IMPROVING AIR QUALITY IN ENERGY EFFICIENT HOUSES: AN ARCHITECTURAL APPROACH

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ABSTRACT

Two energy efficient townhomes were designed and constructed in an experiment designed to improve indoor air quality through manipulation of building architecture. Explored within the context of the townhouse project were architectural means of:

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 homes by substitution of electric, for gas, appliances. To minimize radon gas infiltration, the houses were constructed on ventilated crawlspaces and an air/vapour barrier installed between the main floors and the crawlspaces.

Air quality in the two experimental homes and in two control houses was monitored to evaluate the effectiveness of the designs for improvement of indoor air quality.

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Two energy efficient townhomes were designed and constructed to evaluate the effectiveness of an architectural approach for improving indoor air quality in energy efficient residences. An architectural approach to improving indoor air quality as a design process which takes into consideration not only aesthetic, technological and financial constraints generally associated in the design process, but also considers the impact on indoor air quality of the components and configuration of a building.

In the context of the townhome project, architectural means of improving indoor 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.

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 without consuming any energy resources, provide acceptable indoor air quality.

PROJECT DESIGN

The experimental townhomes are two storey, 1800 square feet, side by side units sharing a party wall (Figure 1). Energy efficient construction technology developed by the Canada Mortgage and Housing Corporation Energy Efficient Housing Program was used in the construction of the townhomes (CMHC 1982). 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 ceiling. 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.

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 (CMHC 1982). As a result, radon gas may infiltrate from the soil into the basement or crawlspace through joints or cracks in the foundation (Figure 2) and accumulate in the home (LaFavore 1986, Meyer 1983).

The architectural design response defined to minimize infiltration of radon gas from the ground into the living areas of the experimental townhomes was separation of the main floors of the townhomes from the soil beneath the homes by means of a crawlspace and air/vapour barrier. (Figure 3). In addition, vents were installed in the crawlspace walls to allow natural cross ventilation of the crawlspaces.

Limiting Indoor Sources of Formaldehyde

Commonly used household equipment and construction and finishing materials which represent a potential source of formaldehyde were identified through a process of identifying each component of a standard residential building and evaluating each component's impact on indoor air quality.

For example, interior grade plywood, which is bonded by urea formaldehyde based glue, is normally used for construction of subfloors in residential buildings in the Vancouver area. 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 off-gasses at a lower rate than interior grade plywood (Meyer 1983). Other possible sources of formaldehyde identified during the building component review were carpeting and linoleum adhesives and gas appliances.

Hardwood flooring and ceramic tile were substituted for carpeting and vinyl flooring as interior floor finishes. Installation of hardwood and ceramic tile minimized the possibility 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 (Kreiss and Hodgsen 1982, Morey 1984).

Electric hot water heaters, space heating systems and appliances were used in the townhomes. Electric appliances eliminate problems associated with indoor combustion of fossil fuels which create formaldehyde, CO, CO_2 and NO_x (Sterling 1979, Traynor 1982).

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).

An alternative vapour barrier technology, known as the Airtight Drywall Approach or ADA has been developed (Lstibore, Lischoff). 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 a polyethylene air/vapour barrier.

EVALUATION

After completion of the homes, and prior to occupancy, radon and formaldehyde, and xylene and toluene concentrations were monitored. One of the control houses was also unoccupied while the second control home was occupied by a single person. It should be noted that formaldehyde levels in occupied residences should be expected to be higher than in unoccupied houses due to the presence of furnishings, etc. (Gesser 1986).

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 Houses A, B and C. The radon detectors were present in Houses A and C for 88 days and 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 in 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 Canadian energy efficient houses was 3.55 pCi/L (Dumont 1986). 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 homes and 59% 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.

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 rooms in which the formaldehyde monitors were placed. Sampling results (Table 4) indicated levels of formaldehyde in both residences between .015 ppm and .032 ppm. The .015 - .032 range is 46 - 71% lower than the average formaldehyde level of .059 ppm recorded in a survey of energy efficient Canadian homes (Dumont 1986).

The recorded formaldehyde concentrations in the experimental townhomes were 35 - 65% lower than the .05 ppm objective. The average formaldehyde level reported in a survey of energy efficient homes exceeds the .05 ppm objective adopted to define acceptable formaldehyde levels in UFFI insulated homes by the Canadian Government Urea Formaldehyde Remedial Program (Dumont 1986).

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 (Meyer 1983). The polyethylene air/vapour barrier 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.

Xylene and Toluene Testing

Airborn xylene and toluene concentration in the experimental townhomes was monitored using Dupont AA Passive Air Monitoring Devices. The monitor devices were hung at the mid point of the dining rooms of the townhomes 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 (Table 3, 4). The outdoor concentration of xylene was recorded as .012 and .080 ppm. The outdoor concentrations (for toluene) were .011 and .012 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. In fact, the level of toluene recorded in the unit constructed with the polyethylene air vapour barrier was 50% more than the unit constructed using the drywall air vapour barrier system. While no specific source of the additional toluene recorded was identified, it would seem that some component of the drywall air/vapour barrier system, most likely the vapour proof paint, is off-gassing more toluene than the components of polyethylene air/vapour barrier system.

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. The effectiveness of the measures, specifically use of electric appliances, in reducing formaldehyde concentrations in energy efficient homes also implies reduction of other combustion generated contaminants such as CO, CO_2 and NO_x. 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.

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Table I. Results of radon measurements in three houses in Vancouver.

			Yearly WLM[2]
	pCi/L[3]		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 (Occupied Control)	Basement	0.82	
	First Floor	1.57	0.0079

[1] 1 WL = 200 pCi/L, assuming an equilibrium 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] pCi/L - picocurie per litre,(measurement of concentration of radon)

Table II. Results of formaldehyde measurements in two experimental townhomes in Vancouver.

	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).

Table III. 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 IV. 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).

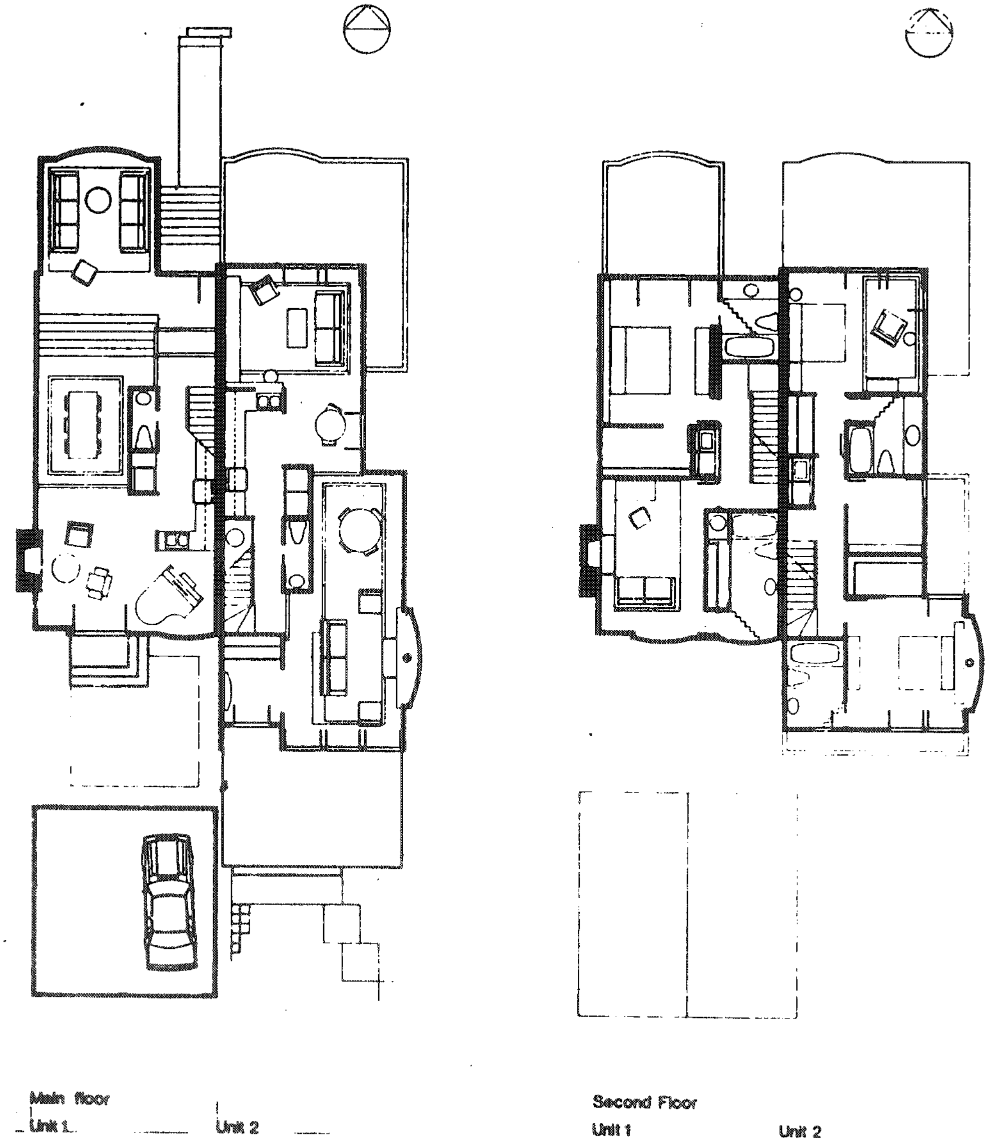

Figure 1. Main and second floor plans of experimental townhomes.

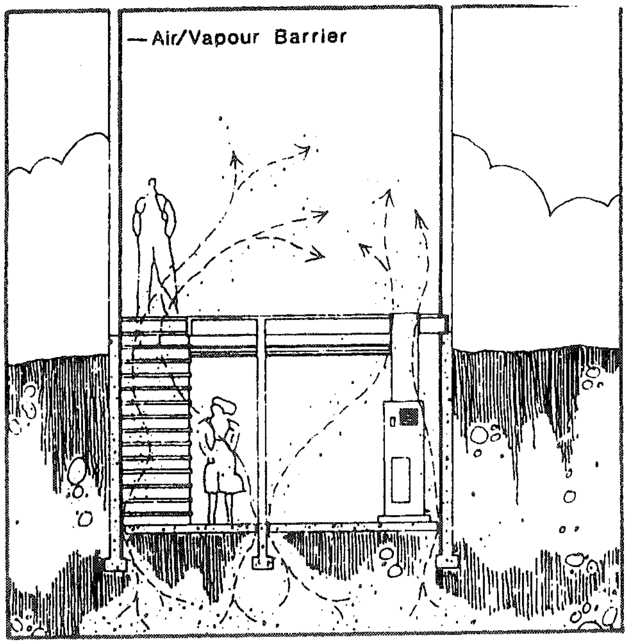

Figure 2. Standard basement/crawlspace/living area configuration showing infiltration of radon gas into the occupied area.

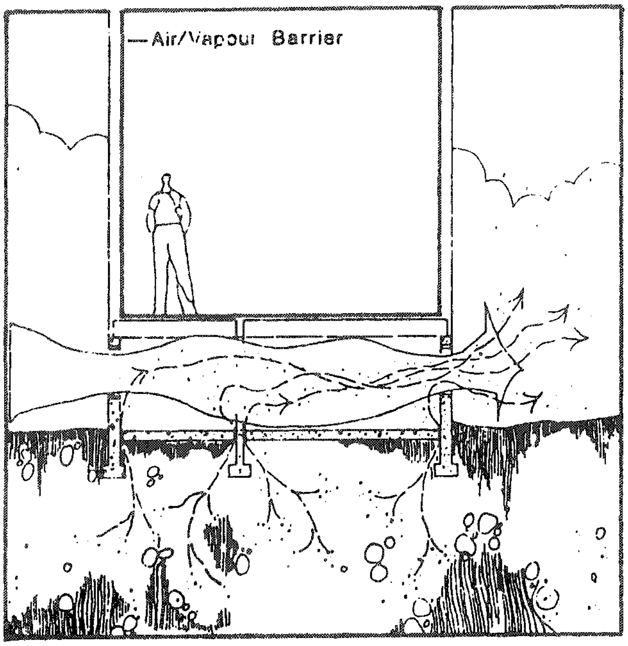

Figure 3. The experimental townhomes were separated from the ground by means of a ventilated crawlspace and plywood air/vapour barrier.

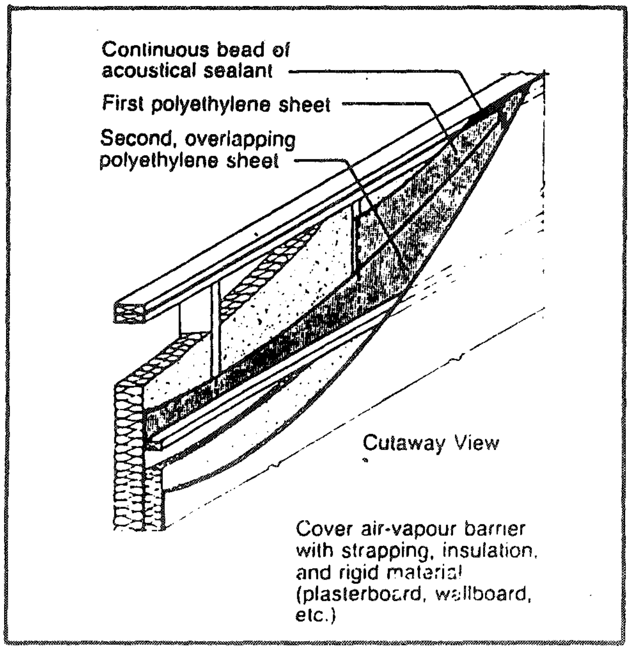

Figure 4. Standard polythylene/acoustical sealant air/vapour barrier.

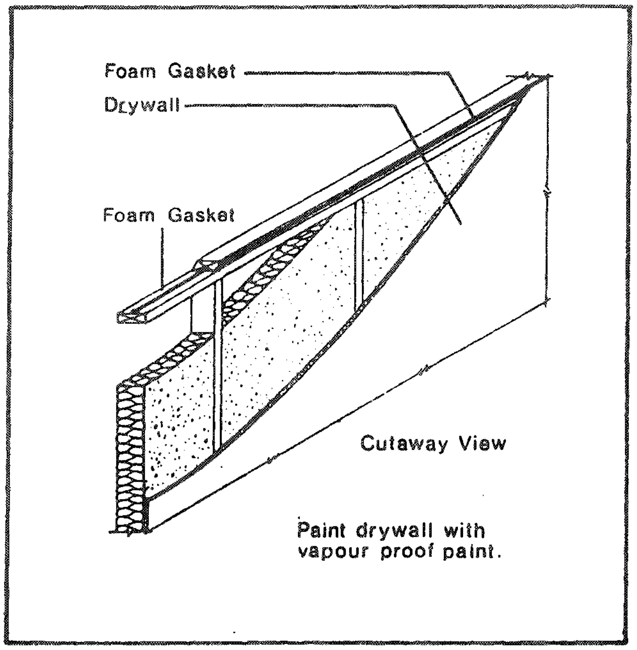

Figure 5. Drywall/gasket/vapour proof paint air/vapour barrier.