in houses. Any measure taken to increase the airtightness of a house which contains open combustion systems should not be considered complete without a check to ensure that all products of combustion can be completely exhausted even under the worst conditions. Simultaneous operation of extraction fans, fire places, clothes dryers etc., can create this worst consolidation.

The need for such a procedure has been made all the more important because of the emerging service industry of airtightening already-built houses. Without the protection of such a check on the safety of an airtightened house, a contractor may be left in a vulnerable position.

Worst Case Simulation

The essence of the simple test procedure that evolved requires no special equipment and is designed to be carried out and by the average householder. It involves the following steps:

1. Check that the wind is below 10 kph and the temperature difference between inside and outside falls within the prescribed ranges.

2. Seal all air intakes, close all windows and exterior doors.

3. Turn down thermostats.

4. Turn on all exhaust fans.

5. Check for a draft in the furnace exhaust flue, above the hood or barometric damper, using a candle held next to a small hole in the flue. If there is a draft, the candle flame will be drawn towards the hole.

6. Light a fire in the fireplace.

7. Check for spillage of smoke at the fireplace.

8. Re-check draft in the furnace flue.

There are, of course, varients of this check list according to the heating and venting equipment and configuration of a house.

The procedure is based on the fact that the most critical situation occurs when a furnace starts and attempts to establish an exhaust flow up the chimney. Once a flow is established, it is typically maintained, but any circumstances which encourage a cold chimney makes the establishment of a draft more difficult. For example, an external, uninsulated chimney, a flue damper and long intervals between furnace on-time will contribute to a cold chimney.

Field Testing

The primary purpose of the field test was to evaluate the simple test procedure described above. An accurate method of assessment was also required to validate the simple version. The testing was carried out in two stages. The first stage of detailed testing involved nineteen houses, in four locations across Canada, and used a fan depressurizing door to establish the air flow/pressure characteristics of each house, under a variety of conditions. The sample of was selected to include a broad cross-section of house types, and included both gas and oil furnaces. All were known to have troublesome heating systems. The second stage tested the same nineteen houses used in the first stage, plus an additional twenty houses. All thirty-nine were subjected to the simple test.

Detailed Testing (First Stage)

The conditions prescribed for the testing are described below. They require three, progressive states of house sealing, plus permutations in the operation of the heating and ventilation equipment in each house.

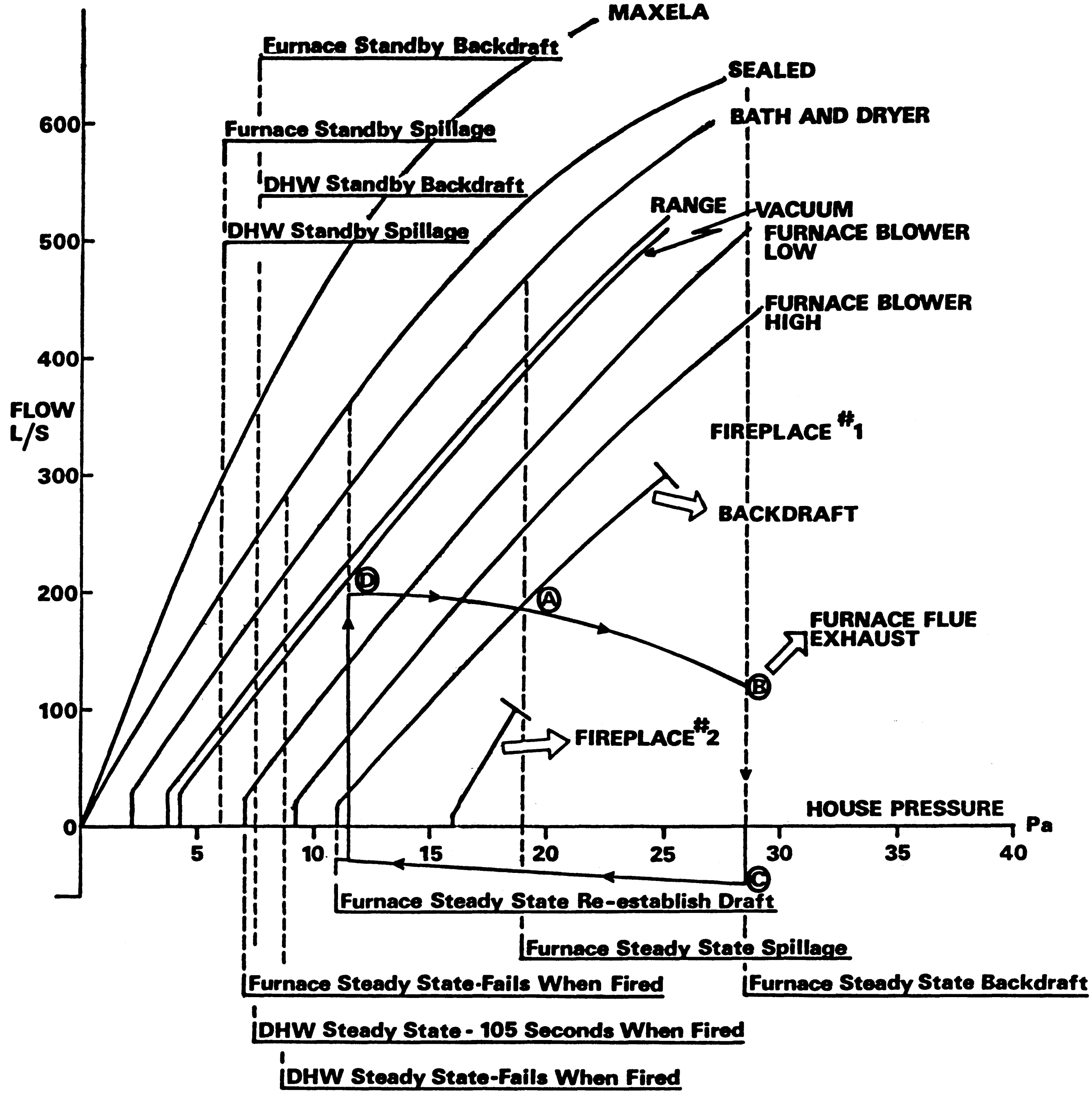
The three states of house sealing were:

1. MAXELA (MAXimum Equivalent Leakage Area).
2. SEALED (all external openings, intakes and exhausts taped shut).
3. EXHAUST VENTING (SEALED plus progressive use of exhaust fans and fireplaces)

A diagrametic representation of the results from one of the houses is shown in Figure 1. It shows:

1. The pressure differences required to generate a given air flow through the fan-door, and
2. The pressure and flow conditions that generated a reversal of air flow both in furnace and fireplace chimneys.

   Nine of these nineteen houses were thus shown to be vulnerable to backdrafting.



HOUSE I.D.:	**BC #2**
APPLIANCES:	**120,000 BTU Gas Furnace**
	38,000 BTU Gas DHW
CHIMNEY:	**Factory Built**
TEST CONDITIONS:	**Wind 11 Kph**
	Temp. Outdoor: 6°C
	Temp. Indoors: 20°C

FIGURE 1

TYPICAL PRESSURE/VENT PROFILE

Simple Testing (Second Stage)

The purposes of this second stage were twofold: firstly, to technically evaluate the results of the simple test against the detailed test, and; secondly, to determine the ability of householders to understand, carry-out and interpret the test. About half of the "simple" procedures were carried out by the households themselves, with the consultant acting only as an observer. Surprisingly little difficulty was found, though it is clear that much could be done to further clarify the procedure.

Of the thirty-nine houses, sixteen failed this "simple" test. A failure was registered when the furnace was unable to establish a draft in its chimney, within 3 minutes of firing. Four failed solely on account of operating exhaust fans. One failed when, in addition to operation of the fans, the furnace fan was also running. Eleven failed when a fire was also lit in the fireplace.

A basement window was opened and adjusted in area to prevent a backdraft failure condition. From measurements of the opening, the size of an additional air intake, needed to make the house safe, could be estimated. In some houses this area was unreasonably large.

Conclusions

1. There was a good match between what was detected in the first stage and the findings of the second.

2. There are certainly deficiencies in the procedure: it does not check out backdrafting of fireplaces; it does not have a built-in safety margin sufficient to cover all weather conditions; and modelling the worst conditions to cover the great variety of housing characteristics is beyond our present capability.

3. There was no noticeable correlation between the measured airtightness and the propensity to backdraft. This must be considered a tentative but important conclusion which should be verified by further testing. However, the effects of backdrafting may be very much a function of tightness. We can speculate that two mechanisms will make the situation worse in an airtight house. Firstly, a lower air change rate will result in a more rapid rise in contaminant levels because there is less dilution. Secondly, restriction of the fresh air supply to the furnace area, can result in reingestion of combustion products back into the furnace, causing incomplete combustion and a rapid rise in the output of CO. The more confined the space and the smaller the house, the more rapidly this could occur.

4. Although the precise conditions needed to create a serious problem did not occur during any of the tests, the mechanism that generates a rapid build up of CO is now clarified.

Recommendations

The survey has shown the dimensions of the problem. The development of the "backdrafting checklist" has demonstrated that one of the major causes of CO poisonings can be predicted. The departments sponsoring this work will therefore be carrying out the following:

1. Further refinement of tests procedures needed to assess the possibility of hazardous conditions arising from operation of heating equipment.
2. Limited use of the present test, under controlled conditions.
3. Promotion of heating systems that are not likely to cause CO problems. (Happily ,sealed combustion furnaces and areodynamically isolated fireplaces parallel energy efficiency requirements.)
4. Implementations of testing procedures, when they are thoroughly proven.
5. Development of corrective actions for affected houses.

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