IMPROVING AIR QUALITY IN ENERGY EFFICIENT HOUSES: AN ARCHITECTURAL APPROACH

E.D. McIntyre and E.M. Sterling
Theodor D. Sterling Ltd.
#70 - 1507 W. 12th Avenue
Vancouver, B.C.
V6J 2E2

ABSTRACT

Two energy efficient townhomes were designed and constructed in an experiment of improvement of indoor air quality by:

1. Limiting infiltration of outdoor radon gas.
2. Reducing indoor levels of formaldehyde off-gassed by construction and finishing materials and combustion gases generated by appliances.

To reduce indoor concentrations of formaldehyde generated by finishing and construction materials, chemically stable materials were used wherever possible and limited use made of glues, sealants, interior grade plywood and particle board. Indoor sources of combustion gases were eliminated from both units by use of electric appliances. To minimize radon gas infiltration, the houses were constructed on ventilated crawlspaces and an air vapour barrier installed between the main floors of the townhomes and the crawlspaces. Air quality in the two experimental units and in other control buildings was monitored to evaluate the effectiveness of the designs for improvement of indoor air quality.

1. INTRODUCTION

Two energy efficient airtight townhomes were designed and constructed to evaluate the effectiveness of an architectural approach for providing acceptable indoor air quality in energy efficient, airtight buildings. An architectural approach implies a design and construction process defined not only by aesthetic, technological and financial considerations, but also by the impact on indoor air quality of the components and configuration of buildings.

The most significant advantage of an architectural approach to provision of acceptable indoor air quality is energy efficiency. Acceptable air quality is provided through manipulation of the architectural component of a building. The form and structure of the building work, without consuming any energy resources, is to provide acceptable indoor air quality.

In the context of the townhome project, architectural solutions for improving air quality by limiting radon gas infiltration and limiting indoor sources of formaldehyde were explored. After construction of the townhomes, the effectiveness of an architectural approach in reducing indoor radon and formaldehyde levels was evaluated through air quality monitoring. Radon and formaldehyde, and also xylene and toluene concentrations in each of the two experimental townhomes were recorded.

2. PROJECT DESIGN

To meet local building code regulations, the townhomes were designed as two storey, 1800 square feet, side by side units sharing a party wall (Figure 1).

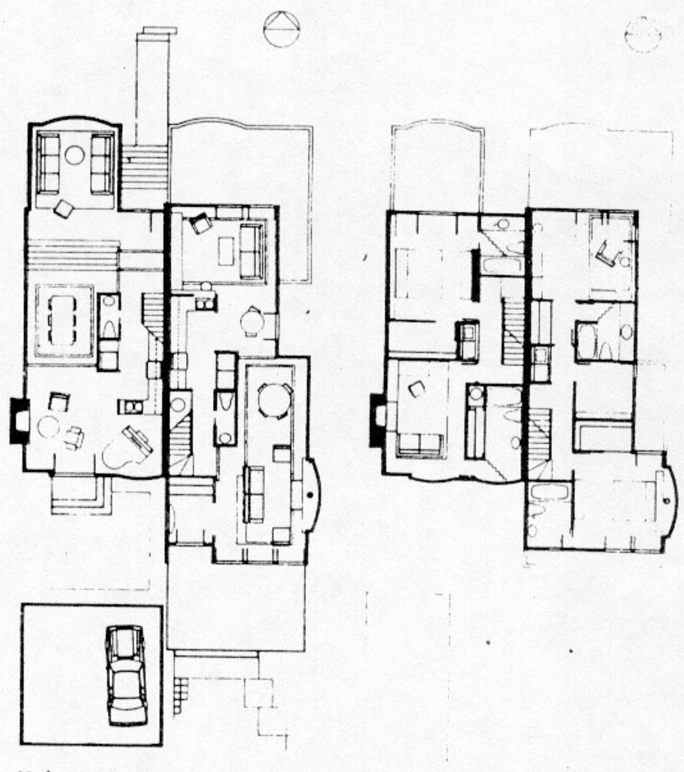

Fig. 1. Main and Second Floor Plans of Experimental Townhomes

Energy efficient construction technology developed by the Canada Mortgage and Housing Corporation Energy Efficient Housing Program was specified and used in the construction of the townhomes (1). Exterior walls were constructed with 2" x 6" lumber, and 2" x 10" wood joists were used in the roof construction. R20 fibreglass insulation was installed in the exterior walls and R28 fibreglass insulation installed in the exterior ceilings. Airtight air/vapour barriers were installed at the interior surface of exterior walls to prevent heat loss through, and moisture damage to the building structure. After construction, airtightness testing found Unit 1 to have an airtightness rating of 3.7 air changes per hour and Unit 2 a rating of 3.6 air changes per hour.

2.1 Limiting Infiltration of Radon Gas

In standard energy efficient residential construction, the basement or crawlspace beneath a home is not separated from the living areas by an air vapour barrier (1). As a result, radon gas may infiltrate into (Figure 2) and accumulate in the living areas of a home (2) (3).

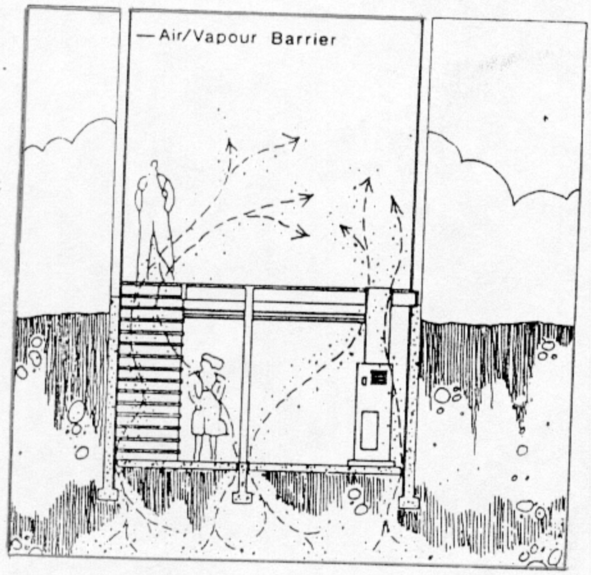

Fig. 2. Standard Basement/Crawlspace/Living Area Configuration Showing Infiltration of Radon Gas into the Occupied Area

To minimize infiltration of radon gas from the ground into theliving areas of the experimental townhomes, the main floors of the townhomes were separated from the ground by crawlspaces. Vents were installed in the crawlspace walls to allow natural cross ventilation. The living areas of the homes were then separated from the crawlspaces by a plywood air vapour barrier subfloor installed between the crawlspaces and main floor (Figure 3).

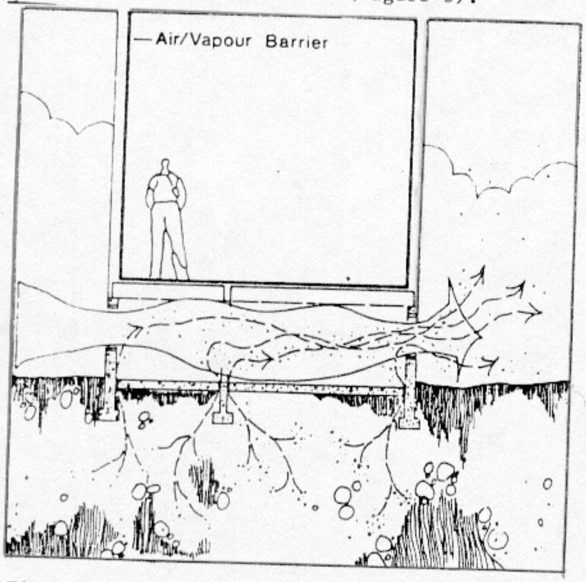

Fig. 3. The Experimental Townhomes Were Separated from the Ground by Means of a Ventilated Crawlspace and Plywood Air Vapour Barrier.

2.2 Limiting Indoor Sources of Formaldehyde

Commonly used household equipment and construction and finishing materials which represent a potential source of formaldehyde were identified. Alternates were substituted where possible.

For example, interior grade plywood, which is bonded by urea formaldehyde based glue, is normally used for construction of subfloors. In the experimental townhomes, interior grade plywood was replaced with exterior grade plywood. The plys of exterior grade plywood are bonded together by phenol formaldehyde based glue which offgasses at a lower rate than interior grade plywood (3). Hardwood flooring and ceramic tile were substituted for carpeting and vinyl flooring as interior floor finishes. Installation of hardwood and ceramic tile minimized the possiblity of formaldehyde off-gassing from glues and synthetic carpet fibres. It should also be noted that the substitution of hardwood for carpeting also avoided bacterial, shampoo residue and fibre problems which may be associated with carpets (4) (5).

Electric hot water tanks, heating systems and appliances were used in the townhomes. Electric appliances eliminate problems associated with indoor combustion of fossil fuels such as creation of formaldehyde, CO, CO_2 and NO_x (6) (7).

Further review of construction technology and finishing materials for possible sources of formaldehyde identified acoustical sealant as a possible source of xylene and toluene. Acoustical sealant is used in energy efficient homes to seal the sheets of polyethylene used to construct an air vapour barrier into a continuous membrane (Figure 4).

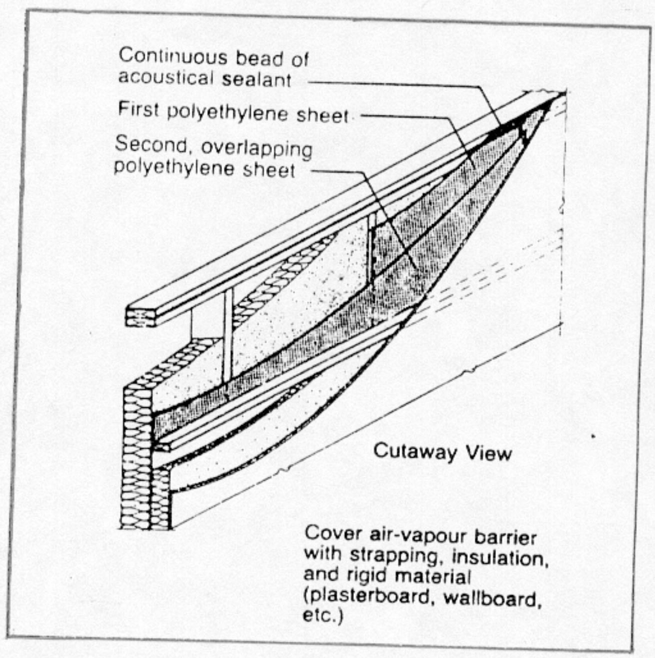

Fig. 4. Standard Polyethylene/Acoustical Sealant Air Vapour Barrier

An alternative vapour barrier technology, known as the Airtight Drywall Approach or ADA has been developed (8). The ADA (Figure 5) approach eliminates the use of polyethylene and requires only minimal use of acoustical sealant. The drywall, in conjunction with foam gaskets and a vapour proof paint is used to seal the building. In order to quantify the effect of acoustical sealant on indoor air quality, one of the townhomes was constructed with an ADA air vapour barrier, and the other townhome was constructed with a polyethylene air vapour barrier.

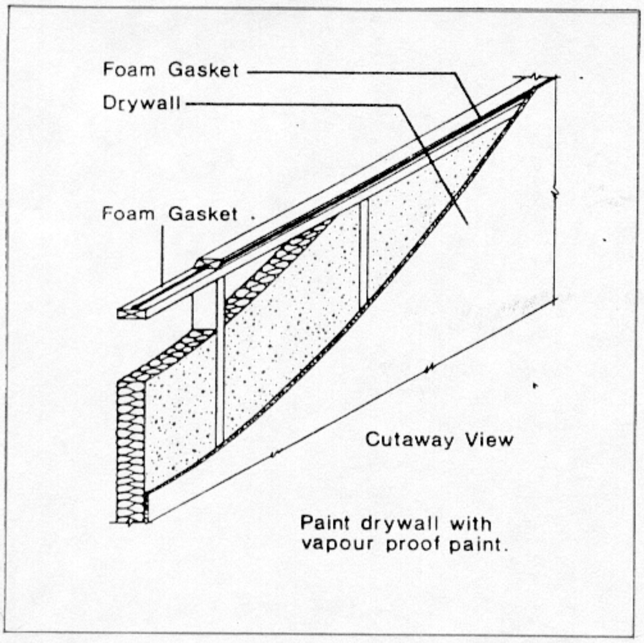

Fig. 5. Drywall/Gasket/Vapour Proof Paint Air Vapour Barrier

3. EVALUATION

After completion of the homes, and prior to occupancy, radon and formaldehyde, and xylene and toluene concentrations were monitored.

3.1 Radon Testing

The effectiveness of direct outdoor ventilation of the crawlspace in reducing occupant exposure to radon contamination was evaluated by comparing indoor radon levels in one of the experimental townhomes and two immediately adjacent residences during October to December 1985:

House A: Experimental townhome, Unit 2

House B: A 67-year old unoccupied house with a basement.

House C: A 50-year old occupied house with a basement.

All three houses are two-storey wood frame homes and are located adjacent to each other.

Terradex Trac Etch Type SF Radon Detectors were placed in the basement/crawlspaces and living areas of House A and C for 88 days and of House B for 75 days. In all locations, the Trac Etch Detectors were pinned to interior vertical partition walls a minimum of 9 feet away from exterior windows and midway between the floor and ceiling.

A concentration of .82 pCi/L (picocurie per litre, measurement of concentration of radon) was recorded in the living area of House A (Unit 2 of the experimental townhomes) compared with 2.04 pCi/L and 1.57 pCi/L in Houses B and C respectively (Table 1). The average radon level measured in a sample of Canada R2000 energy efficient houses was 3.55 pCi/L (9). The ventilated crawlspace and living areas separated by an air vapour barrier in the experimental townhome (Unit 2), resulted in reduction of indoor radon levels approximately 65% as compared to Houses B and C. In addition, the .82 pCi/L measurement recorded in the experimental townhomes is 77% lower than the average concentration reported in energy efficient R2000 homes and 58% lower than the 2 pCi/L concentration defined by the American Society of Heating, Refrigeration and Air Conditioning Engineers 62-1981 Ventilation Standard as acceptable (10).

TABLE 1

RESULTS OF RADON MEASUREMENTS IN THREE HOUSES IN VANCOUVER

			Yearly WLM[2]
		pCi/L	WL[1]
House A (Test House)	Crawlspace	0.07	
	First Floor	0.82	0.0041
House B (Unoccupied Control)	Basement	0.38	
	First Floor	2.04	0.0102
House C (Unoccupied Control)	Basement	0.82	
	First Floor	1.57	0.0079

[1] 1 WL=200 pCi/L, assuming an equilbrium between radon and its daughters of 0.5. U.S. EPA recommend remedial action if WL>0.015.

[2] 1 WLM=680 hours of exposure to 1 WL.

3.2 Formaldehyde Testing

The effectiveness of the use of exterior grade plywood, hardwood and ceramic tile flooring and electric appliances in reducing indoor levels of formaldehyde was evaluated by monitoring formaldehyde concentrations in the two townhomes. Air Quality Research Inc. International PF-1 Passive Formaldehyde Paired Monitors were installed for approximately 118 hours in the two townhomes. The monitors were installed at waist level in the centre of the test spaces. Sampling results (Table 2) indicated levels of formaldehyde in both residences between .015 ppm (parts per million) and .032 ppm. The .015 - .032 range is 46 - 71% lower than the average formaldehyde level of .059 ppm recorded in a R2000 program survey of airtight energy efficient Canadian homes (9).

TABLE 2

RESULTS OF FORMALDEHYDE MEASUREMENTS IN TWO EXPERIMENTAL TOWNHOMES IN VANCOUVER[1]

	Unit 2	Unit 1	Outdoor
Sampling Time (Hours)	118.2	118.2	118.4
Sample 1	.021	.031	.038
Sample 2	.015	.032	.037

[1] All measurements in parts per million (ppm).

Both the formaldehyde levels measured in the two experimental townhomes and the average level reported in the R2000 sponsored survey are well below the Canadian Department of Health and Welfare guidelines of .1 ppm (9). However, the energy efficient R2000 home survey average formaldehyde concentration exceeds the 105 ppm objective adopted to define acceptable formaldehyde levels in UFFI insulated homes by the Canadian Government Urea Formaldehyde Remedial Program (9). The recorded formaldehyde concentrations in the experimental townhomes are 35 - 65% lower than the 105 ppm objective.

It should be noted that the formaldehyde measurement levels of .021 ppm and .015 ppm recorded in Unit 2 were significantly lower than the .031 and .032 measurements recorded in Unit 1. While no specific cause for this difference has been identified, it may be due to the different air vapour barrier technologies used in the two Units. Fibreglass insulation is a source of formaldehyde (3). The polyethylene air vapour used in Unit 2 may be a more effective barrier against infiltration of formaldehyde off-gassed from the fibreglass insulation than the drywall air vapour barrier used in Unit 1.

3.3 Xylene and Toluene Testing

The improvement in indoor air quality associated with use of a drywall air vapour barrier, and the impact on air quality of acoustical sealant in conjunction with polyethylene air vapour barriers was evaluated by monitoring xylene and toluene concentration in the experimental townhomes using Dupont AA Passive Air Monitoring Devices. The monitor devices were hung at the mid point of the test spaces and at an outdoor location on the townhome site. Sampling times ranged between 523 minutes and 535 minutes. Measurement range of .015 - .026 ppm was recorded for xylene and .012 - .068 ppm for toluene in the experimental townhomes (Tables 3, 4). The outdoor concentration of xylene was recorded as .012 and .080 ppm. The outdoor concentrations were .011 and .012 ppm.

TABLE 3

RESULTS OF XYLENE MEASUREMENTS IN TWO EXPERIMENTAL TOWNHOMES IN VANCOUVER[1]

	Unit 2	Unit 1	Outdoor
Sampling Time (Minutes)	535	530	523
Sample 1	.015	.026	.080
Sample 2	.017	.013	.012

[1]All measurements in parts per million (ppm).

TABLE 4

RESULTS OF TOLUENE MEASUREMENTS IN TWO EXPERIMENTAL TOWNHOMES IN VANCOUVER[1]

	Unit 2	Unit 1	Outdoor
Sampling Time (Minutes)	535	530	523
Sample 1	.023	.068	.012
Sample 2	.012	.030	.011

[1]All measurements in parts per million (ppm).

Comparison of indoor and outdoor xylene and toluene concentrations indicate that acoustical sealant used to create a polyethylene air vapour barrier does not have significant impact on air quality in an energy efficient, airtight building. However, comparison of recorded toluene measurements in Units 1 and 2 indicate that some component of the drywall air vapour barrier system, most likely the vapour proof paint, is off-gassing approximately 50% more toluene than the components of polyethylene air vapour barrier system.

4. CONCLUSION

An architectural approach to improving air quality can be an effective and energy efficient means of improving air quality in buildings. Separation of the living area from the ground by a crawlspace and installation of an air vapour barrier between the crawlspace and living areas of the townhomes resulted in radon concentrations 65% lower than those recorded in adjacent homes. Radon concentrations in the experimental townhomes were also 77% lower than the average concentration reported in a survey of Canadian energy efficient homes. Use of exterior grade plywood, hardwood and ceramic tile flooring and electric appliances was effective in reducing formaldehyde concentrations in the experimental townhomes as compared with the average concentration reported in the energy efficient home survey. Acoustical sealant does not appear to have any significant impact on air quality in buildings constructed with a polyethylene air vapour barrier. However, toluene concentrations in homes constructed with a drywall air vapour barrier system may be significantly higher.

5. NOMENCLATURE

pCi/L - picocurie per litre, measurement of concentration of radon

ppm - measurement in parts per million

6. REFERENCES

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