RESEARCH REPORT

Investigation Of Crawl Space Ventilation and Moisture Control Strategies for B.C. Houses: Appendices

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INVESTIGATION OF CRAWL SPACE VENTILATION AND MOISTURE CONTROL STRATEGIES FOR B.C. HOUSES

APPENDICES

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APPENDIX I

DESCRIPTION OF CURRENT PRACTICES

IN B.C. HOUSES

A synopsis of the conversations with local builders and inspectors in the B.C. lower mainland is given below and serves as a general outline of typical crawl space design practice:

1. **Foundation**: Perimeter foundation stem walls are moisture sealed on the exterior from footing to grade level with a bituminous water proof emulsion. A very few builders will waterproof inside walls and the top of foundation walls but this method is not favoured by framing contractors because of the residue that is picked up on tools, hands and boots during sill plate installation;

2. **Drainage**: Requirements for site preparation and drainage differ from one municipality to another depending somewhat on soil types and water tables but mostly on storm sewer capacities. In Surrey B.C., housing development has outgrown storm sewer capacity and sites are required to be graded, as well as possible away from the building. Surface water from roof drainage then percolates through soil slowly enough to avoid overburdening the storm sewer.

In general three types of site drainage systems are found:

- **Dual system:** In the Greater Vancouver district a two pipe or "Dual" system has been adopted since August 1987 (See *Sewer Separation Program* in Appendix IV). Rain water is drained directly to the storm sewer through a rigid 100 mm PVC pipe from rainwater down pipes on 2 sides of the building. Groundwater around the building is also drained to the storm sewer through a second system of flexible 100 mm corrugated or rigid-perforated drain tile. Perimeter and roof drainage will usually terminate at a sump or collection box located at the lowest point in the system and then on to the storm sewer.

- **Combined system:** Also in Vancouver and vicinity, a combined system is still in use in many new and existing homes. This is where rain water run-off and foundation drainage are combined. A riser from the foundation drain to the surface is tied to a rain water down pipe and the single drain tile is sloped to a sump and then to the storm.

- **Single Pipe system:** In Surrey , Langley and other areas, only a foundation drain is installed. Rain water leaders are directed to a splash trough which diverts water away from the foundation wall.

The tile is believed to be placed beside the footing to ensure that it lies below the crawl space floor but this is very difficult to ensure. A minimum slope is required of 1 in 50 (depending on maximum load on drain) and placement depends on the slope of the footings, site grading, minimum depth below grade and other factors beyond the inspectors control (such as a builders' competence). This is a major concern among inspectors who claim that placement at or above floor height is common and is a potential source of problems.

3. **Insulation**: Perimeter walls are usually insulated on the interior with 2" Styrofoam (RSI 0.53) extending from 25 mm below sill plates to 300 mm below frost line which in the lower mainland is 25 cm below grade. The styrofoam boards are fastened mechanically and often adhesives are used in combination with mechanical fasteners. In most cases a minimum of fasteners are used - ie. 2 concrete nails centred on a 600 mm X 2400 mm panel - and air and moisture are free to travel behind them causing warpage which decrease its effectiveness dramatically. A better approach taken by some builders is applying the insulation to the exterior of the foundation wall from grade to footing. This assures a warmer interior surface temperature. Better quality SM Polystyrene insulation board with higher insulation value (RSI 1) is used sometimes depending on builders.

4. **Capillary Break**: In the lower mainland, a 100 mm layer of compacted fine granular sand is typically placed over a roughly graded fill on the crawl space floor. The sand is considered a free draining soil with a negligible capillary effect although water vapour can travel freely through it. In actuality however, the type of sand used has a capillary rise of 10 to 30 cm making it an ineffective break. Some local builders use a more coarse granular fill or torpedo gravel which has virtually no capillary rise. In areas outside of the lower mainland, sand or gravel fill is rarely used, with concrete poured directly on the compacted soil.

5. **Ground Cover**: At this point the builder will usually choose to use one or both of the following ground covers:

   - 0.15 mm poly moisture barrier with 100 mm overlap at joins, laid over the compacted sand; and/or,
   - A 50 mm concrete skin coat.

   The skin coat surface is finished with a "bullfloat" - a long handled 1 meter wide trowel producing a relatively smooth but very porous surface. Sometimes a simple 1 to 2 meter long sraight-edged board is used as a float and dragged across the surface by two workers holding opposite ends. The skin coat can vary in thickness from almost nothing to 100 or 125 cm. Although the combined use of polyethylene vapour barrier and skin coat was never enforced, it constitutes good construction practice, and is recommended by most architects, builders, and inspectors. But without a pre-slab inspection, poly is left out. A single floor drain is sometimes provided at the lowest point but not always.

   A recent issue, which has caused some confusion regarding the use of 6 mil (0.15 mm) poly vapour barrier, is that two types of poly are available to builders that are both called "6 mil". When purchasing poly as a vapour barrier one can receive either 6 mil nominal or 6 mil vapour barrier. The former was frequently applied although it has an actual thickness of only 3.3 mil (0.08 mm) and does not meet the CMHC standards imposed for this application[1].

[1] Sheltair experienced this problem firsthand when purchasing poly for the House #6 retrofit. It was not discovered that the wrong material was being applied until 1/3 of the floor was covered.

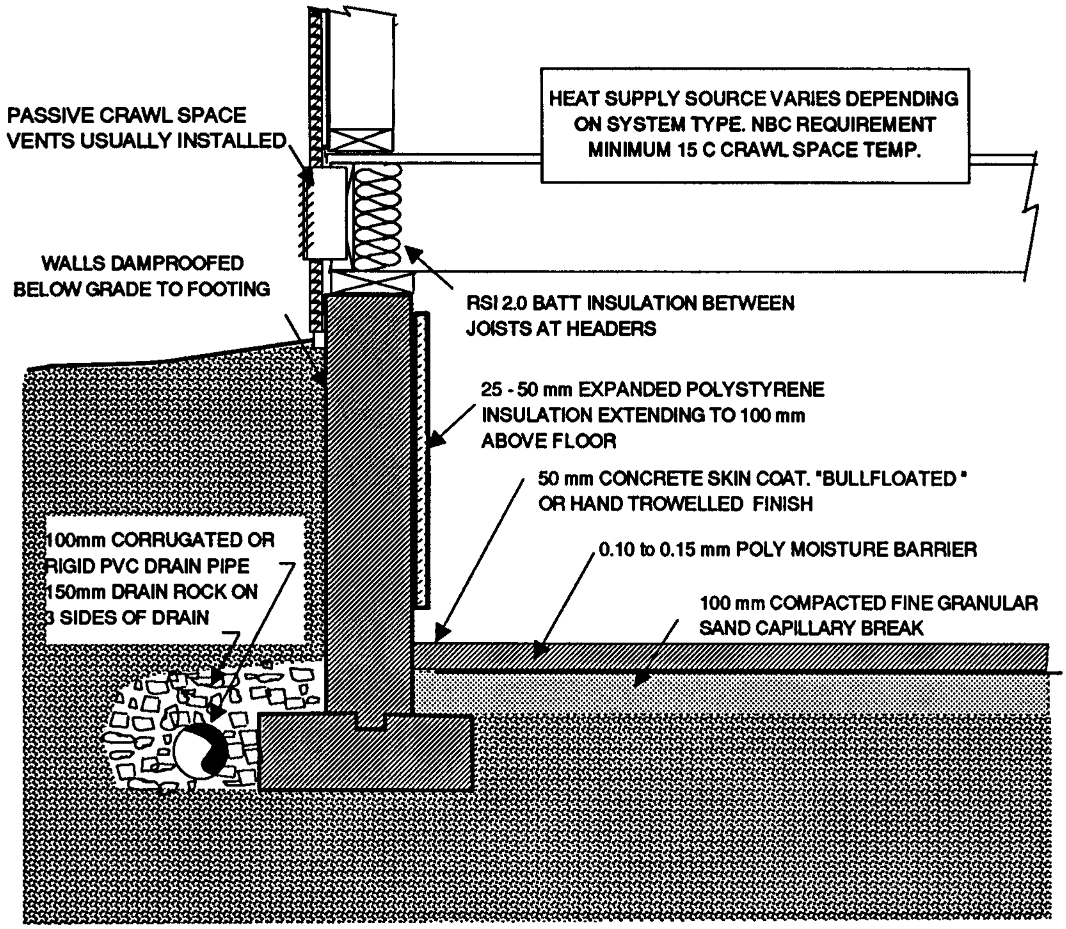


Figure A1-1: Typical Heated Crawl Space Construction in B.C.

6. **Ventilation**: Crawl space vents are required by most inspectors if the crawl space is non-heated (ie. if the crawl space temperature can fall below 15 °C). In Greater Vancouver there are stringent requirements for ventilation of the crawl space and it is only considered *heated* when complying with Article 6.2.4.4 (3) of the BC code (stated in the section below). The net vent area should be greater than or equal to 0.1 m^2 for each 50 m^2 of floor area. This is rarely calculated or measured on site by the inspector however, and it seems that an estimation is usually made. For example a typical vent has a free area of 350 cm^2. Therefore a 150 m^2 crawl space would require 9 vents.

   The ventilation issue can be considered the "grey area" of crawl space design. Codes are enforced differently in different municipalities and even by individual inspectors.

7. **Heating:** In some municipalities, like Surrey and Langley B.C., passive vented crawl spaces with forced air heating ducts represent approximately 50% of all new housing. If the crawl space is to be heated, supply outlets (forced air heating) or space heaters must provided to ensure the 15 °C minimum is met. Space heaters however are rarely prescribed and were not encountered during the field investigations in the lower mainland. Confusion about use of the term *warm air plenum* in Article 6.2.4.4.(3), and 9.18.3.5 of the B.C. Building Code has caused overheating of many crawl spaces with forced-air systems installed in them. the BC code requirement in Article 6.2.4.4.(3) states:

- In crawl spaces used as warm air *plenums*, at least 4 supply outlets shall be provided and located to direct the air towards the corners of such crawl spaces.

Typical Problems:

As groundwater moves through the soil, the house acts as a dam to impede its flow. If drainage is insufficient, or drain tile slightly blocked or positioned incorrectly (ie. at a higher elevation than the crawl space floor), then the water tables rise and the soil beneath the crawl space floor becomes saturated. The groundwater then migrates through the slab as vapour or directly by hydrostatic forces. In the case of House #9, groundwater levels were above the crawl space floor level and inundated the entire area causing excessive damage to property. It is likely that drain tile had been crushed or silted and rendered ineffective.

Crawl spaces built with uninsulated subfloors remain quite warm all year round (above 15 °C) and the surface water evaporates easily (House #6). As the surface drys, the capillary effect of the concrete pores increases and the surface water is continuously replenished until the soil beneath is dry (practically never).

All other moisture problems in the these crawl space were directly related to groundwater seepage, its migration and subsequent evaporation. Some of these problems are listed below.

- Bottom plates of structural support walls sitting on the slab absorb water (as in House #2 where wood moisture content (MC) was 25 to 30%[2]) and eventually decay leading to expensive repairs;
- Moisture from humid crawl space air condenses behind insulation on cold perimeter wall surfaces and on header joists;
- Moisture-laden air migrates into living spaces through interface air leakage points or via forced air duct work. The higher humidity levels increase window condensation potential in the living areas especially during the fall & winter ;

[2] ASHRAE Fundamentals 85, 21.2 states that the required MC to sustain decay has been estimated at 24 to 31%. The recommended MC target is 20% for sufficient safety margins.

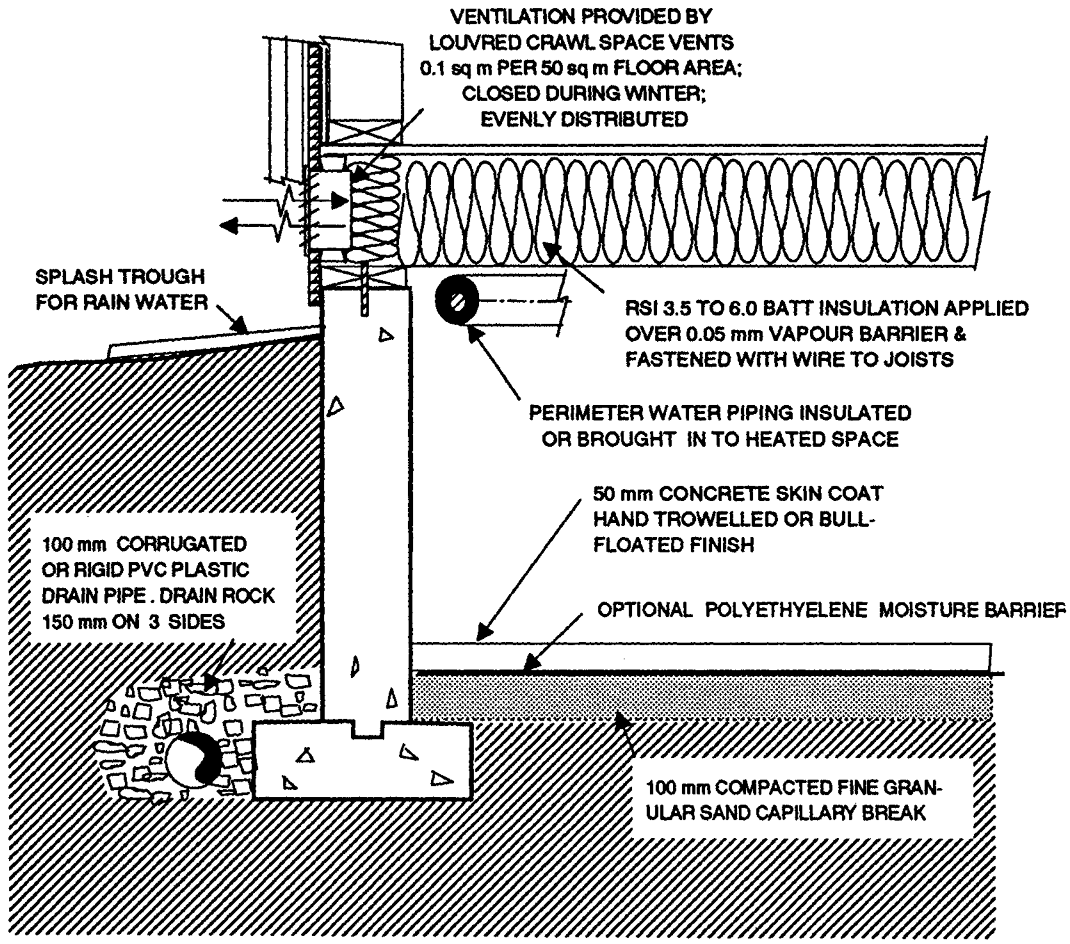


Figure A1-2: Typical Non-heated Crawl Space Construction

- Musty odours from efflorescence and fungal growth in the crawl space travel through living spaces and tend to linger, especially in cold rooms or rooms that have lower air change rates than others (House #6 #1

- Energy costs are higher due to added requirements for heating moist air and for increased ventilation of house and C.S. (ie. if a humidity controlled fan is installed in the crawl space it may be energized for extended periods); and,

- using the crawl space as a storage facility becomes impractical. In some cases unexpected flooding caused extensive property damage (House #9);

- general discomfort and anxiety are experienced by occupants when problems persist.

IMPORTANCE OF GROUND COVER

As a Moisture Barrier: The *Building Foundations Design Handbook (Labs et al 1988)* notes that ground cover membranes are the single most important way to prevent condensation and wood decay problems in crawl spaces. It is our opinion also, at this time, that an effective *moisture* barrier will solve most of the present problems experienced locally. This (moisture/air/vapour) barrier functions dually to reduce entry of soil gasses (methane and radon) in regions that are prone to them in excessive quantities.

As a Soil Gas Barrier: Soil gas problems created by elimination of vents may be resolved by the existence of an effective and properly installed moisture barrier. However, it is extremely difficult to ensure such an effective seal in practice. Coupling of the crawl space to the house may still cause soil gasses to infiltrate into the house. A solution for this may be to add an exhaust outlet to the crawl space if appropriate ventilation equipment is installed.

One drawback to establishing an extremely effective moisture barrier is that, should flooding occur, the barrier will prevent easy permeation of water back into the soil. To account for this floor drain(s) *must* be provided at the lowest elevation of the slab to ensure quick surface water removal.

Site Conditions & Classification:
The issue of site conditions is usually addressed in most code books in a similar fashion; General phrases like, "If high groundwater levels exist" or "if moisture conditions are excessive" or "if water can accumulate" are standard for drainage related codes. The question that is raised by this is; How can these issues be determined and by whom?
Ideally, a builder or homeowner should research groundwater history for any particular building site or area and then if necessary decide to use extra precautionary measures such as - installing a sump-pump (rare in the lower mainland) or increasing drainage capacity. Unfortunately, this type of hydrological study is complicated and impractical for an individual residential site. A Geotechnical engineer must be brought in to do this job (or a douser). In a conversation with a local Geotechnical firm, the procedure for site inspection was outlined.

A senior Hydrological engineer could assess a site as follows:

1. reviewing the local climate and topography;
2. make a site visual inspection;
3. review existing drainage and climate, and make an estimate of conditions;
4. decide whether a sub-surface investigation was required;
5. drill a test pit or pits, document results, test permeability; and,
6. make recommendations.

The estimated cost for the preliminary investigation (before any sub-surface testing takes place) would be $300 to $500. Further testing requires machinery for test pit drilling and operators at costs from $100/hr.

NBC 1985 & 1990 Subsection 9.18.5.1.(and BCBC 5.5.3.2.) address the issue of special drainage considerations for crawl spaces. The article states that:

> Unless *groundwater* levels and site conditions are such that water will not accumulate in the crawl space, the crawl space shall be sloped to drain to a sewer, ditch or dry well.

The term "site conditions" here is key to the article and could be interpreted in two ways:

1. The site is in an area where groundwater levels are very low due to obvious reasons such as high elevation or semi-arid climate as in the Okanagon; or,

2. The site is in a potentially high groundwater area but has been investigated by a hydrological professional.

Thus, there is no clear statement made in the article.

As a result of the PIRF crawl space study performed by DOW Chemicals, an Inspection Checklist was developed as a tool for builders, installers, and inspectors. In general the checklist looks at proper drainage and site grading to assure surface water run off. A similar checklist could be developed in house by B.C. Municipal Buildings Inspection groups.

Assurance of proper site grading and drainage for known problem areas would greatly assist in the resolution of these issues. The small percentage of sites that require extensive drainage systems would not impose a penalty on all housing in B.C..

Moisture Barriers & Soil Gas Entry:
Changes to the NBC in the 1990 edition address damproofing of concrete slabs. Slabs will have improved resistance to soil gas, particularity radon-bearing soil gas. An important revision has been made to Article 9.13.1.3. (1) which presently states that:

(1) Except in garages, slabs-on-ground shall be damp-proofed *unless it can be shown to be unnecessary.*

The 1990 NBC requirement is more specific. Article 9.18.6.1. (3) read as follows:

(3) Where a crawl space serves a *dwelling unit* and is not vented to the outside air, a ground cover consisting of not less than 0.15 mm polyethylene sheet conforming to CAN2-51.34-M, "Vapour Barrier". Except in garages and unenclosed portions of *buildings,* concrete slabs-on-ground **shall be damproofed.**

The suggested materials for damproofing follow including CAN2-51.34-M, "Vapour Barrier, Polyethylene Sheet, for use in building construction. The revised version is more stringent than the 1985 version. The advantages to the homeowner of this proposed policy far outweigh disadvantages, such as additional cost, which in the base case is very low.

John Haysom of the National Research Council commented on the 1990 code revisions that the measures implied to reduce radon infiltration, are all *difficult to retrofit,* but they are *low-cost,* and *desirable* for the benefits that they provide.
An earlier draft of this proposed code change allowed for concrete with a strength of greater than 25 MPa as an alternative to dampproofing as it would reduce the permeability, but sources Canadian Portland Cement Association (CPCA) and others imply that the measure would not reduce cracking which is thought to be a more important determinant of slabs resistance to soil gas entry.

APPENDIX II

DETAILED CASE STUDIES OF TEN

LOWER MAINLAND HOUSES

List of Photos & Figures

List of Photos & Figures

1. CASE STUDY HIGHLIGHTS

The most significant findings arising from the 10 house survey are summarized in this section. Issues and observations are presented in the order that they are addressed in the Building Codes. Occupant concerns are also included to provide a more complete perspective.

Site Conditions
In the case of completed homes, site conditions can only be evaluated from surface observations, the occasional test hole with a shovel, and the homeowners or builders re-collections. For this reason, research into site conditions only "scratched the surface".

Excavation -

- At House #6, the site had previously been used for the storage of several tons of non-indigenous clay which were removed during the excavation. In total some 1200 cubic yards of clay were removed and replaced, after completing the foundations, with more than a meter of local fill. We speculate that a residual layer of clay was left below causing a ground water to be *perched* above its normal level. This could be partly responsible for the high ground water levels at this site.

- At House #2, a large municipal storm drain had been placed on the property line between House #2 and an adjacent lot. This is not a common phenomenon and homeowner believed that a failure in the piping system may be causing his ground water levels to be high. This would explain the absence of problems in the houses on neighbouring lots.

- At House #9, ground water tables were well above the crawl space floor level. The site had been situated more than a metre lower than the adjacent lot. Run-off from the neighbouring lot is partly responsible, since conditions are worse on rainy days. It is also possible a spring is located under the slab since water levels are only kept under control by frequently pumping from sump pits that have been recently installed. While on site, Sheltair observed backfill which contained a large percent of organic matter which had been thrown in by the builder. A test of the foundation drain showed a blockage and almost no drainage from the highest point.

Run-Off Water Retention - Many sites were found to have low permeability in the upper soil regions. Rainwater run off tends to be retained on the lawn surfaces for more than 12 hours after rainfall. If this low permeability is restricted to the top layer, it can be beneficial in reducing storm sewer requirements especially in municipalities where systems are already heavily overburdened like Surrey. Most sites have lawns installed by landscape contractors. The rolled sod often has a clay base which acts to reduce permeation of surface water.

Drainage

Foundation drainage - Foundation drainage systems were virtually identical in all but 1 of the houses visited and consists of a 100 mm plastic flexible perforated drain tile terminating at a collection box or sump. In House #5 the dual system was employed and rigid PVC used. In some of the houses no special measures were taken at the initial building stage in anticipation of problems. None of the sites had clean outs or risers located so as to easily test or service foundation drains. House #5 employed the dual drainage system in which rain run-off water and foundation drainage are carried separately to a sump and then to the storm sewer.

Floor Drains - Only four of the ten houses had floor drains. In House #10, the floor drain was installed to accommodate the overflow drainage requirement for the domestic hot water tank (see Appendix) and not as functional floor drain. In House #1 the floor was sloped to a 5 gallon pail serving as a sump for emergency flood control.

Drainage Problems: In the case of the problem houses, NHWP commissioned drainage system testing as a first step in diagnosing moisture problems.

- In House #6, an especially confusing problem misled the contractor into unnecessary expense. Incidence of water, pooling under a chimney cavity in the crawl space, led to an assumption that the drain tile was blocked or damaged. The entire front elevation of the house was re-excavated and drain tile replaced. To ensure quick migration of groundwater drain rock was installed to a full 1 metre in depth above the footing. It was later determined by Sheltair that the water pooling had been caused by the migration of moist crawl space and house air into the back of the fireplace opening. Moisture was condensing on the cold masonry and metal surfaces in the chimney cavity then running down the inside foundation wall into the crawl space. This type of confusion reflects a need for builder education or technical support services in the area of moisture, humidity, and foundation construction.

- In House #9, it is suspected that silted drain tile has reduced the effectiveness of the system and is partly responsible for the moisture problems. An on site investigation of the drain tile showed a fully saturated layer of fill at the top of the tile and an absence of drain rock cover. Other research has shown that fine silts can travel with the flow of groundwater through coarse fill and into the perforated tile, eventually causing blockage.

Floor & Curb Wall Construction

All of the houses studied had concrete ground covers typically 50 mm thick. In four of the ten, Houses #1, #6 and #10) no poly vapour barrier was installed beneath the concrete. Not surprisingly, these were 4 of the 6 houses with reported problems. All of the houses had fine granular sand placed below the concrete as a supposed capillary break. In two of the houses, Houses #8 and #10, concrete was observed to have thinned to nothing in some locations, exposing poly and sand. In House #10, the areas where the concrete was thin were notably wet compared to other areas.

Extensive cracking of the skin coat was common to all houses. House #5 and House #8 slabs were the most severe effected. These were also two of the driest crawl spaces. In House #8, examination of a large crack permitted investigations to assess whether concrete cracking might be effecting the vapour seal. It was observed that a 12 mm wide crack in the concrete had no effect on the poly barrier which remained intact.

The absence of concrete curb walls for interior support walls may cause structural damage in many houses built in this manner. Three (3) of the houses visited had support walls built at floor level and in House #2 and House #10, measured wood MC's were greater than 20 % at the sill plates. These pony walls rest on a concrete footing that is flush with the floor slab. Moisture moving horizontally through the floor slab saturates the sill plates. Figure 4 shows the typical moisture gradient of sill plates resting on the slab.

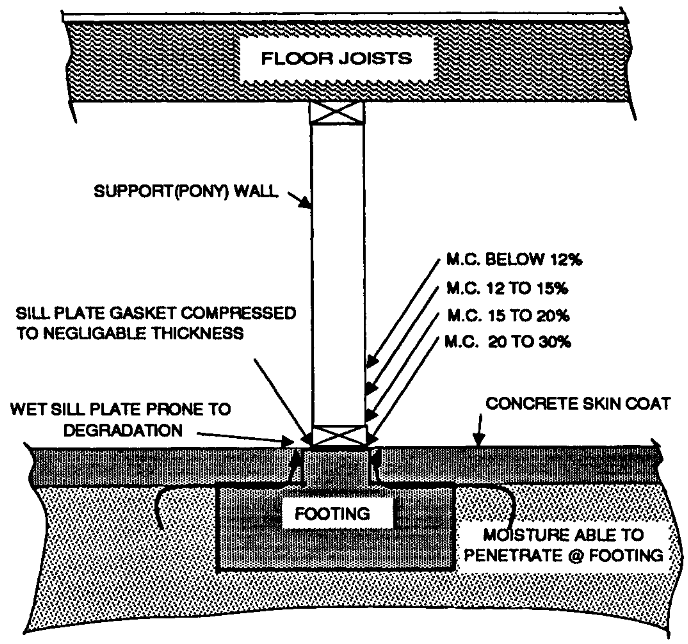


Figure A2-1: Typical support wall moisture gradient.

Insulation

Perimeter Walls: Poorly applied rigid insulation leaves more opportunity for condensation along concrete walls above grade, especially if humidity is high. In the three NHWP problem houses, insulation had been removed to dry the concrete surface. The best practice, used in House #5, is to insulate from the outside at grade level. All other nine houses were insulated from the interior with 35 to 50 mm expanded polystyrene board. In most cases the insulation extended from sub floor level to 70 cm. The minimum requirements are for insulation to extend to below the frost line, which in the lower mainland is 30 cm below grade. The common method of fastening insulation to the walls is to use two (2) concrete nails per 30 cm X 240 cm sheet. In some of the houses an adhesive was also used in combination with the fasteners. In House #8, no adhesive had been used and the sheets had warped leaving 25 to 50 mm air spaces behind the rigid insulation permanently reducing the effectiveness.

Floors: None of the houses had perimeter insulation installed below the concrete. In House #10, as a retrofit in House #1 and in a portion of House #7, the sub-floor above the crawl space was insulated.

Joist Headers: All of the houses except House #5 had headers insulated to approximately RSI 2.1. Batt insulation was used in all cases, without a vapour barrier, except in House #10. The highest wood MC's were measured behind the joist header insulation. In Houses #6 and #9 an MC of > 20 % was typical. Four weeks after the House #6 retrofit, drying has brought these levels to < 20 % in most areas.

Heating

Provision of Heat: Heat is provided by the forced-air distribution systems in five of the houses. The amount of supplied warm air varies from a single grill in House #10, to four (4) supply sources in House #2. Despite the variety of systems, air temperatures in the crawl spaces were warm, achieving temperatures above the 15°C requirement cited in the codes. Monitoring in House #6 has shown that, with no supplemental source of heat other than radiation from the subfloor, an average and relatively stable temperature of approximately 14 °C was maintained, even though hot water piping to radiators had been insulated, the 4 crawl space vents were open and outdoor temperatures had dropped to as low as -5 °C.

Poor Duct Construction: In House #4, abnormally high fuel costs for the heating season were reported. A cursory investigation revealed that these could be related to crawl space heat loss. Crawl space vents were left open during the winter bringing a supply of cold air into the very leaky return air plenum, causing high infiltration during furnace on cycles. During the investigation in the crawl space, a 60 X 70 cm opening was discovered in the return air duct only 1 m from the furnace blower inlet. The installer had forgotten to close the duct. Also, duct tape used to seal the duct work had failed in many areas.

Ventilation
Six of the ten case study houses had installed passive ventilation. In three houses the passive vents had been installed as retrofits in order to lower humidity levels (House #1 and House #9). Of the six forced-air heated houses, four are now vented[1].

The tracer gas air change tests in House #2 and House #5 , showed that even at moderate outdoor temperatures of 7 to 10 °C, natural air change was adequate. In House #5, with no installed vents, the average natural air change rate was 0.36 ACH. In House #2 with all but two (2) vents blocked with insulation, an average of 0.59 ACH was measured with an outdoor temperature of 7 °C and a crawl space temperature of 14 °C.

Air Tightness
Air tightness testing with a door fan was performed in 9 of the 10 houses (House #9 was not tested at request of the homeowner). The leakage areas were broken down into 3 categories and described below:

- **Crawl Space Vent & Total Leakage Area:** The average vented crawl space leakage area was 1920 cm^2 ([2]). This figure includes the installed vent leakage area and the accidental leakage area around the sill plate and other penetrations to the outdoors below the interface. Comparatively, the leakage area for the non-vented houses averaged 428 cm^2. The tightest non-vented house was House #5 at 330 cm^2. The greatest leakage area, House #4 at

[1] Duct leakage probably provides ample air change in three of these houses, regardless of any air change resulting from the installed ventilation area.

[2] (not incl. Dalgliesh house)

2764 cm^2, was 15 % greater than the code required ventilation of .1 m^2 / 50 m^2. The installed ventilation area in House #4 was actually 67% of the code requirement. All other houses measured well below the code requirement, even when accidental leakage areas are added to the installed vent area.

- **Interface Leakage:** The dependant factor for the size of the interface leakage area was the type of heating system. On average, forced air houses had an interface leakage 510% larger than the radiant houses. Duct leakage and supply air outlets make up this difference for the most part[3]. The largest interface leakage was House #3 at 1628 cm ^{2} and the smallest was House #10 at 256 cm^2 . The latter is surprising because it is a forced-air house. However, the amount of ducting in the space and the plan area of House #10 are small, the ducts are well constructed, and the only supply air opening was closed during the test.

- **House Leakage:** House leakage includes only leakage above the interface. The average house leakage was 1045 cm^2. House #2 & House #5s have the largest envelope areas and were also the leakiest; House #7 was the tightest. In a normal airtightness test, leakage into the crawl space would be added to the house leakage. The latter would not be as high as the interface leakage measured in our test however, because of the pressure drop between the two zones.

[3] Because of the measurement technique used, this does not include leakage into wall cavities via duct runs.

2. DETAILED CASE STUDIES

House #1.

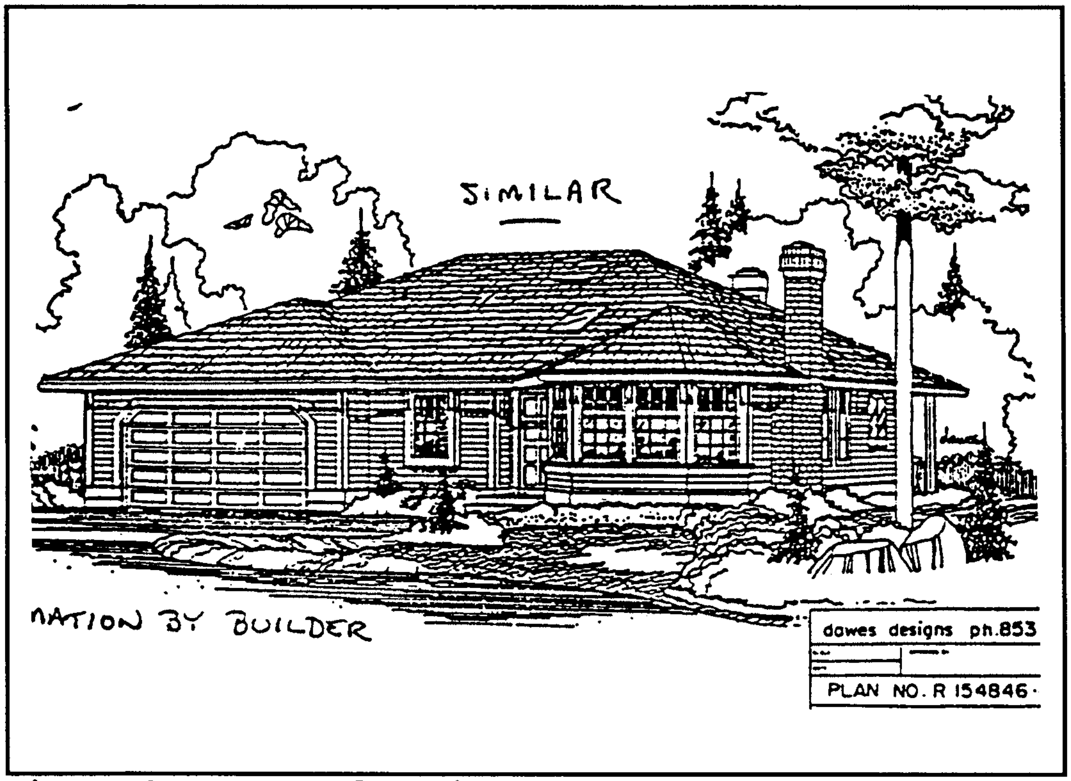


Figure 1: Front Elevation of House

House Characteristics: House #1 is a large single storey rancher with a floor area of approximately 160 m^2 (1710 ft^2) located in Chilliwack B.C., 80 km from Vancouver. The house age is 1 1/2 years and normally has only two occupants. The heating system is forced air and the only source of ventilation is an active air supply attached to the return air plenum.

Crawl Space Description: The crawl space initially had no passive crawl space vents. Styrofoam 35 mm board insulation was initially applied to C.S. perimeter walls but had been removed by NHWP as a measure to reduce condensation on the concrete. The slab is a 50 mm skin coat and it is assumed that no poly moisture barrier was installed beneath it though this has not yet been confirmed. Joist headers were insulated with RSI 1.75 batt insulation. A sump hole was placed near the centre of the space probably intended to serve as a pump well in the case of flooding. Heating is provided to the crawl space from 2 outlets cut directly in the supply plenum.

Problem History & Remedial Measures Taken: Large wet areas were found on the C.S. floor. Concrete was found to be cracked in some sections. Occupants experienced high humidity in all areas of the house, condensation on windows in winter and odours in the living room in fall & spring. Two weeks after our visit NHWP proceeded to take measures to reduce moisture. Six (6) passive vents were cut through headers and the entire floor above the C.S. was insulated wit RSI 2.9 batt insulation. Heating ducts were also wrapped with batt insulated. A 0.5 m X 3 m test strip of polyethylene was placed on a wet area of the floor by NHWP to test its effectiveness.

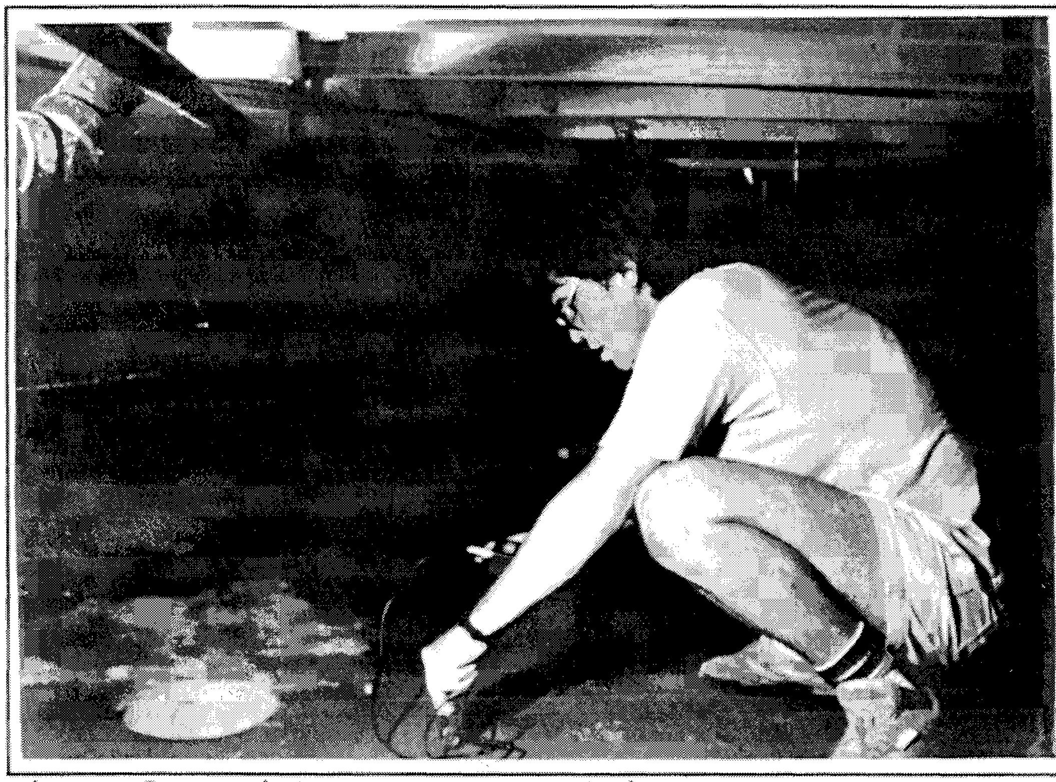


Figure 2: Moisture measurement in wet area

Test Results & Observations: High summer temperatures, humidity and winds prevailed on the day of testing. MC content of the crawl space floor was > 85% in areas though the wood MC was low. In winter conditions, the wood MC is expected to be much higher and a return visit is planned to verify this. Air leakage testing was difficult because of high winds and also because of the location of the crawl space hatch. The ELA of the crawl space was 1340 cm^2. This figure includes the below floor leakage (Qa) and the interface leakage (Qb). The house ELA was 928 cm^2 (Qc).

The house was referred to Sheltair by NHWP who had received a complaint about surface water on the crawl space floor and high moisture and a musty smell in the living areas of the house.

House #2.

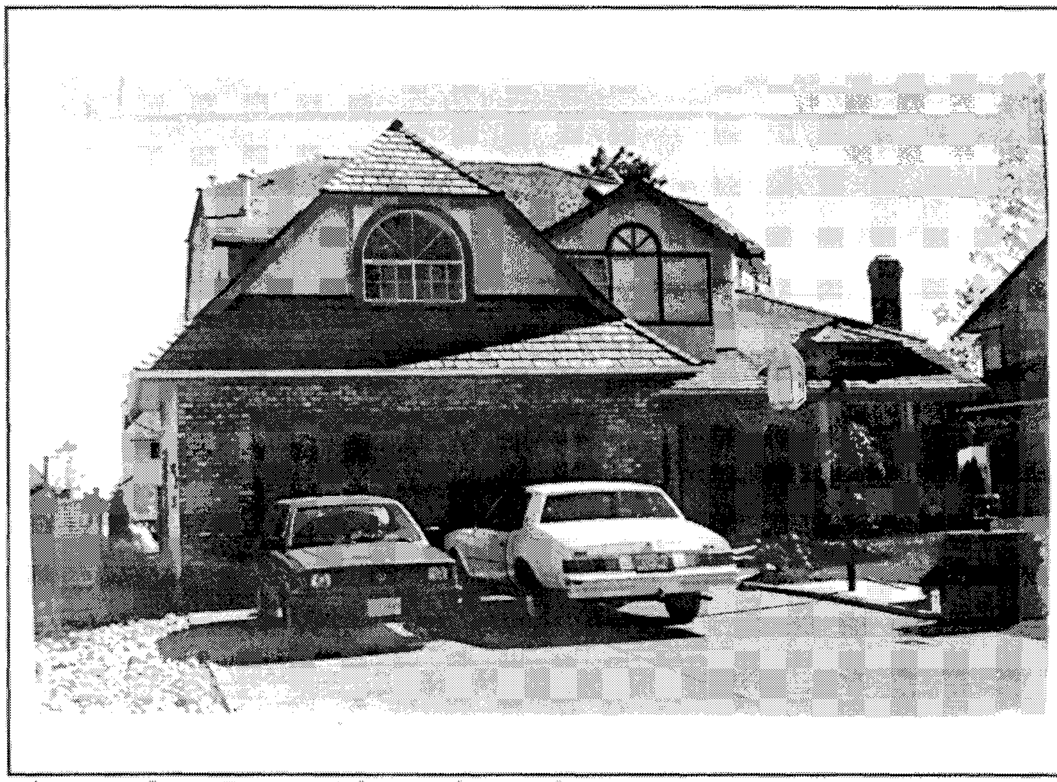


Figure 3: Front Elevation of House

House Characteristics: House #2 has two stories, an unheated double garage and an in-ground swimming pool comprising most of the back yard area. The soil is in the area is a gravelly glacial till. The plan area of approximately 115 m^2 (1225 ft^2 not including garage) and is located in Surrey B.C. The heating system comprises of a downflow furnace with forced-air ducting running through crawl space. Ventilation is provided by an active air supply attached to the return air plenum and the furnace has a two speed blower for optional continuous operation.

Crawl Space Description: The crawl space of House #2 was initially a heated and non-vented but groundwater problems led to remedial measures by NHWP. Before our visit, six 300 cm^2 inoperable louvred crawl space vents were installed by NHWP. Insulation was initially applied to C.S. perimeter walls but again had been removed by NHWP to reduce condensation on the concrete. Joist headers were insulated with RSI 1.75 batt insulation. As in House #1 heating is provided to the crawl space from 2 supply outlets cut directly in the main plenum, fitted with 50 mm X 300 mm grilles. There is also a return grill and a 5" return duct in a far corner of the space fitted with a damper. The duct is presently sealed.

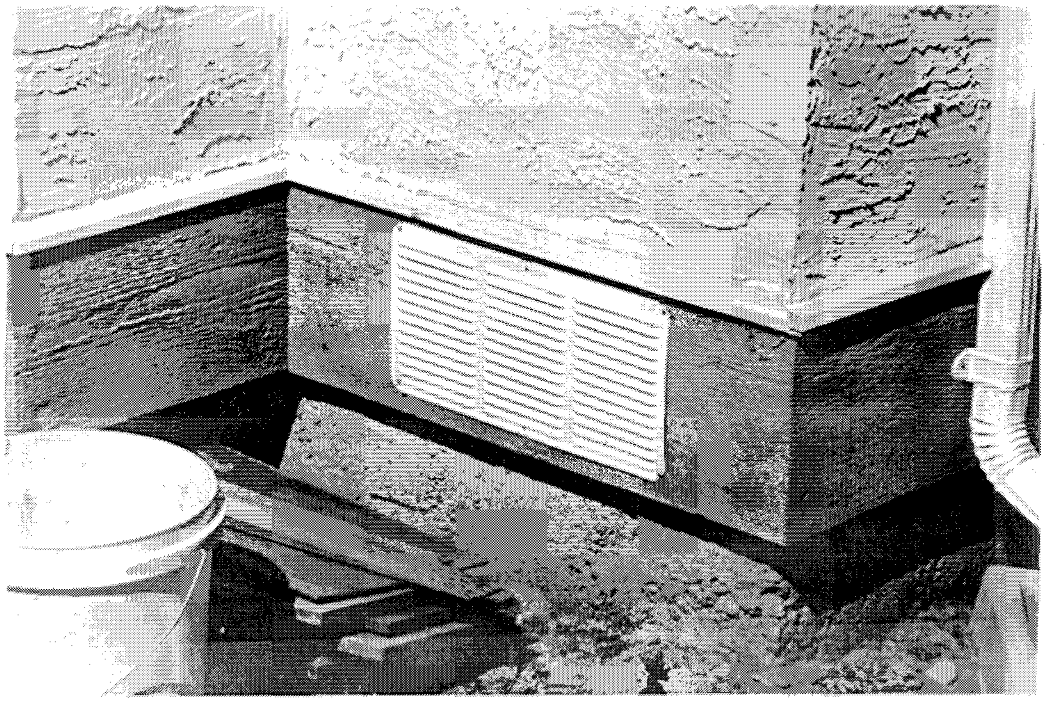


Figure 4: Crawl Space Vent

Problem History & Remedial Measures Taken: Groundwater entry into the crawl space was the main persistent problem which was addressed by NHWP who tried several techniques to resolve the situation including 1) installing vents, 2) removing insulation, 3) adding a dehumidistat operated fan, 4) applying at least two types of concrete sealants to the crawl space floor and finally 5) covering the slab with a layer of 6 mil poly. The poly barrier was the most effective at reducing the moisture level but did not stop water entry into support-wall sill plates, resting directly on the slab. The absence of a concrete curb under the walls may result in yet another expensive and labour intensive task - reconstruction of the support walls. Occupants experienced high humidity in all areas of the house and condensation on windows last winter and a musty odour in the living room most of the time.

Test Results & Observations: House #2 was visited twice, first in July (after House #1 visit), and in mid October. There was evidence of moisture entry throughout all areas of the crawl space with stains on walls and efflorescence on some section of the floor. Bottom plates of support walls registered the highest MC's at 32% measured in October. The ELA of the crawl space was 1600 cm^2 through cracks and vents, house ELA was 1400 cm^2 and interface leakage 1400 cm^2.

October humidity measurements suggest that very little evaporation of crawl space moisture is taking place. Higher indoor absolute humidity than crawl space seems normal when taking into account the warmer indoor air's greater capacity to absorb moisture.

HOUSE #2 AIR EXCHANGE TESTING

House #2 represents a typical forced-air heating system installed with air distribution ducting running through the crawl space. There are four (4) air supplies in the crawl space, one supply grill on the main plenum near the furnace and three 5" feeder ducts branching into the three corners of the crawl space.

A single tracer gas air change test was performed at House #2 in Surrey. The objective of the test was to examine the interaction between the ground floor and crawl space and also to measure the rate of natural infiltration in both zones. The Halitec multiple-point tracer gas analyzer was used with Freon 22 as a test gas. Figure ?? shows the sensor distribution in the crawl space and the direction of air flow through the vents in the crawl space. The test procedure and results are described in detail below.

Procedure for air change test

a) Test Conditions

The tests were conducted without attempting to alter air temperature or humidity indoors or in the crawl space. Conditions at the time of testing are recorded below:

	Temperatures (C)		Absolute Humidity (gm/kg)	
	start	end	start	end
Indoor	22.0	19.4	7.4	7.5
Crawl Space	16.5	13.8	7.6	6.7
Outdoor	6.3	7.3	5.2	4.8

b) House Setup:

- All windows and exterior doors were closed and interior doors opened;
- Of the 6 crawl space vents installed in the house, 4 had been blocked with insulation by the homeowner. These were left in the same condition;
- All heating registers remained as found but most were fully open.
- After heating the house to 22 °C, the thermostat was dropped to 19 °C. However, it was later realized that a thermodisk had accidentally been tripped and no heat other than the direct vent gas fireplace was added to the building over the three hours of testing.

c) Sensor Distribution:

Five gas sensors were placed in the house as follows:

Crawl space:

A) South wing near supply outlet; mid height
B) Central area; mid height
C) North central; mid height

Main Floor:

D) Kitchen Nook (south side) above supply register; waist height
E) Central Hallway (north side) above return grill; waist height

d) Tracer Gas Injection:

With the furnace blower de-energized and the crawl space hatch closed, the tracer gas was injected into the crawl space using plastic disposal bags and a 150 L/s 600 mm house fan. An estimation was made based on the b^Xxs and the crawl space volume so as to bring the levels to between 500 and 600 PPM. The bag was emptied into the inlet of the fan and directed so as to distribute the gas as well and as quickly as possible thereby avoiding exfiltration to the main floor.

d) Test #1: Forced Mixing and Decay:

For the first part of the test, the furnace blower was energized within 1-2 minutes of mixing the tracer gas in the crawl space. Measurements of the tracer gas concentrations were made over one (1) minute intervals and logged automatically by the analyzer. After 1 hour 40 min. the levels in both zones had decayed to approx 70 PPM throughout.

e) Test #2: Natural Air Change:

With tracer gas concentrations at 70 - 75 PPM in both zones, the furnace blower was de-energized and further decay was measured for 1 hour 20 min until the concentrations were 35 to 50 PPM. Below this level, accuracy of the measurements became questionable.

Results of air change tests

Table A1 gives the results of the air change analysis for all sensors. Air change rates were calculated from regression fits on the data based on solutions to the continuity equation shown below:

$$C(t) = C_o * E^{-It} \quad (1)$$

Where:
C(t)= Tracer gas concentration at time t;
C_o = Initial tracer gas concentration;
I = Air change rate (AC/hr)
t = Time (hours)

Test #1: Forced Mixing and Decay:

The decay of tracer gas in the crawl space was analyzed in three stages, relating to distinct changes in the slopes of the logarithmic curves. On the main floor, only two distinct changes in the curves occurred corresponding to mixing and decay. The graphs in Figure A1 show these distinctions as well as the calculated and measured tracer gas concentrations for sensors located in the crawl space as well as on the main floor.

The three stages or "phases" of mixing correspond to time intervals as follows:

Phase 1: Initial Mixing
During Phase 1 (35 minutes), crawl space air was thoroughly mixed and most of the crawl space and the initial exchange of tracer gas between the main floor and the crawl space was complete.

Phase 2: Partial Mixing
In Phase 2, (from 35 min. to 55 min.), seeded air from the crawl space began recirculating through the house, returning to its origin and exfiltrating through crawl space vents and leaks. This phase is difficult to understand because more than two variables are involved in the air interchange.

Phase 3: Decay
Phase 3 represents the average house and crawl space air change this zone with interaction of fresh air and recirculated air occurring as follows:

Sources of Infiltration Air:

- fresh air entering the crawl space through leaks;
- active 4" air supply tied in to return plenum of furnace; and,
- air leakage on main floor (below neutral pressure plane);

Sources of Exfiltration Air:

- air leaving through crawl space vents ^Xxe to wind pressure and pressures created by an imbalance of supply and return air in crawl space;
- duct leakage into wall cavities and into attic spaces; and,
- air leakage on main floor (above neutral pressure plane);

Measured Air Change Rates

Crawl Space:In Phase 1 the average rate of exchange **2.94 ACH** in the crawl space. This included exfiltration of **0.457 ACH** (the crawl space was slightly pressurized by the supply).

In Phase 2 the combined exchange rate of tracer gas leaving the crawl space averaged **1.24 ACH** (including exfiltration).

The average air change in the crawl space during the Phase 3 was **0.451 ACH.**

Main Floor: On the main floor, the initial exchange of tracer gas between the house and the crawl space was complete within 20-25 minutes. The initial air change rate (Phase 1) measured in the supply near the kitchen on the south side of the house was **8.96 ACH** and **6.30 ACH** measured near the return. During the second interval, after mixing, steady decay rates of **0.52 & 0.40 ACH** respectively were measured.

Test #2: Natural Air Change:
In order to evaluate the natural infiltration rates measured in Test 1, it seemed simple enough to measure the rate of natural infiltration in the crawl space and in the house while the tracer gas was well mixed throughout the building. Unfortunately, the fact that air direction reversed in the crawl space after turning off the blower just made any proper analysis even more of a problem.

Test conditions: Over the course of testing, outdoor temperatures increased only 1 °C but winds from the southeast increased from negligible to 10 - 15 kmh. Temperatures in the crawl space had dropped 3 °C since the beginning of Test 1, actually decreasing the stack effect. With the furnace blower off, the only source of heat in the house during Test 2 was a direct vent gas fireplace in the family room.

Crawl space; It is suspected that the flow of air had reversed due to stack effect. During Test 1 the direction of air flow through the two open vents was established using a smoke pencil from outdoors. It was found to be flowing outwards as was expected by the imbalance of supply and return air. Flow from the other vents was indeterminable.

The air change rate in Test 2 averaged **0.60 ACH.** This represents a *negative* air change with air being drawn in to the zone from leaks and vents below the interface. The Test 1 air change was a *positive* forced-air change of air exfiltrating below the interface and recirculation air from above the interface. The analysis becomes very complicated and more testing would be needed to establish the exact exfiltration from each zone.

Main Floor: The natural air change rate on the main floor was 50% lower than in the crawl space at **0.296 ACH** average. Without installed intentional openings above the interface this was to be expected.

It can be assumed that most of the air entering the main floor is passing through the interface between the two zones. Stack pressure most likely overcame the effects of the light winds.

Volume Weighted Average for Tests 1 & 2;

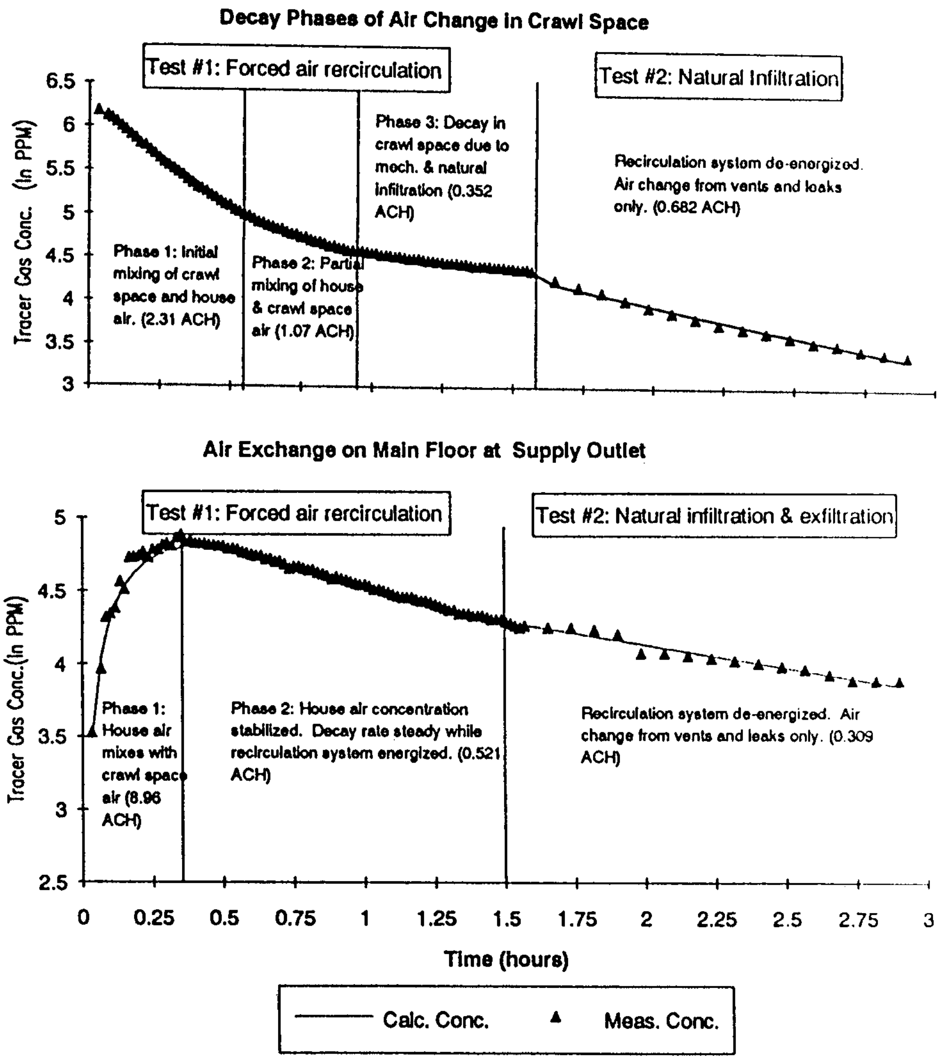
The average air change rate in the house was almost identical for tests 1 & 2 @ 0.455 ACH during the decay in test 1 and 0.447 for natural infiltration.

The average rate at which the air was mixed between the two zones was 5.29 ACH.

Table I: Summary of Air Change Test Results

Summary of Air Change Rate for Tests 1&2				
		Test 1		Test 2
	Phase 1	Phase 2	Phase 3	Natural
	(ACH)	(ACH)	(ACH)	(ACH)
C.S. South	3.780	1.437	0.513	0.526
C.S. North	2.734	1.216	0.489	0.590
C.S. Central	2.311	1.068	0.352	0.682
Mn Supply	8.964	-	0.521	0.309
Mn Return	6.304	-	0.396	0.282
Whole Hse Avg	5.287		0.454	0.447
Crawl Space Vol.	138	(m^3)		
Main Floor Vol.	296	(m^3)		
Whole House Vol.	684	(m^3)		
*Est. recirculation	1000	(L/s)		
**Est. Ventilation	86.4	(L/s)		
* Based on house avg. ACH				
** Based on house avg decay				

Figure A2-2: Phases of Tracer Gas Mixing in House #2.



3. House #3

House Characteristics: House #3, located in Mapleridge near Vancouver, has two stories and has an unheated double garage. The soil characteristics are not yet determined but the permeability of seems fair to good. The plan area of approximately 120 m^2 (1300 ft^2) not including the garage. The heating system is forced air with a downdraft furnace arrangement. Continuous ventilation is provided by an 4" active-air supply duct attached to the return air plenum. The furnace blower is intended to be run continuously on low speed switching to high speed when furnace high temperature limit is reached. An exhaust fan controlled by a dehumidistat is also installed in the house.

Crawl Space Description: The crawl space of House #3 is heated by direct supply from the forced-air system. 1" Styrofoam board insulation is attached to the inside of C.S. perimeter walls from the sill to 4" above the floor. Joist headers are insulated with R12 batt insulation.

Problem History & Remedial Measures Taken: Absolutely no problems have been reported nor were any found during the initial investigation.

Test Results & Observations: House #3 was visited only once and because of time considerations, only the air leakage tests and photographs were taken. A return trip is planned to complete the testing under winter conditions. An air leakage test was performed to compare the interface leakage with and without energizing the furnace blower. It was calculated from this test that the active air supply was drawing 40 L/s of outdoor air into the house.

The house was referred by a Mapleridge builder whose company had built the house for resale.

Sheltair did not return to the site for a winter condition assessment or to acquire missing data.

4. **House #4**

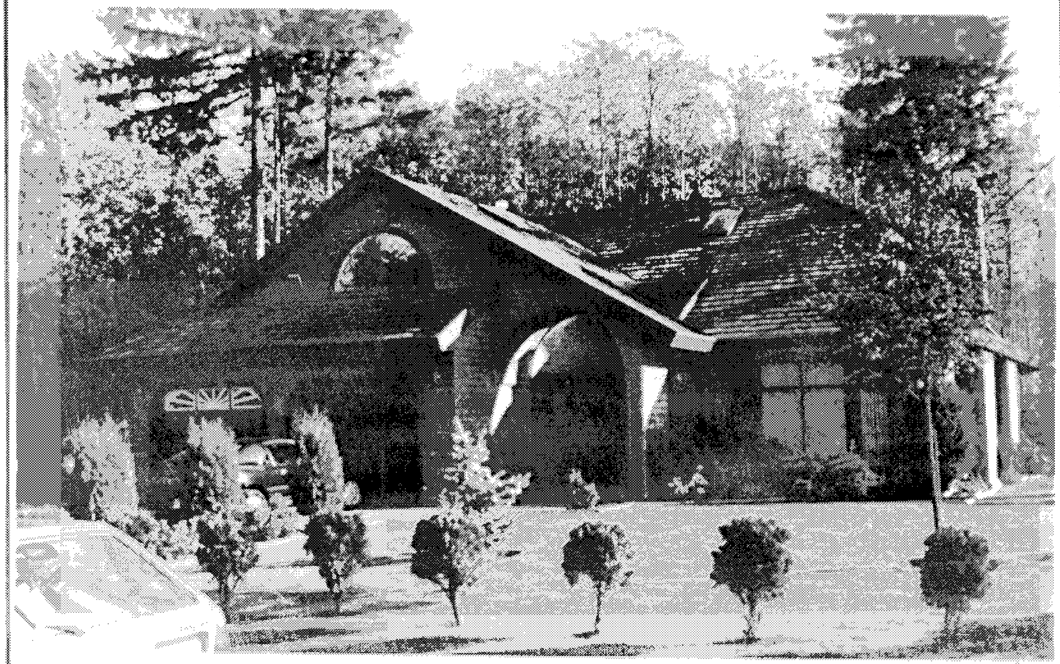


Figure 6: Front Elevation of House

House Characteristics: House #4 is a two storey rancher with and an unheated double garage. The soil characteristics were not determined. The plan area of approximately 120 m^2 (1300 ft^2) (garage not included) and is located in Surrey B.C. The heating system is forced air and ventilation is provided unintentionally (explained below) through the crawl space. The residents have a gas fireplace in the living room which is frequently in use.

Crawl Space Description: The crawl space is heated *and* vented with six 365 cm^2 operable louvred crawl space vents. The floor is covered with a 2" concrete skin coat over a 6 mil poly barrier. Perimeter walls are insulated with 1" Styrofoam boards, similar to House #3 and joist headers are insulated with R12 batt insulation. The floor above the C.S. is not insulated. Heating is provided to the crawl space from 2 supply grilles cut into the plenum. A return grill is also installed provided in the crawl space.

Problem History & Remedial Measures Taken: The occupants had problems with high humidity in the living area and window condensation. A musty odour was also present last winter that originated from the crawl space. Wet areas were noticed on the C.S. floor in one section and the homeowner placed a carpet over the area which he uses for storage. It was suspected that the poly moisture barrier had been omitted. The residents experienced very high winter heating costs which we suspect are related to crawl space over-ventilation. Vents in the crawl space were mistakenly left closed during most of the summer and two weeks before our investigation these were opened.

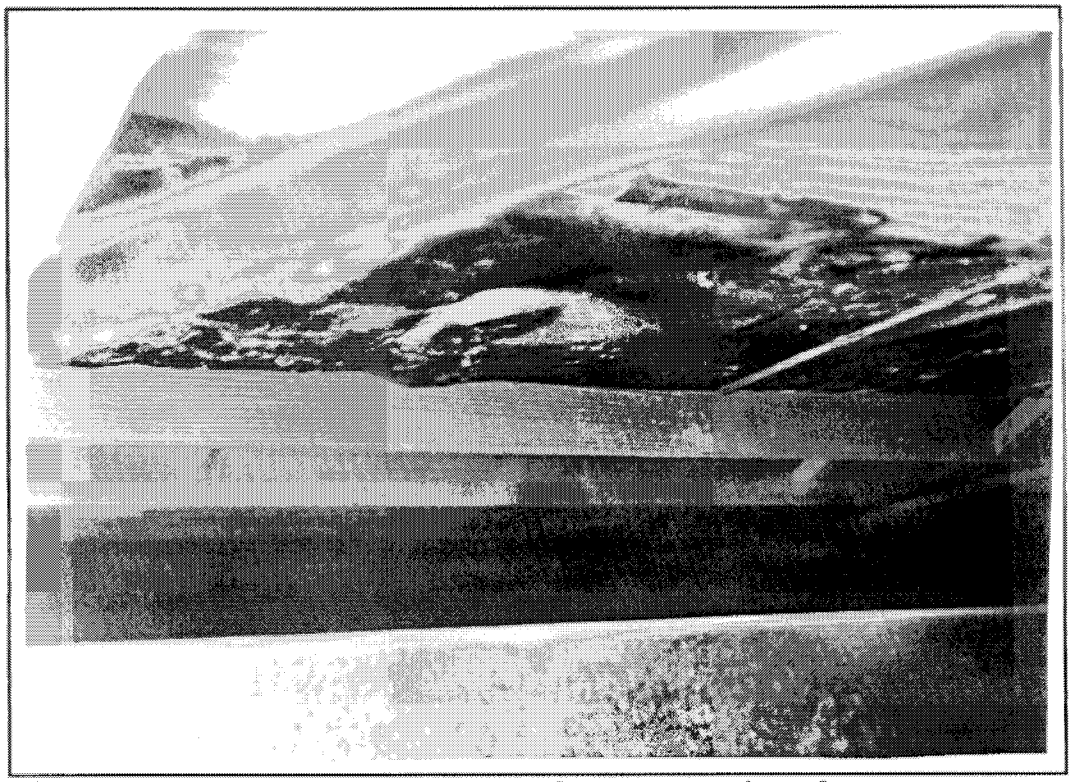


Figure 7: Poorly Constructed Return-air Plenum

Prior to our visit, no remedial measures had been taken.

Test Results & Observations: was visited at the end of September. MC content of the crawl space floor 55% underneath the carpeted section where the in areas though the wood MC was low. The interface air leakage was high at 1500 cm^2 and the house had a measured ELA of 940 cm^2.

The heating duct installation at House #4 was done very poorly. A 16" X 20" section of sheet metal was found missing on the return air plenum 5 feet from the furnace. We estimate that a large percentage of recirculation air was actually fresh air being drawn from the crawl space. The opening was covered temporarily with cardboard and sealed with tape. A measurement of the static pressure drop across return air grills on the main floor was made before and after this and an increase of 2 to 6 Pa resulted, almost doubling pressures in one of the returns. This calculates to increases in flow from 25 to 50% at each of the three return grills.

The sealing of return duct and a suggestion that during the winter season the crawl space vents be shut should improve energy efficiency of the house to some degree. This can be evaluated by comparing the last years utility records to this coming winters records.

The existence of the poly barrier was proved by drilling 4 holes in the concrete skin coat in different areas. Unfortunately, it was not resolved whether or not vapour barrier had been used or a nominal 6 mil. polyethylene of a higher perm rating.

Sheltair did not revisit the house for more testing.

5. **House #5**

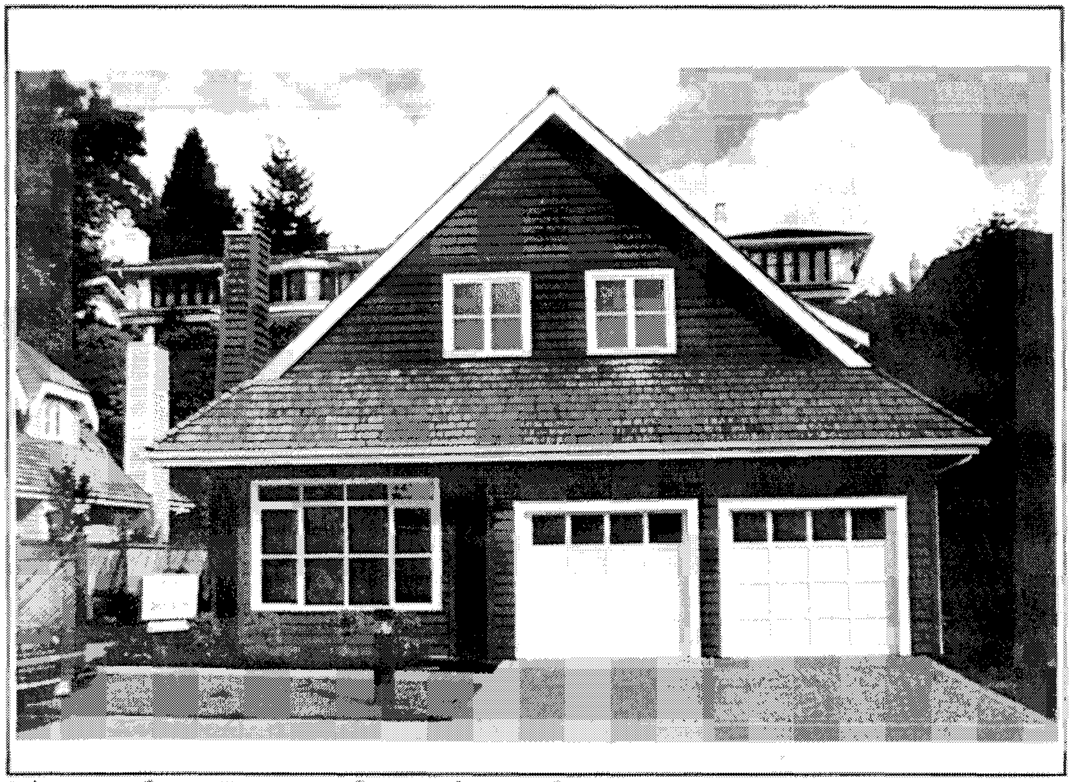


Figure 8: Front Elevation of House

House Characteristics: House #5 is a large 2 storey rancher with a floor area of 145 m^2 (1450 ft^2) located in Vancouver. The house is new and presently unoccupied. The heating system is gas radiant with underfloor heating coils on the main floor and radiators on the second floor. Ventilation is provided intermittently by an exhaust fans (downdraft kitchen fan, three bathroom fans). A 45 L/s fan is also installed on the second floor controlled by a dehumidistat. A 250 mm X 250 mm make-up air grill on the main floor ceiling has been provided by the ventilation contractor, intended to reduce the potential for house depressurization potential (hardly likely). The boiler and DHW are located in a separate room accessed from the garage. Soil is a silty/clay of relatively low permeability. Ground fill for the subdivision was transported from a local shopping mall site in Burnaby B.C..

Crawl Space Description: The crawl space is non-vented and non-heated except by radiation from uninsulated piping in the floor above the crawl space. Perimeter foundation walls are insulated on the exterior with 1" Styrofoam bo^Xxd insulation Joist headers are not insulated. The floor is a 2" concrete skin coat poured over a 6 mil poly barrier. Support walls are built directly on the floor without curb walls. Shims were used in some areas to compensate for the uneven floor. The drainage is standard 4" corrugated pipe with drain rock and there are no floor drains on the crawl space floor.

Problem History & Remedial Measures Taken: No problems exist as yet. The crawl space was found in a relatively dry condition. Only one wet area was observed in the crawl space at the base of a stem wall that does not yet constitute a problem but has the potential to become one.

Test Results & Observations: Tests were performed in mid October in mild dry weather. Air leakage tests were performed and the interface ELA was measured to be 285 cm^2 and the crawl space 332 cm^2. MC levels in both wood and concrete were normal except in one small area where concrete at the base of the perimeter wall was wet. Measured MC of the concrete wall at that point was 55% and the floor 85 %. Concrete was notably cracked in several areas as can be seen in the photograph below. This implies fast curing with no expansion joints provided to accommodate for the shrinkage.

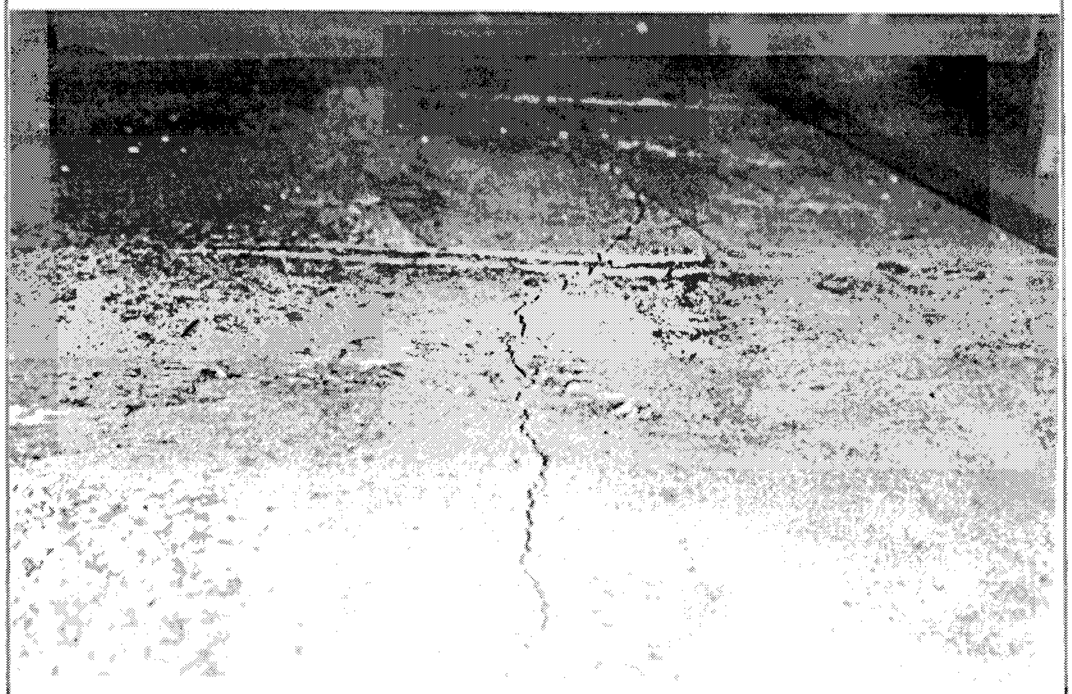


Figure 9: Cracks in concrete skin coat.

Modification of the crawl space construction had been considered for this house. Project limitations made this an unworkable option.

Tracer Gas Air Change Test: The house was initially unconditioned and the heating system was energized after initial moisture measurements were taken. When the house reached stable temperature conditions a tracer gas air change test was done. The air change test commenced in the evening and the tracer gas analyzer was left running until the next morning with an average ACH for the crawl space of 0.356. This calculates to 13.3 L/s of outdoor air entering the space through cracks and leaks driven by wind and stack pressure. The average temperature outdoors was 10 °C and in the space 18 °C. A summary of the data collected is provided below as well as a graph showing the decrease in air change rate as the distance from the crawl space hatch increases. It was observed that most of the interface leakage is in this area because of plumbing penetrations and the hatch itself.

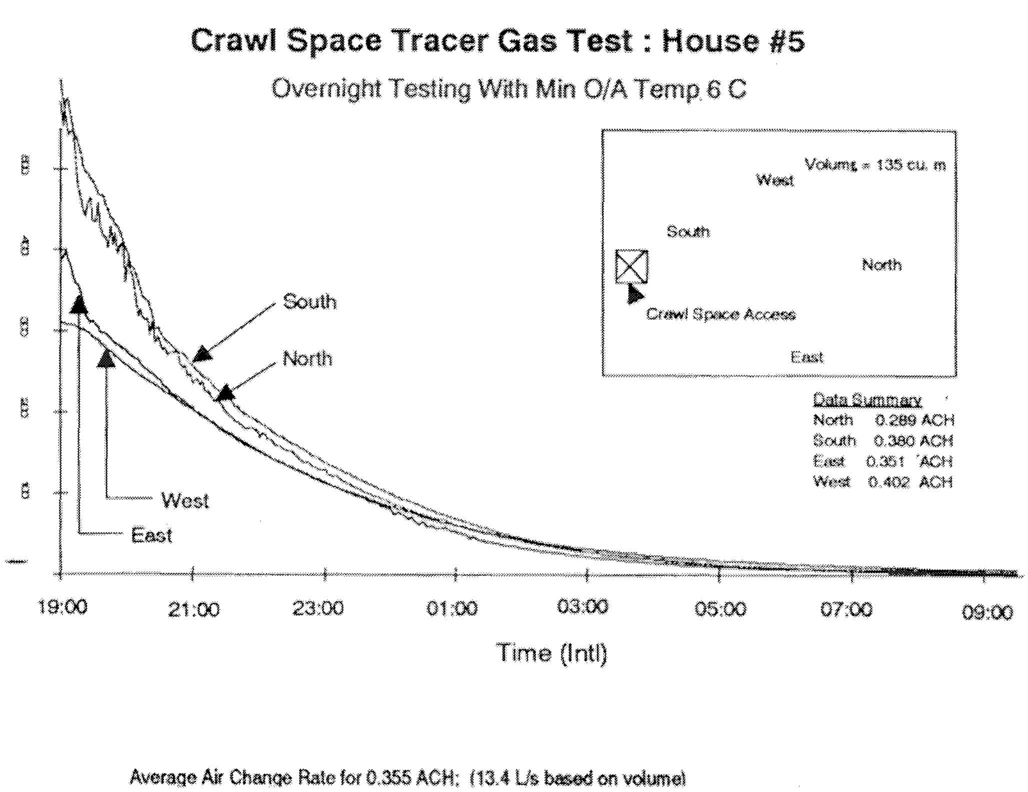


Figure 10: Graph Showing Steady Decay of Tracer Gas in House #5 Crawl Space

6. House #6

Figure 11: Front Elevation of House

House Characteristics: House #6 is a large single storey rancher with a floor area of approximately 250 m^2 (2700 ft^2) located in Surrey B.C.. The house is 3 years of age and normally has only two occupants. The heating system is gas radiant and ventilation is provided by a Heat Recovery Ventilator (HRV) installed on the main floor with ducting in the ceiling.

Crawl Space Description: The crawl space is non-heated and vented with 4 passive crawl space vents with operable louvres. Styrofoam 1" board insulation was initially applied to C.S. perimeter walls but had been removed by NHWP as a measure to reduce condensation on the concrete. Joist headers are insulated with R12 batt insulation. The floor is a 2" concrete skin coat with no moisture barrier, although the initial design called for a 6 mil poly barrier it was never installed. Support walls are built on 4" curbs on separate footings.

Problem History: Large wet areas were found on the C.S. floor. A test hole revealing the absence of polyethylene vapour barrier. Concrete was found to be cracked in some sections. Occupants experienced high humidity in all areas of the house, condensation on windows in winter and a persistent musty odour in the living room. Carpets in that room had been stained at fringes by air movement beneath partition walls. The homeowner believed that this was due to mould migrating through from below but it is not confirmed. NHWP had cleaned the carpets once recently and there were only traces to be seen during our investigation.

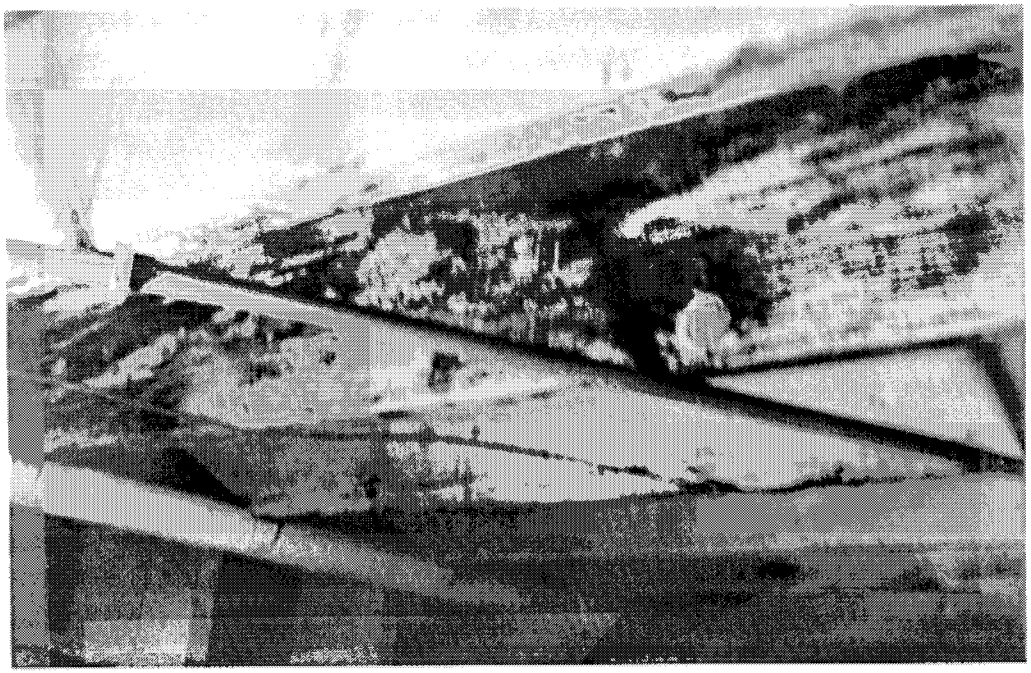


Figure 12: Mould Growth on Joists in Crawl Space

Test Results & Observations: House #6 was visited in mid October after one week of more than average rainfall. MC in wood and concrete were very high. The MC of the header joist behind insulation was 26 % and subfloor plywood was 20 % in some areas. In one corner, adjacent to the drainage collection box, perimeter walls were visibly wet. Although it is possible that this is due to seepage but condensation of crawl space moisture on the surface is suspect.

A brick fireplace chimney, terminating at the subfloor level, that was exposed to moisture laden air experienced condensation on cold metal surfaces in the cavity. Water began pooling into the crawl space beneath it so steadily that it was a suspected moisture source. Through a hole that had been cut through subfloor plywood, it was identified as condensation.

Of the 4 vents in the crawl space, 2 were partly blocked by insulated heating pipes and joists running parallel to the outside trimmer joists. Despite this, the vent leakage was measured to be approximately 1320 cm^2 which implies a free area close to actual area.

House #6 offered one of our best opportunities for evaluating the pre and post retrofit effectiveness. Because of the extremely high moisture levels presently being experienced due to a lack of proper ground cover, the effects of remedial work should be dramatic and easy to assess if monitored.

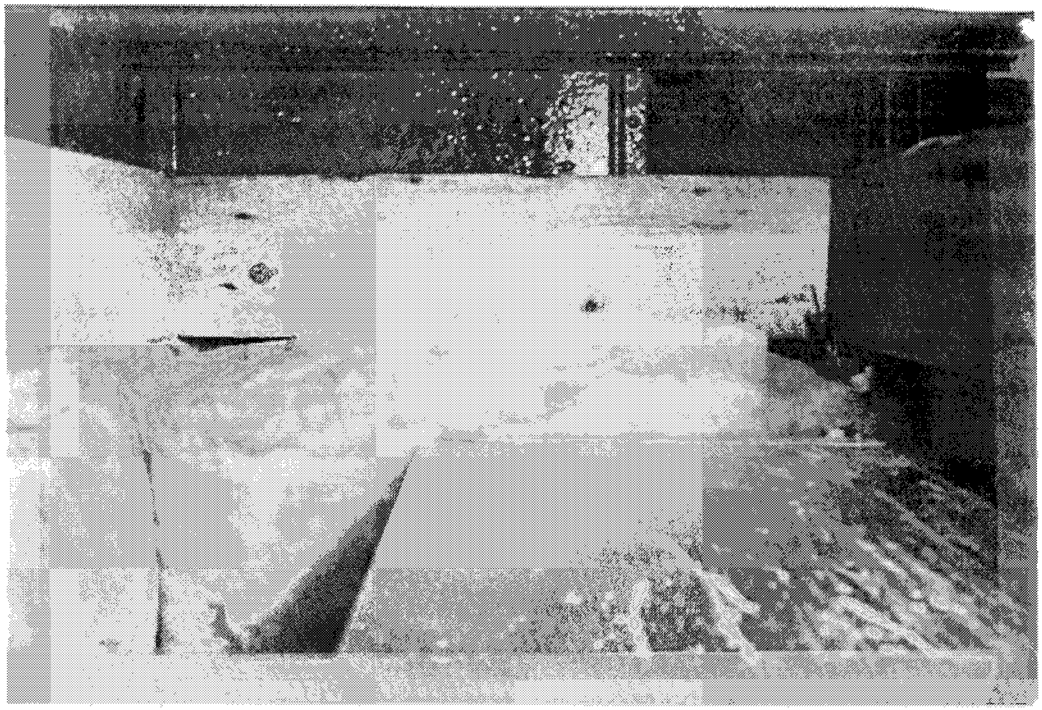


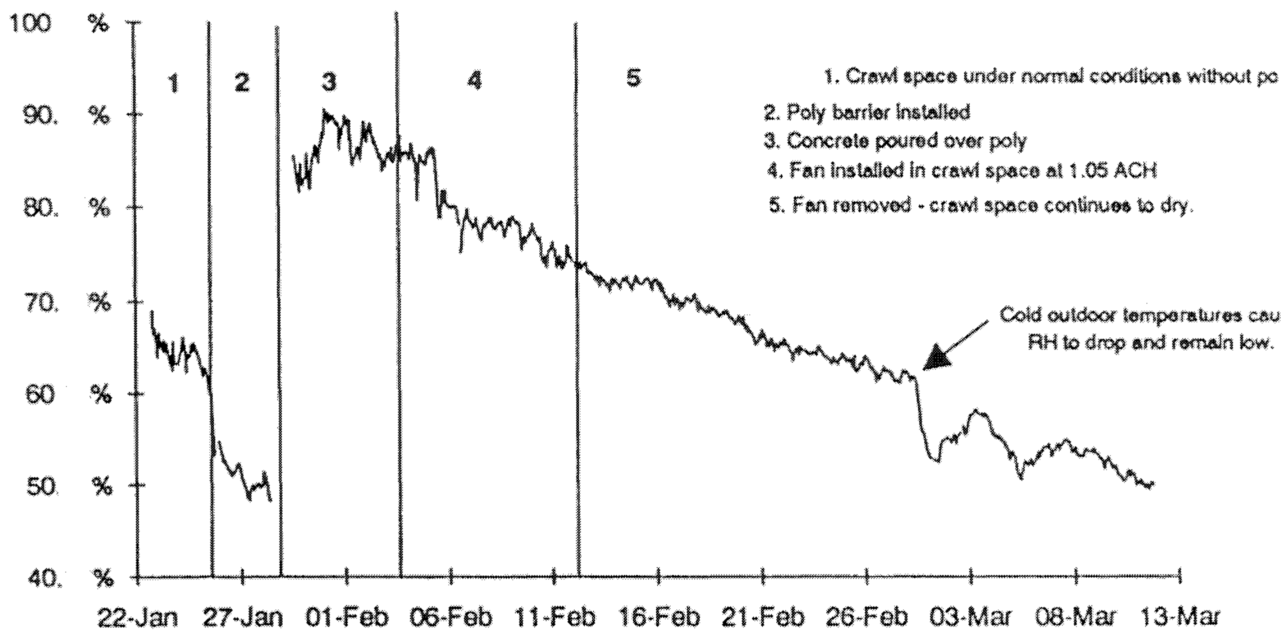
Figure 13: Condensation in Chimney Cavity

Sheltair monitored conditions and installed a poly vapour barrier on the existing concrete. After 3 days of monitoring, an additional 50 mm concrete skin coat was applied to the existing slab, sandwiching the new poly. The reduction in moisture levels was monitored for 40 days until conditions were quite stable. An option was left to seal the vapour barrier to the perimeter walls and sealed to the top of the insulation. Poly sheets were cut oversized so that enough material extended to join to the board insulation terminating 25 cm from the floor.

Review of the Long Term Monitoring

After reviewing the data collected, it was seen that the moisture levels in the crawl space had stabilized at approximately 1.5 gm/kg higher than outdoors. This was a similar level that measured just prior to the placement of the new floor. This does not imply that the retrofit was not successful. The monitoring period was not long enough to give any satisfactoring conclusions about the long term effectiveness. At the time the data logger was removed, there was still considerable residual moisture in the structural members to hold the moisture at this steady level. During a cold period however, as can be seen in the graphs below, the crawl space dried out very quickly over 1 - 2 days and the levels did not rebound. Measurements of the slab MC show that the new concrete is already much drier than the original concrete MC. The following graphs & tables show the pattern of events and moisture levels over the entire monitoring period.

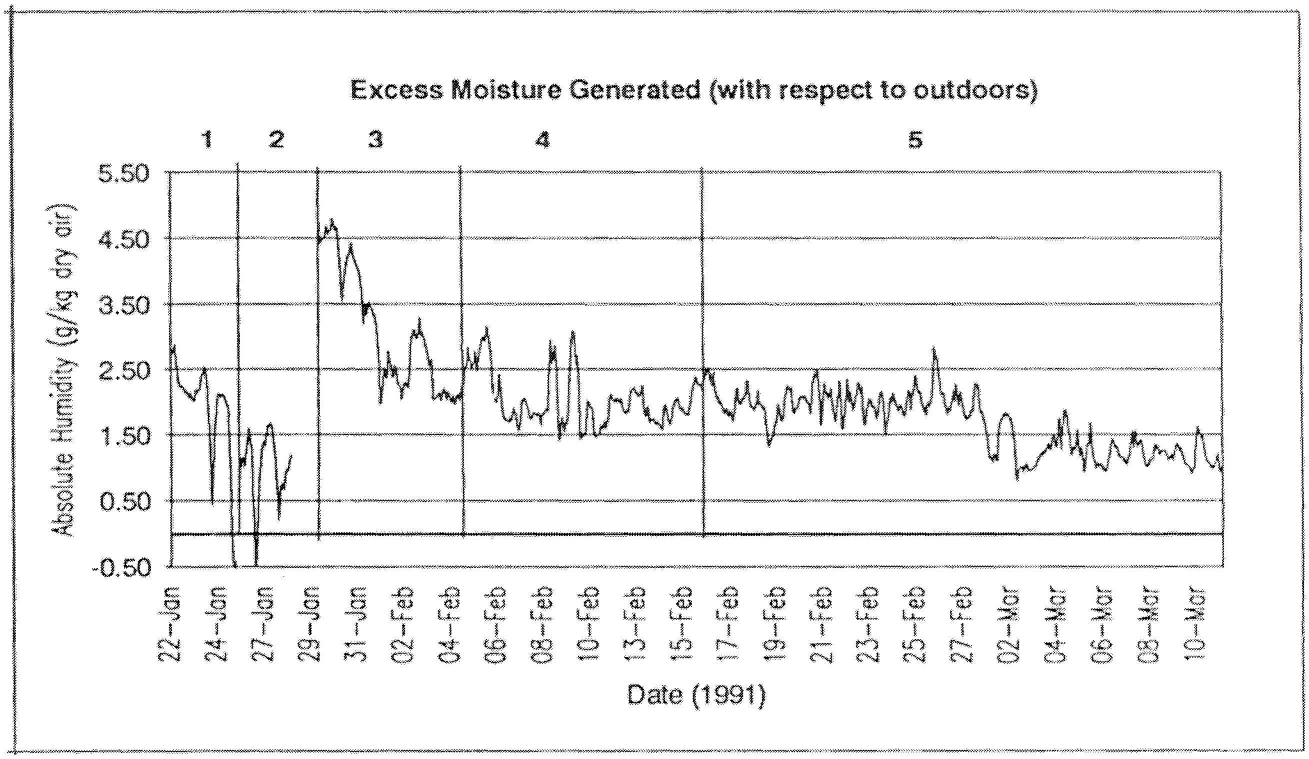
House #6 Post-retrofit Crawl Space Relative Humidity



House #6 Data Summary for Period from Jan/22/91 - Mar/11/91

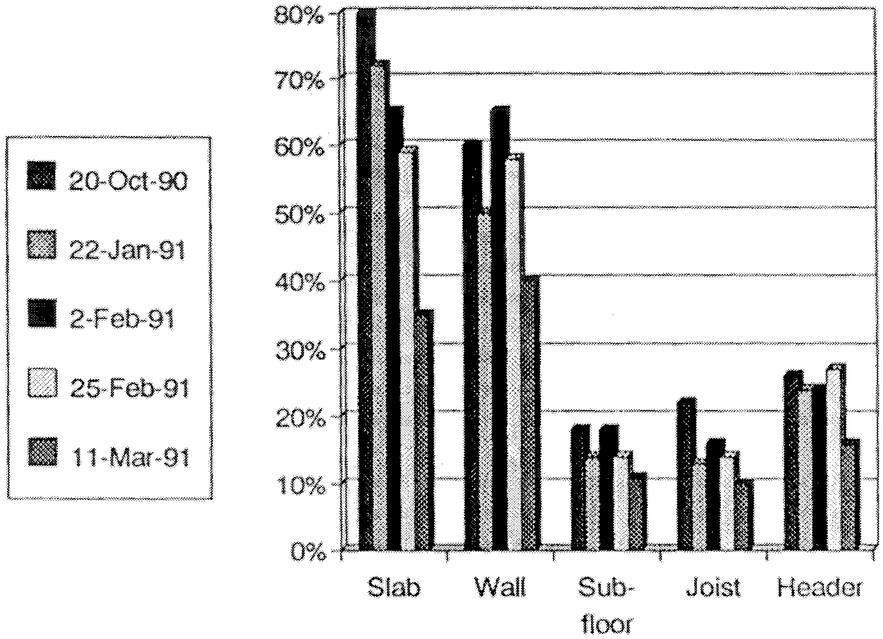
	*Average	Minimum	Maximum	No. obs (hrs)	StdDev
Temperatures (C)					
Indoor	22.87	20.46	26.01	1152	0.87
Outdoor	5.48	-3.87	17.1	1152	3.85
Crawl Space	14.79	13.11	16.01	1152	0.63
Average Absolute humidity (gm/kg)				corresponds to day of concrete pour	
Indoor	6.85	4.67	9.49	1119	0.89
Crawl Space	7.12	4.85	9.18	1119	1.24
Outdoor	5.19	3.21	7.02	1119	0.85
Excess Crawl Space	1.94	-0.53	5.06	1119	0.77
Average Relative Humidity (%)					
Indoor	39%	26%	53%	1119	5.03%
Crawl Space	67%	48%	91%	1119	11.60%
Outdoor	88%	34%	100%	1119	13%

* Average, min & max are based on the overall 1 hour averages for the monitoring period.



Time Table of House #6 Retrofit Activity

Period	Date	Event
1	Jan/22/91	Install monitoring equipment
2	Jan/25/91	Lay 6 mil "vapour barrier" over existing concrete skin coat
3	Jan/28/91	Pour additional 50mm concrete skin coat over poly.
4	Feb/03/91	Install fan in crawl space to force air change @ est 1.05 ACH.
5	Feb/12/91	Fan shut off ; vents dampers 1/2 closed.
6	Mar/11/91	Remove monitoring equipment.



Moisture content measurements in House #6 crawl space over course of monitoring period.

	Location of measurement				
	Concrete M.C.		Wood M.C.		
Date	**Slab**	**Wall**	**Sub-floor**	**Joist**	**Header**
20-Oct-90	80%	60%	18%	22%	26%
22-Jan-91	72%	50%	14%	13%	24%
2-Feb-91	65%	65%	18%	16%	24%
25-Feb-91	59%	58%	14%	14%	27%
11-Mar-91	35%	40%	11%	10%	16%

7. House #7

Figure 14: Front Elevation of House

House #7 is a single storey rancher located in Surrey B.C. The house was referred to Sheltair by a Vancouver builder who was responsible for the construction of a recent addition to the house. Some of the important details of the house are as follows:

Exterior Finish: Stucco extending below sill plate level. Continuously vented aluminum soffits.

House Addition: 55 m^2 added to back of house, completed in February 1990. The new section added a small bedroom, a master bedroom and ensuite bathroom and a portion of another bedroom.

Heating system: Electric baseboard heating in the existing part of the house. New part uses the ESWA radiant heating panels installed in the ceilings. There is also a wood fireplace.

Drainage System: One pipe system of foundation drainage using 4" drain tile. Roof drainage by means of gutters with rain water leaders terminating at splash troughs which divert water into soil away from house.

Soil Characteristics: Standing water on lawn suggests low permeability as no rain had fallen for 10-12 hours prior to visit.

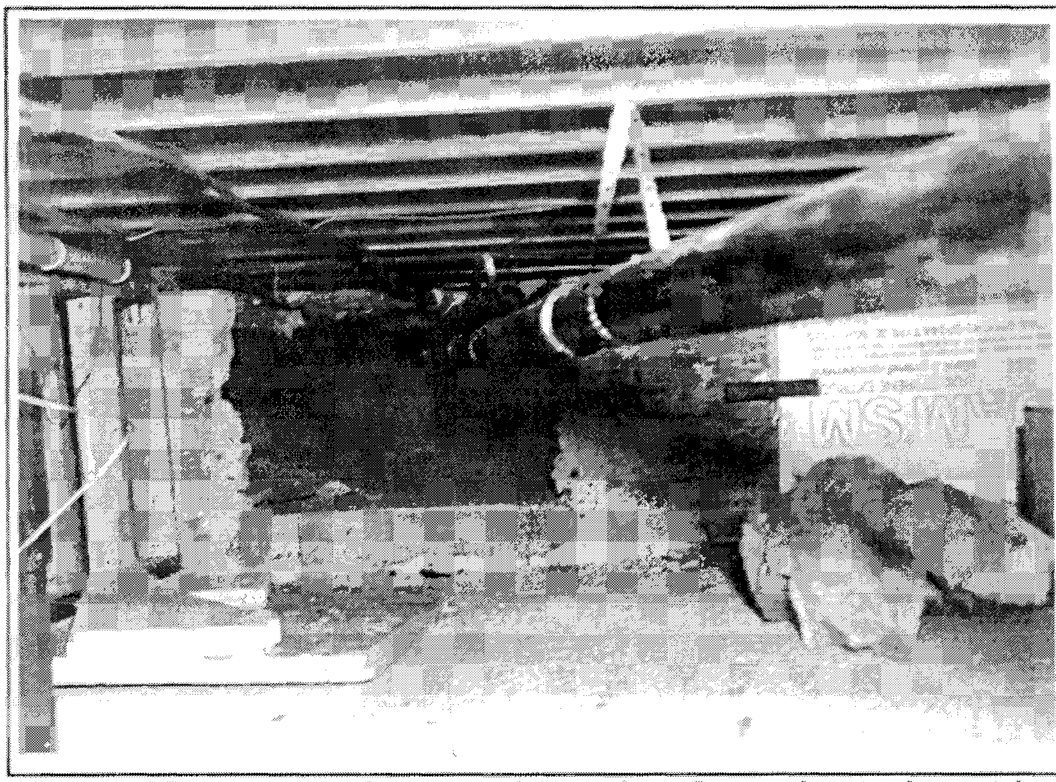


Figure 15: Access between heated and non-heated portion of crawl space.

Crawl Space Description: The crawl space is split into two distinct construction types corresponding to the new and existing sections of the building.

Existing crawl space: Floor consists of a 2" concrete skin coat with a rough brushed finish and it is assumed that a 6 mil polyethylene moisture barrier was installed beneath. Perimeter walls are well insulated from inside with 2" "SM" polystyrene board (RSI 1) fastened mechanically with concrete nails. Joist headers are insulated with batt insulation and the floor above the crawl space is not insulated. Support walls are built on a concrete curb. No direct source of heat into crawl space was installed. Crawl space height is approximately 1 m to the bottom of the joists.

Addition: The unheated approach was used. The floor is similar to the existing and the perimeter walls are not insulated. All areas of the floor above the space are insulated with RSI 4.32 batt insulation.

The existing perimeter wall was used as a separation between the two crawl spaces and is insulated on the warm side with "SM" board. An access was cut into the concrete about 0.67 m in width. Ventilation is provided by 4 operable aluminum vents, two in each crawl space. Three vents are installed on the north side of the house and 1 on the east side. All except one of the vents was blocked with insulation and all were shut for winter operation.

Problem History: Homeowner had reported moisture problems prior to the addition but was not aware of any moisture source. Attic moisture levels had previously reached a level high enough to cause blackening on the attic sheathing from mould. The mould growth was restricted to the north side of the building. Condensation had occurred on double glazed windows on the main floor during shoulder seasons and in winter and the problem persisted after the addition. The window frames are not thermally broken. There was no complaints of moisture or standing water problems in the crawl space.

Remedial Measures Taken: Attic moisture was reduced after pulling back insulation from the soffited section of the eave construction allowing better ventilation.

Findings & Observations: A visit in December/90 revealed that indoor humidity was indeed very high due to an inherently low natural air change rate related to building tightness, shielding class and absence of flue or gas appliance.

Temperature & Humidity: Both old and new sections of the crawl space were found to very dry. However, the absolute humidity level in the crawl space was 30% higher than outdoors suggesting some evaporation. The new crawl space was measured to be 2 °C cooler than the existing due to insulation in the floor above.

Crawl Space vents had been blocked with insulation but were observed, using a smoke pencil, to be drawing a significant amount of air into the crawl space.

Moisture Content: Extremely dry throughout.

Air Tightness: Because of access difficulties, the air leakage test was performed in a slightly different fashion than other 8 houses tested. Tests were done using only one fan. Measurements @ 10 Pa. were made with the crawl space hatch open and then closed. This yielded the values for crawl space and house leakage but did not distinguish the interface leakage. Crawl space vents were left as found for the test.

8. House #8

Figure 16: Front Elevation of House

House #8 is a single storey 1635 sq. ft. (151 m^2) house located in Surrey, British Columbia. The house is one year in age, and was selected for testing and inspection on a random basis, from a collection of houses in a locality where soils are wet and elevations low. Some of the important details of the house are as follows:

Exterior Finish: Vinyl siding extending two inches below sill plate level. Continuously vented aluminum soffits.

Heating System: Gas radiant floor coils. The manifolds and piping for the radiant heating system are all located in the crawl space, and are uninsulated.

Drainage System: One pipe system of foundation drainage using 4 inch drain tiles. Roof drainage by use of gutters with rain water leaders terminating at splash troughs which divert water into soil two feet away from house.

Ventilation System: Bathroom ceiling fans are controlled by dehumidistat. Kitchen range with fan is vented to the outdoors.

Soil Characteristics: Undefined

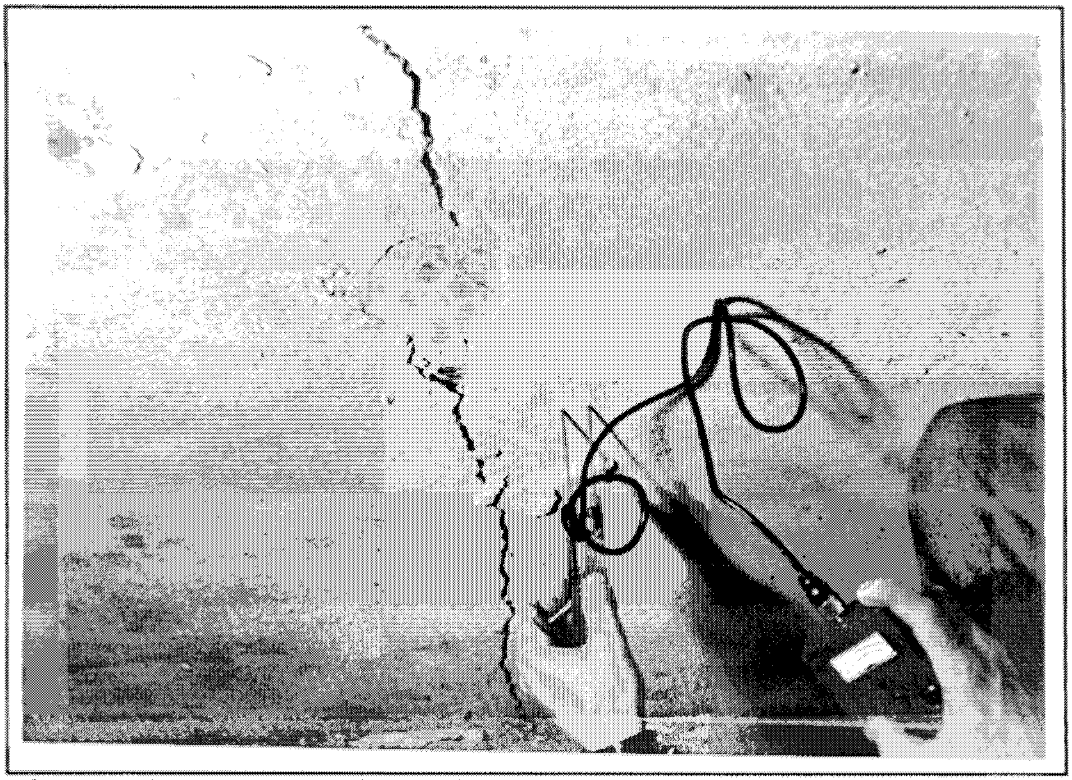


Figure 17: Crack in Thin Concrete Revealing Poly

Crawl Space Description: Crawl Space floors covered with a skin coat of concrete, overtop of a 6 mil. polyethylene barrier. The poly is lapped up and visible around the perimeters in most locations, and also through cracks in the skin code in various locations. The inside of the crawl space foundation wall is insulated with one inch expanded polystyrene board insulation from sill plate to below grade. In accordance with typical construction practice, each board of insulation is attached with two nails to the concrete, causing the boards to bow away from the wall and destroying the effectiveness of the insulation. Pieces of RSI 2.9 batts are stuffed in the joist ends. Supporting pony walls in the crawl space are sitting on a foam gasket and concrete curb.

Six standard crawl space vents were evident, two of which are fitted with 125 mm diameter grills with 90 degree elbows, (for no apparent reason). At the time of inspection the adjustable dampers on all vents had been closed, and three of the vents had been covered with insulation batts. The crawl space access hatch was located inside the two car garage.

Problem History: No moisture problems had been experienced with this crawl space. The homeowner complained of comfort problems during coldest weather, due to egress of cold air through the crawl space vents. Cold air continued to cause problems even after the dampers had been shut, due to leaky design. The homeowner had gone to the trouble of stuffing batts against the most accessible vents to try and alleviate this problem.

Findings and Observations: Inspection in January 1991 revealed that the concrete skin code in the crawl space was excessively thin (less than one inch) in a number of areas, and had suffered from cracking during curing. Some of the cracks in the concrete were wide enough to permit inspection of the polyethylene beneath the concrete. It was interesting to observe that despite the movement associated with cracking concrete, no damage had been done to the polyethylene. There is no evidence of moisture problems anywhere in the crawl space. However the crawl space was very warm at the time of the inspection due to the heating pipes throughout.

Temperature and Humidity: The actual humidity level in the crawl space was approximately 30% higher than outdoors. Indoor house humidity levels were higher still approximately 70% greater than outdoors. The house is occupied by an elderly couple who were home at the time of the inspection.

Moisture Content: This crawl space was found to be extremely dry, with less than 10% moisture content in wooden joists, and 15% m.c. in the wall sheathing. The leakage areas for the house and the crawl space were close to the mean for the houses in this project, with the house measuring 1040 sq. centimetres, and the crawl space measuring 920 sq. centimetres. Leakage between the crawl space and house in this radiant heated home amounted to 342 sq. cm.

9. House #9

Figure 18: Front Elevation of House

House #9 is a two storey house located in Surrey B.C., with a one car garage, an exterior insulated chimney, and a Mansard Roof. The house is build on a terraced lot part way down a hill in a new subdivision overlooking the Fraser Valley. The house was referred to the research team by neighbours, who knew the homeowners had been suffering from severe crawl space moisture problems since purchasing the new home. Some of the important details of the house are as follows:

Exterior Finish: Vinyl siding extending to grade. Continuously vented aluminum soffits.

Heating and Ventilating System: Forced air natural gas heating. Furnace is a counter flow unit, with warm air ducts distributed throughout the crawl space, and a single return air grill central hallway next to the furnace room. The furnace is equipped with a two speed blower, which operates continuously.

Drainage System: One pipe system of foundation drainage using four inch drain tile. Roof drainage by use of gutters with rain water leaders terminating at splash troughs diverting water two feet away from the house.

Soil Characteristic: A test hole dug next to the foundation wall during the inspection, revealed the usual mix of wood waste, rocks, course gravel and back fill. At the level of the footings, the soil became quite gooey with substantial clay content. Water table was close to the level of the footings at the time of the testing. A large earth berm in the back yard, combined with the hilly terrain in the neighbourhood, meant that surface drainage was directed towards the house on both south and west sides. (The high sides of the house). Much of the roof drainage is also spilled next to the foundation wall on the high side.

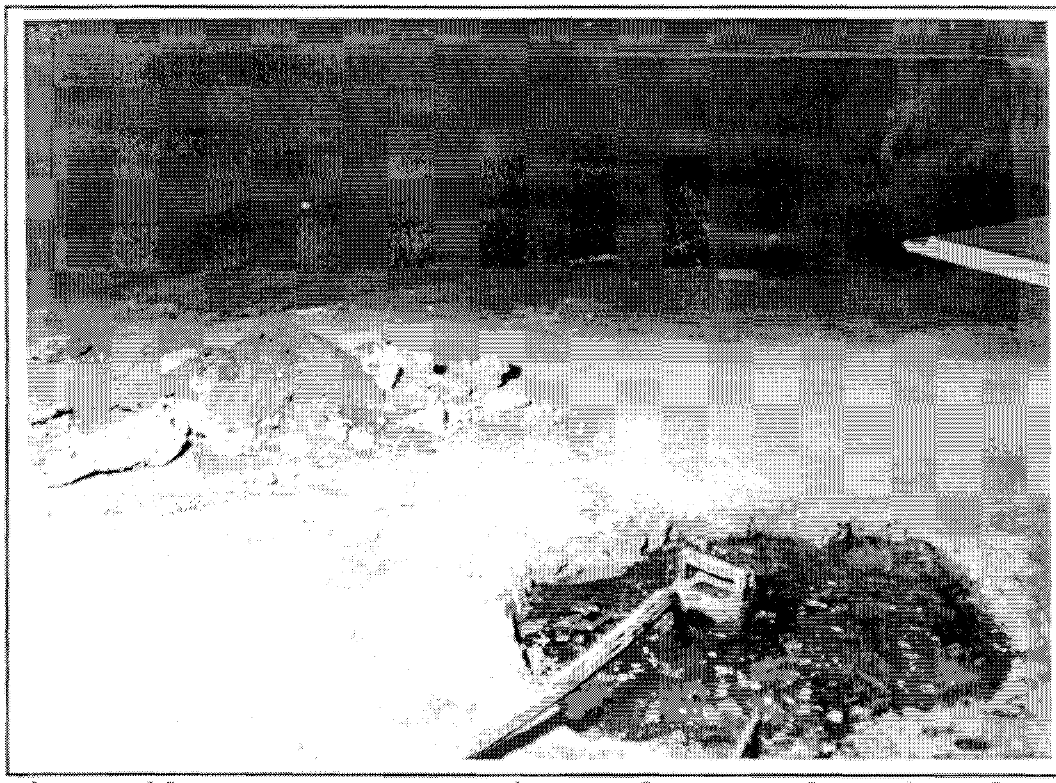


Figure 19: Temporary Sump in Crawl Space Floor for Flood Relief

Crawl Space Description: The crawl space floor consists of a two inch thick concrete skin coat. No polyethylene moisture barrier had been installed below the concrete. The more exposed sections of the crawl space wall had been insulated with fibreglass batts, held in place by two by four framing with a polyethylene moisture barrier against the concrete. Batts had been stuffed in all the box ends. One inch expanded polystyrene boards had been nailed to the interior of the concrete foundation wall on the west and north sides. Crawl space vents had not been installed initially, but had been retrofitted in place the day prior to inspection, as part of remedial measures for moisture problems. At the time of inspection, four vents were identified, all with louvres and open dampers. In one case the new crawl space vent had been located directly in front of the household plumbing lines.

Problem History: The owners had moved into their new home in May 1990. They used the crawl space for storage of camping gear and other materials. Dampness was noticed throughout the house by occupants. After several months of living in the home it was discovered that all of the materials stored in the crawl space had been ruined by excessive moisture. During raining periods the crawl space would be in float with up to six inches of water. The occupants assumed that poor drainage was the cause of their problems. The west side of the house was especially problematic, and became a swamp in wetter weather. The homeowner attempted to drain the entire lot, by digging a ditch along the west perimeter, and laying drain tiles at the bottom of the ditch. The ditch proved unsuccessful. The builder had no suggestions on how to solve the problem. The homeowners received help from the site supervisor for the developer of the subdivision, who first visited the site in November 1990. On December 24, 1990 three holes were broken through the concrete skin coat in the concrete, three pits were dug. A Little Giant water pump and piping system was installed as a temporary sump pump. (see photo) Continuous pumping reduced water levels from six inches to puddles. On January 3, 1991, vents were installed around the perimeter of the crawl space and left open, and additional warm air registers were opened into the crawl space. (see photos)

Findings and observations: The visit by researchers on January 4, 1991 revealed very high moisture levels in the crawl space and house. It would still be too early for the remedial measures to have any impact. Due to the cold weather at the time, windows throughout the house were covered in thick condensation and ice. Inspection of the crawl space revealed an extremely wet situation, with pooling and running water throughout, and heavy condensation build-up behind batts and behind the wall moisture barrier.

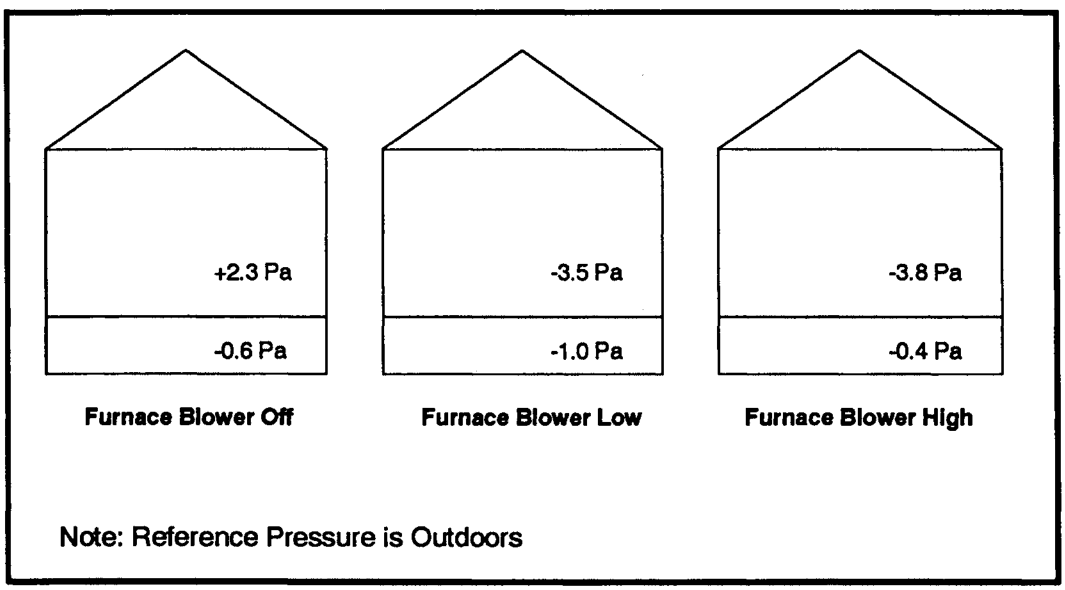


Figure A2-3: House #9; Pressure Differentials (after the installation of 4 crawl space vents and closing return air openings in crawl space)

It was difficult to understand the strategy that had been adapted by the contractor to resolve the moisture problem. The addition of crawl space vents would presumably assist in drying out the space. The addition of warm air supply to the crawl space may also be explained in terms of shortening the dry out period. However with open puddles around the crawl space, warmer temperatures could lead to additional humidity entering the living areas of the house. To evaluate this potential problem measurements were taken of pressure differential between the house and crawl space and outdoors. Figure 20 illustrates the pressure differentials in between these three zones, and reveals that under the normal operating condition, with the furnace blower running at low speed, the house is depressurized by over two Pascals relative to the crawl space. With the furnace blower operating at high the situation is even worse. The homeowners can expect more moisture problems indoors than before, given this situation. Advice was offered by researchers free of charge to assist in reversing the air and moisture flows. An offer was also made to develop a long term solution for their crawl space moisture problems. However the occupants decided to wait for further action from the site supervisor, or from the New Home Warranty Program if necessary. A short term solution was outlined for the residents, as follows:

1. Seal ducts in the crawl space with a liquid sealer on joints
2. Close off all return air and supply air openings to the crawl space.
3. Close the vents to the outdoors and plug these vents, and remove batts from box ends and pony walls.
4. Place a float controlled sump pump in pit and cover pit and plug in pump to permit automatic operation.
5. Seal crawl space house connection interface using foam-in-place urethane and other appropriate materials.
6. Lay polyethylene over the entire floor slab, tenting over the pits.
7. Connect a combustion air duct to furnace to return air plenum, adding a manually controlled damper in-line.
8. Operate the furnace blower at low speed and measure pressures indoors to crawl space. Adjust the manual damper in the supply air duct until house is positive by two to three Pascals relative to the crawl space.

Temperature and Humidity: The indoor and crawl space absolute humidity was approximately 100% greater than outdoor humidity, - not surprising given the condition of the crawl space.

Moisture Content: Moisture content of wood varied considerably depending on location, with the wall sill joints ranging from 60 - 85%, and the sills themselves ranging from 15-24%.

10. House #10

Figure 20: Front Elevation of House

House #10 is a two storey house located in Langley B.C. with a single garage. The house age is about 7 years. The house was referred to Sheltair by the regional CMHC office where a telephone inquiry from the homeowner regarding his moisture problems. Some of the important details of the house are as follows:

Exterior Finish: Vinyl siding extending to 2" below sill plate level. Continuously vented aluminum soffits.

Heating system: Forced air, natural gas heating. There is also a wood fireplace which has been blocked off. The crawl space is heated by a hole cut into the supply plenum which has been temporarily fitted with a cardboard damper.

Drainage System: One pipe system of foundation drainage using 4" drain tile. Roof drainage by means of gutters with rain water leaders terminating at splash troughs which divert water into soil away from house. The crawl space has a single floor drain which also serves to drain the overflow from the DHW.

Soil Characteristics: Soil type was not defined. Through an inspection hole in

Figure 21: Support Wall Resting on Slab

the crawl space it was noted that at least 100 mm of fine sand had been placed beneath the concrete skin coat and a loose gravelly fill was used extending 300 mm further. The hardpan was not reached and the homeowner was not able to define the soil type.

Crawl Space Description: Floor consists of concrete skin coat with an extremely rough finish. Large gravel was used in the pore and no attempt was made to smooth or float the surface. Polyethylene moisture barrier was not present Joist headers are insulated with batt insulation and the floor above the crawl space was partially insulated (50-60%) by the homeowner with R12 batt insulation. Support walls are built at floor level and freely soak up floor moisture. Crawl space height is approximately 1.3 m to the bottom of the joists.

Standard crawl space vents were not provided though a single screened hood was installed which opened into the crawl space. The hole was blocked with insulation.

Problem History: Condensation had occurred on double glazed windows throughout the house during winter Some wet areas in the crawl space had been found.

Remedial Measures Taken: None

Findings & Observations: The visit in January/91 revealed that the concrete skin coat in the crawl space had thinned to fill level in a number of areas. These areas shows signs of wetness. Although the crawl space was very dry at the time of the test, there were many signs of moisture entry including stained sill plates and support wall studs and efflorescence. The soil beneath the slab was completely saturated in some areas.

Temperature & Humidity: The absolute humidity level in the crawl space was only 10% higher than outdoors indicating little evaporation. House humidity levels were slightly high but may have been related to activity prior to the visit.

Moisture Content: Mostly dry throughout except for isolated areas where soil was exposed. The highest wood MC of 20% was measured at the base of the support walls which were sitting at floor level. MC behind insulation on headers was 15 -16%. Perimeter walls were 60-65% in some areas, highest at the base.

Air Tightness: The house was moderately tight at an ELA of 850 cm^2. The crawl space/house interface leakage was small in comparison to other forced air heated houses in this study. In House #10, the difference was that only one supply grill was installed and as mentioned, it was fitted with a damper.

APPENDIX III

SUGGESTED REVISIONS TO

1990 NATIONAL BUILDING CODES

This appendix outlines the types of changes that are needed in order resolve many of the problems uncovered in this research and to acheive the objectives outlined in the discussion and conclusions of the report.

An alternative moisture control strategy is illustrated in Figure A3-1. In general heated crawl space in B.C. should be treated as shallow basements. Our objective in these recommendations is to replace the present code sections in which we are not in agreement. This should be done at the same time that the 1990 NBC revision in section 9.18.6.1 (3) regarding "vapour barriers" is accepted in the B.C. and municipal codes revisions.

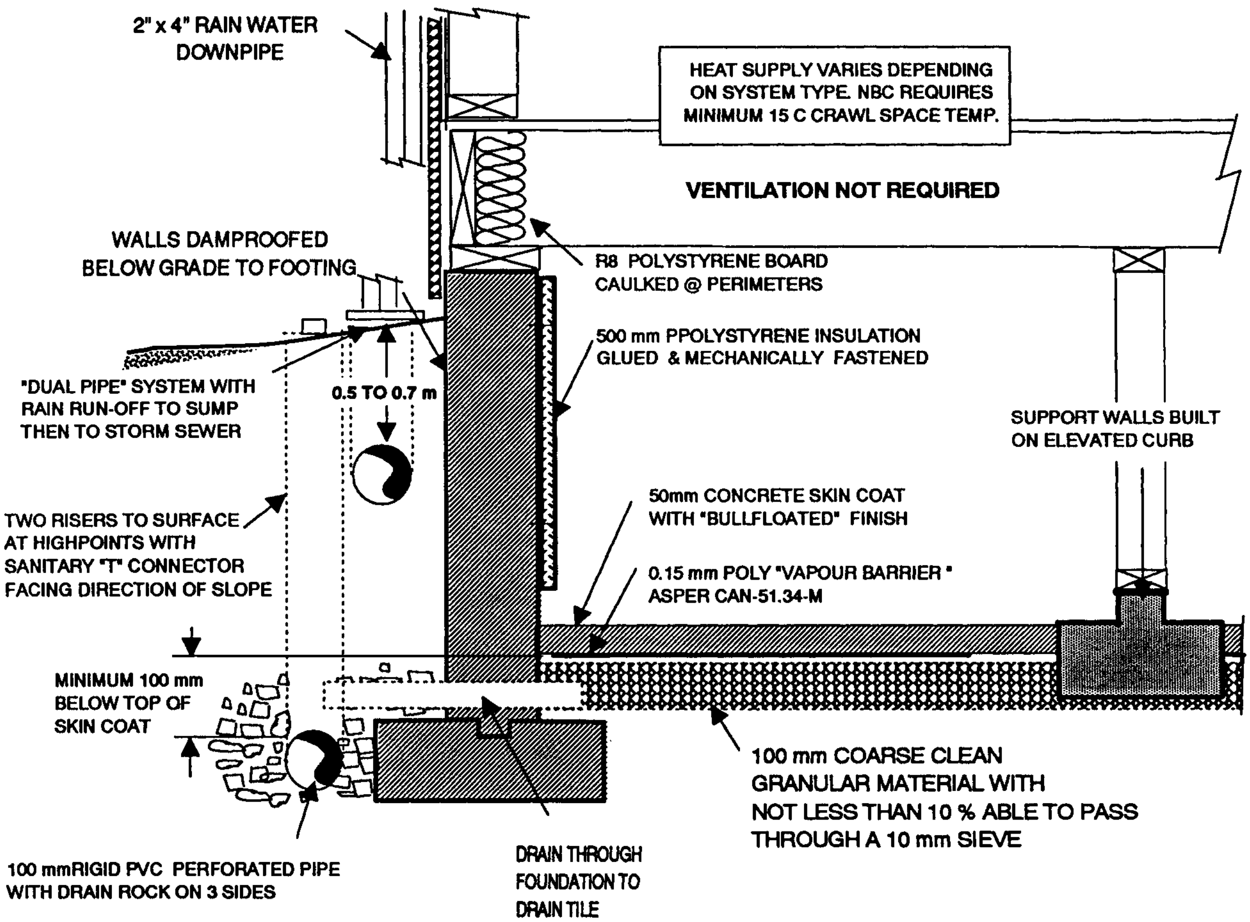


Figure 1: Effective Moisture Control System for Heated Crawl Spaces in B.C. Houses

1 DRAINAGE

1.1 Foundation Drains:

a) Should be constructed of 100 mm rigid PVC perforated drain pipe;

b) Should be provided with clean outs using a sanitary "T" connector and placed at highest elevation of the system in order to facilitate cleaning and testing in either direction towards the sump;

1.2 Grading of Backfill: Wherever possible, backfill should be graded to prevent drainage towards the foundation after settling;

1.3 Slab Drainage:

a) Where crawl space is to be designed as per item 3.1 of this Appendix then a coarse granular fill 10 mm clean gravel shall be placed over compacted soil.

b) Where proper granular fill is used on a site, a drain through the footing to the foundation drain should be provided at the lowest point or points[1].

c) On sites where maximum ground water levels are known to be higher than the slab height, an internal sump pit and appropriate pump should be installed in crawl space.

2 INSULATION

2.1 Foundation walls: Perimeter foundation walls should be insulated from the exterior wherever possible with an appropriate rigid type insulation board. When insulating internally using a rigid insulation board, the boards should be fastened with an appropriate adhesive and also mechanically fastened with concrete nails in each corner of the board.

2.2 Floor Perimeter: Headers and trimmers should be insulated using rigid board insulation and should be sealed with caulking to minimize air and moistureinfiltration to the joists.

3. MOISTURE BARRIER

3.1 A polyethylene soil gas barrier should be placed under a 50 mm concrete skin coat as specified in the 1990 NBC 9.18.6.1 (3).

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[1] On sites with high ground water tables, water frequently collects beneath the slab but cannot escape to the perimeter drains since water flows are obstructed by footings. Instead the water is driven upwards by hydrostatic pressures. The installation of drains through the footings to connect the sub slab granular fill with the perimeter drainage does not appear to be common anywhere in British Columbia.

3.2 On sites where soil gas concentrations are above guidelines, crawl space slabs should be treated as defined in NBC 1990 A-9.13 and A-9-16.2.1.

4. VENTILATION

4.1 Article 9.18.3.2 in the 1985 BCBC & 1990 NBC should be revised to refer to a revision of Article 9.18.3.5. The revised article should read:

9.18.3.5. Ventilation to the Outside Not Required. "When the crawl space ground cover is constructed as in Article 9.18.6.1.(3), or if the crawl space is vented to an adjacent basement ..."

4.2 Article 9.18.6.1.(3) should be revised to read:

9.18.6.1.(3) Ground Cover; Materials & Installation. Where a crawl space serves a dwelling unit it need not be vented to the outside air if a ground cover consisting of not less than 0.15 mm polyethylene ... is provided in every crawl space.

5. HEATING

The confusion in regards to heating crawl spaces in B.C. stems somewhat from the code requirement in B.C.BC 6.2.4.4. (3) for heating crawl spaces used as warm-air *plenums*. This article should be moved to the Appendix and clarified or removed altogether. The article should be replaced with the Article 6.2.4.5 (5) of the NBC 1990 which states:

6.2.4.5.Warm Air Supply Outlets (5) In *basements* and heated crawl spaces, the calculated heat gain from the *supply ducts* and *plenum* surfaces may be considered in calculating the design heat loss.

Any other references to heating of crawl spaces should be refer to NBC 1990 6.2.4.5.(5).

APPENDIX IV

EXCERPTS FROM RELEVANT

CODES & BYLAWS

be removed from the *soil* to a depth of not less than 300 mm in unexcavated areas under a *building*.

(3) The bottom of every *excavation* shall be free of all organic material.

9.12.1.2. Standing Water. *Excavations* shall be kept free of standing water.

9.12.1.3. Protection from Freezing. The bottom of *excavations* shall be kept from freezing throughout the entire construction period.

9.12.2. Depth

9.12.2.1. Excavation to Undisturbed Soil. *Excavations* for *foundations* shall extend to undisturbed soil.

9.12.2.2. Minimum Depth of Foundations

(1) Except as provided in Sentences (4) and (5), the minimum depth of *foundations* below finished ground level shall conform to Table 9.12.2.A.

(2) The minimum depth of *foundations* for exterior concrete steps with more than 2 risers shall conform to Sentences (1) to (5).

(3) Concrete steps with 1 and 2 risers are permitted to be laid on ground level.

(4) The *foundation* depths required in Sentence (1) are permitted to be decreased where experience with local *soil* conditions shows that lesser depths are satisfactory, or where the *foundation* is designed for lesser depths.

Table 9.12.2.A.
Forming Part of Sentence 9.12.2.2.(1)

Minimum Depths of Foundation				
Type of *Soil*	*Foundation* Containing Heated *Basement* or Crawl Space		*Foundation* Containing no Heated Space	
	Good *Soil* Drainage to not less than the Depth of Frost Penetration	Poor *Soil* Drainage	Good *Soil* Drainage to not less than the Depth of Frost Penetration	Poor *Soil* Drainage
Rock	No limit	No limit	No limit	No limit
Coarse grained *soils*	No limit	No limit	No limit	Below the depth of frost penetration
Silt	No limit	No limit	Below the depth of frost penetration	Below the depth of frost penetration
Clay or *soils* not clearly defined [1]	1.2 m	1.2 m	1.2 m but not less than the depth of frost penetration	1.2 m but not less than the depth of frost penetration
Column 1	2	3	4	5

Note to Table 9.12.2.A.:
[1] See Appendix A.

A-9.12.2.A. Minimum Depths of Foundations. The requirements for clay soils or soils not clearly defined are intended to apply to those soils that are subject to significant volume changes with changes in moisture content.

1990 - NBC Related to Crawl Space

be removed from the *soil* to a depth of not less than 300 mm in unexcavated areas under a *building*.

(3) The bottom of every *excavation* shall be free of all organic material.

9.12.1.2. Standing Water. *Excavations* shall be kept free of standing water.

9.12.1.3. Protection from Freezing. The bottom of *excavations* shall be kept from freezing throughout the entire construction period.

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(2) The minimum depth of *foundations* for exterior concrete steps with more than 2 risers shall conform to Sentences (1) to (5).

(3) Concrete steps with 1 and 2 risers are permitted to be laid on ground level.

(4) The *foundation* depths required in Sentence (1) are permitted to be decreased where experience with local *soil* conditions shows that lesser depths are satisfactory, or where the *foundation* is designed for lesser depths.

Table 9.12.2.A.
Forming Part of Sentence 9.12.2.2.(1)

Minimum Depths of Foundation				
Type of *Soil*	*Foundation* Containing Heated *Basement* or Crawl Space		*Foundation* Containing no Heated Space	
	Good *Soil* Drainage to not less than the Depth of Frost Penetration	Poor *Soil* Drainage	Good *Soil* Drainage to not less than the Depth of Frost Penetration	Poor *Soil* Drainage
Rock	No limit	No limit	No limit	No limit
Coarse grained *soils*	No limit	No limit	No limit	Below the depth of frost penetration
Silt	No limit	No limit	Below the depth of frost penetration	Below the depth of frost penetration
Clay or *soils* not clearly defined[1]	1.2 m	1.2 m	1 2 m but not less than the depth of frost penetration	1 2 m but not less than the depth of frost penetration
Column 1	2	3	4	5

Note to Table 9.12.2.A.:
[1] See Appendix A.

A-9.12.2.A. Minimum Depths of Foundations. The requirements for clay soils or soils not clearly defined are intended to apply to those soils that are subject to significant volume changes with changes in moisture content.

(f) CAN2-51.34-M, "Vapour Barrier, Polyethylene Sheet, for Use in Building Construction."

9.13.3. Waterproofing of Walls

9.13.3.1. Preparation of Surface

(1) Unit masonry walls to be waterproofed shall be parged on exterior surfaces below ground level with not less than 6 mm of mortar conforming to Section 9.20.

(2) Concrete walls to be waterproofed shall have all holes and recesses resulting from removal of form ties sealed with mortar or waterproofing material.

9.13.3.2. Application of Waterproofing Membranes. Concrete or unit masonry walls to be waterproofed shall be covered with not less than 2 layers of bitumen-saturated membrane, with each layer being cemented in place with bitumen and coated over-all with a heavy coating of bitumen.

9.13.4. Waterproofing of Floors

9.13.4.1. *Basement* floors to be waterproofed shall have a system of membrane waterproofing provided between 2 layers of concrete, each of which shall be not less than 75 mm thick, with the floor membrane mopped to the wall membrane to form a complete seal.

9.13.5. Dampproofing of Walls

9.13.5.1. Preparation of Surface

(1) Unit masonry walls to be dampproofed shall be parged on the exterior face below ground level with not less than 6 mm of mortar conforming to Section 9.20, and shall be coved over the footing when the first course of block is laid.

(2) Concrete walls to be dampproofed shall have holes and recesses resulting from the removal of form ties sealed with cement mortar or dampproofing material.

9.13.5.2. Application of Dampproofing Material. Bituminous or other dampproofing material shall be applied over the parging or concrete below ground level.

9.13.5.3. Interior Dampproofing of Walls

(1) Where a separate interior cladding is applied to a concrete or unit masonry wall which is in contact with the *soil*, or where wood members are applied to such walls for the installation of insulation or finish, the interior surface of the *foundation* wall below ground level shall be dampproofed.

(2) The dampproofing required in Sentence (1) shall extend from the *basement* floor and shall terminate at ground level and no membrane shall be applied above ground level between the insulation and the *foundation* wall.

9.13.5.4. Barrier to Soil Gas and Water Vapour. Masonry walls which are to be dampproofed and which are not dampproofed on their interior surface as required in Sentence 9.13.5.3.(1) shall include a course of masonry units without voids or be sealed with flashing material extending across the full width of the masonry at or below the level of the adjoining floor slab or, in the absence of a floor slab, the level of the ground cover required in Article 9.18.6.1. (See A-9.13 in Appendix A.)

9.13.6. Dampproofing and Sealing of Slabs

9.13.6.1. Location of Dampproofing. When slabs are dampproofed, the dampproofing shall be installed below the slab, except that where a separate floor is provided over the slab, the dampproofing may be applied to the top of the slab.

9.13.6.2. Dampproofing below the Slab

(1) When installed below the slab, dampproofing shall consist of polyethylene not less than 0.15 mm thick.

(2) Joints in dampproofing described in Sentence (1) shall be lapped not less than 300 mm

9.13.6.3. Dampproofing above the Slab. When installed above the slab, dampproofing shall consist of not less than 2 mopped-on coats of bitumen, 0.05 mm polyethylene or other material providing equivalent performance.

(3) The top half of joints referred to in Sentence (2) shall be covered with sheathing paper, 0.10 mm polyethylene or No. 15 asphalt or tar-saturated felt.

(4) The top and sides of drain pipe or tile shall be covered with not less than 150 mm of crushed stone or other coarse clean granular material containing not more than 10 per cent of material that will pass a 4 mm sieve.

9.14.4. Granular Drainage Layer

9.14.4.1. Type of Granular Material. Granular material used to drain the bottom of a *foundation* shall consist of a continuous layer of crushed stone or other coarse clean granular material containing not more than 10 per cent of material that will pass a 4 mm sieve.

9.14.4.2. Installation. Granular material described in Article 9.14.4.1. shall be laid on undisturbed or compacted *soil* to a minimum depth of not less than 125 mm beneath the *building* and extend not less than 300 mm beyond the outside edge of the footings.

9.14.4.3. Grading. The bottom of an excavation drained by a granular layer shall be graded so that the entire area described in Article 9.14.4.2. is drained to a sump conforming to Article 9.14.5.2.

9.14.4.4. Wet Site Conditions. Where because of wet site conditions *soil* becomes mixed with the granular drainage material, sufficient additional granular material shall be provided so that the top 125 mm are kept free of *soil*.

9.14.5. Drainage Disposal

9.14.5.1. Drainage Disposal. *Foundation* drains shall drain to a sewer, drainage ditch or dry well.

9.14.5.2. Sump Pits

(1) Where a sump pit is provided, it shall be not less than 750 mm deep, 0.25 m^2 in area and be provided with a cover.

(2) Where gravity drainage is not practical, an automatic sump pump shall be provided to discharge the water from the sump pit described in Sentence (1) into a sewer, drainage ditch or dry well.

9.14.5.3. Dry Wells

(1) Dry wells may be used only when located in areas where the natural *groundwater level* is below the bottom of the dry well.

(2) Dry wells shall be not less than 5 m from the *building foundation* and located so that drainage is away from the *building*.

9.14.6. Surface Drainage

9.14.6.1. Surface Drainage. The *building* shall be located or the *building* site graded so that water will not accumulate at or near the *building*.

9.14.6.2. Drainage away from Wells or Septic Disposal Beds. Surface drainage shall be directed away from the location of a water supply well or septic tank disposal bed.

9.14.6.3. Catch Basin. Where runoff water from a driveway is likely to accumulate or enter a garage, a catch basin shall be installed to provide adequate drainage.

9.14.6.4. Downspouts. Where downspouts are provided and are not connected to a sewer, provisions shall be made to prevent *soil* erosion.

Section 9.15 Footings and Foundations

9.15.1. Scope

9.15.1.1. Application

(1) Except as provided in Articles 9.15.1.2. and 9.15.1.3., this Section applies to concrete or unit masonry *foundation* walls and concrete footings on *soils* with an *allowable bearing pressure* of 75 kPa or greater for *buildings* of wood frame or masonry construction. (See Appendix A.)

A-9.15.1.1.(1) Installation of Mobile Homes. CSA has prepared a standard entitled CAN3-Z240.10.1, "Recommended Practice for the Site Preparation, Foundation and Anchorage of

9.15.3. Footings

9.15.3.1. Footings Required. Footings shall be provided under walls, pilasters, columns, piers, fireplaces and *chimneys* that bear on *soil* or *rock*, except that footings may be omitted under piers or monolithic concrete walls if the safe *loadbearing* capacity of the *soil* or *rock* is not exceeded.

9.15.3.2. Support of Footings. Footings shall rest on undisturbed *soil*, *rock* or compacted granular *fill*.

9.15.3.3. Footing Sizes

* **(1)** Except as provided in Sentences (2) to (6), the minimum footing size shall be as shown in Table 9.15.3.A. provided the length of supported joists does not exceed 4.9 m.

* **(2)** Where the length of the supported joists exceeds 4.9 m, footings shall be designed in accordance with Section 4.2.

(3) The strip footing sizes for exterior walls shown in Column 2 of Table 9.15.3.A. shall be increased by 65 mm for each *storey* of masonry veneer over wood frame construction supported by the *foundation* wall.

Table 9.15.3.A.
Forming Part of Article 9.15.3.3.

Minimum Footing Sizes			
No. of Floors Supported	Minimum Width of Strip Footings, mm		Minimum Footing Area for Columns Spaced 3 m o.c.,(1) m^2
	Supporting Exterior Walls	Supporting Interior Walls	
1	250(2)	200(3)	0.4
2	350(2)	350(3)	0.75
3	450(2)	500(3)	1.0
Column 1	2	3	4

Notes to Table 9.15.3.A.:

(1) See Sentence 9.15.3.3.(6)
(2) See Sentence 9.15.3.3.(3) and (4)
(3) See Sentence 9.15.3.3.(5)

(4) The strip footing sizes for exterior walls shown in Column 2 of Table 9.15.3.A. shall be increased by 130 mm for each *storey* of masonry construction supported by the *foundation* wall.

(5) The minimum strip footing sizes for interior walls shown in Column 3 of Table 9.15.3.A. shall be increased by 100 mm for each *storey* of masonry construction supported by the footing.

(6) The footing area for column spacings other than shown in Table 9.15.3.A. shall be adjusted in proportion to the distance between columns.

9.15.3.4. High Water Table. Where a *foundation* rests on gravel, sand or silt in which the water table level is less than the width of the footings below the bearing surface, the footing width shall be not less than twice the width required by Article 9.15.3.3.

9.15.3.5. Non-Loadbearing Walls. Footings for interior non-*loadbearing* masonry walls shall be not less than 200 mm wide for walls up to 5.5 m high and shall be increased by 100 mm for each additional 2.7 m of height.

9.15.3.6. Thickness. Footings shall be not less than 100 mm thick except when greater thicknesses are required because of the projection of the footing beyond the supported element.

9.15.3.7. Footing Projection. The projection of an unreinforced footing beyond the supported element shall be not greater than the thickness of the footing.

9.15.3.8. Step Footings. When step footings are used, the vertical rise between horizontal portions shall not exceed 600 mm. The horizontal distance between risers shall not be less than 600 mm.

9.15.4. Foundation Walls

9.15.4.1. Foundation Wall Thickness. Where average stable *soils* are encountered, the thickness of *foundation* walls subject to lateral earth pressure shall conform to Table 9.15.4.A. for walls not exceeding 2.5 m in unsupported height.

9.15.4.2. Lateral Support

(1) For the purposes of Article 9.15.4.1., *foundation* walls shall be considered laterally supported at the top if such walls support solid masonry

89 mm where the siding overlaps the *foundation* wall not less than 12 mm.

9.15.5.2. Support of Beams

(1) Not less than 190 mm depth of solid masonry shall be provided beneath beams supported on masonry.

(2) Where the beam referred to in Sentence (1) is supported below the top of the *foundation* walls, the ends of such beams shall be protected from the weather.

9.15.5.3. Pilasters

(1) Pilasters shall be provided under beams that frame into 140 mm unit masonry *foundation* walls.

(2) Pilasters required in Sentence (1) shall be not less than 90 mm by 290 mm and shall be bonded or tied into the wall.

(3) The top 200 mm of pilasters required in Sentence (1) shall be solid.

9.15.6. Parging and Finishing

9.15.6.1. Foundation Walls below Ground. Concrete block *foundation* walls shall be parged on the exterior face below ground level as required in Section 9.13.

9.15.6.2. Foundation Walls above Ground. Exterior surfaces of concrete block *foundation* walls above ground level shall have tooled joints, or shall be rendered, parged or otherwise suitably finished.

9.15.6.3. Form Ties. All form ties shall be removed at least flush with the concrete surface.

Section 9.16 Slabs-On-Ground

9.16.1. Scope

9.16.1.1. Application. This Section applies to concrete slabs supported on ground or on granular fill which do not provide structural support for the superstructure.

9.16.1.2. Structural Floor Slabs. Floor slabs that support loads from the superstructure shall be designed in conformance with Part 4.

9.16.1.3. Dampproofing and Waterproofing. Dampproofing and waterproofing shall conform to Section 9.13.

9.16.2. Granular Material beneath Slabs

9.16.2.1. Except for slabs in garages, not less than 100 mm of coarse clean granular material containing not more than 10 per cent of material that will pass a 4 mm sieve shall be placed beneath slabs in *dwelling units*. (See Appendix A.)

9.16.3. Drainage

9.16.3.1. Prevention of Water Accumulation. Except as provided in Article 9.16.3.2. or where it can be shown to be unnecessary, the accumulation of water underneath a slab-on-ground shall be prevented by grading or drainage.

9.16.3.2. Hydrostatic Pressure. Where *ground water levels* may cause hydrostatic pressure beneath the slab, the slab shall be designed to resist such pressures.

9.16.3.3. Floor Drains. When floor drains are installed (see Section 9.31), the floor surface shall be sloped so that no water can accumulate.

9.16.4. Concrete

9.16.4.1. Surface Finish

(1) The finished surface of concrete floor slabs shall be trowelled smooth and even.

(2) Dry cement shall not be added to the floor surfaces to absorb surplus water.

9.16.4.2. Topping Course

(1) When a topping course is provided for a concrete floor slab, it shall consist of 1 part cement to 2.5 parts clean, well graded sand by volume, with a water/cement ratio approximately equal to that of the base slab.

(2) When concrete topping is provided, it shall not be less than 20 mm thick.

9.17.6. Solid Concrete Columns

9.17.6.1. Materials. Concrete shall conform to Section 9.3.

9.17.6.2. Sizes. Concrete columns shall be not less than 200 mm by 200 mm for rectangular columns and 230 mm diam for circular columns.

Section 9.18 Crawl Spaces

9.18.1. General

9.18.1.1. Application. This Section applies to crawl spaces whose exterior walls have less than 25 per cent of their total area above exterior ground level open to the outdoors.

9.18.1.2. Foundations. *Foundations* enclosing crawl spaces shall conform to Section 9.15.

9.18.1.3. Insulation. Insulation shall conform to Section 9.25.

9.18.1.4. Heating. Heating of crawl spaces shall conform to Section 9.33.

9.18.2. Access

9.18.2.1. Access Openings

* **(1)** An access opening of not less than 500 mm by 700 mm shall be provided to each crawl space where the crawl space serves a single *dwelling unit*.

(2) Access openings shall be fitted with a door or hatch, except when the access opening into the crawl space is from the adjacent *basement* and provides ventilation to the crawl space.

9.18.3. Ventilation

9.18.3.1. General. Crawl spaces shall be ventilated by natural or mechanical means.

9.18.3.2. Natural Ventilation. Except as otherwise permitted in Article 9.18.3.5., natural ventilation for crawl spaces shall be provided to the outside air by not less than 0.1 m^2 of unobstructed vent area for every 50 m^2 of floor area.

9.18.3.3. Design of Vents. Vents for crawl spaces shall be designed to prevent the entry of snow, rain and insects, and shall be provided with tight-fitting covers to prevent air leakage in winter if the crawl space is heated.

9.18.3.4. Distribution of Vents. Vents for crawl spaces shall be uniformly distributed on opposite sides of the *building*.

9.18.3.5. Ventilation to the Outside Not Required. Ventilation to the outside air is not required when the crawl space is used as a warm-air *plenum*, or if the crawl space is vented to an adjacent *basement* with an opening conforming to Article 9.18.3.2.

9.18.4. Clearance

9.18.4.1. Ground Clearance. The ground level in a crawl space shall be not less than 300 mm below the level of all joists and beams, except that in localities where termites are known to occur, the clearance shall be not less than 450 mm, unless the joists are pressure treated with a chemical that is toxic to termites.

9.18.4.2. Access Way to Services. Where equipment requiring service such as plumbing cleanouts, traps and burners is located in crawl spaces, an access way with a height and width of not less than 600 mm shall be provided from the access door to the equipment and for a distance of 900 mm on the side or sides of the equipment to be serviced.

9.18.5. Drainage

9.18.5.1. Drainage

(1) Unless *groundwater levels* and site conditions are such that water will not accumulate in the crawl space, the crawl space floor and access trenches shall be sloped to drain to a sewer, ditch or dry well.

(2) Drains shall conform to Section 9.14.

9.18.6. Ground Cover

9.18.6.1. Materials and Installation

(1) Except as required in Sentence (3), a ground cover consisting of not less than 50 mm of asphalt, 10 MPa Portland cement concrete, Type S creases low frequency sound transmission. Adding an additional layer of drywall inside a double layer wall will also seriously increase sound transmission. Adding blocking inside walls to reduce the risk of firespread should be done so it does not increase vibration transmission from one part of a wall or floor to the other.

To verify that acoustical privacy is being achieved, a field test can be done at an early stage in the construction; ASTM E336 will give a complete measurement. A simpler and less expensive method is ASTM E597, "Standard Practice for Determining a Single Number Rating of Airborne Sound Insulation in Multi Unit Building Specifications." The rating provided by this test is usually within 2 points of the STC obtained from ASTM E336. It is useful for verifying performance and finding problems during construction. Alterations can then be made prior to project completion.

Impact Noise. Section 9.11 has no requirements for control of impact noise transmission. Footstep and other impacts can cause severe annoyance in multifamily residences. Builders concerned about quality and reducing occupant complaints will ensure that floors are designed to minimize impact transmission. A recommended criterion is that bare floors (tested without a carpet) should achieve an impact insulation class (IIC) of 55. Some lightweight floors that satisfy this requirement may still cause complaints about low frequency impact noise transmission. Adding carpet to a floor will always increase the IIC rating but will not necessarily reduce low frequency-noise transmission. Good footstep noise rejection requires fairly heavy floor slabs or floating floors. Impact noise requirements are being considered for inclusion in future versions of the NBC.

Most frequently used methods of test for impact noise are ASTM E492, "Method of Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies Using The Tapping Machine", or ASTM E1007, "Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures".

Machinery Noise. Elevators, garbage chutes, plumbing, fans, and heat pumps are common sources of noise in buildings. To reduce annoyance from these, they should be placed as far as possible from sensitive areas. Vibrating parts should be isolated from the building structure using resilient materials such as neoprene or rubber.

A-9.13 Exclusion of Soil Gas (see also A-9.16.2.1.) Outdoor air entering a dwelling through above-grade leaks in the building envelope normally improves the indoor air quality in the dwelling by reducing the concentrations of pollutants and water vapour. It is only undesirable because it cannot be controlled. On the other hand, air entering a dwelling through below-grade leaks in the envelope may increase the water vapour content of the indoor air and may also bring in a number of pollutants which it picks up from the soil. This mixture of air, water vapour and pollutants is sometimes referred to as "soil gas." One pollutant often found in soil gas is radon.

Radon is a colourless, odourless, radioactive gas that occurs naturally as a result of the decay of radium. It is found to varying degrees as a component of soil gas in all regions of Canada and is known to enter dwelling units by infiltration into basements and crawl spaces. The presence of the decay products of radon in sufficient quantity can lead to increased risk of lung cancer.

The potential for high levels of radon infiltration is very difficult to evaluate prior to construction and thus a radon problem may only become apparent once the building is completed and occupied. Therefore various sections of Part 9 require the application of certain radon exclusion measures in all dwellings. These measures are

(1) low in cost,
(2) difficult to retrofit, and
(3) desirable for other benefits they provide.

There are two principal methods of excluding soil gas:

(1) Sealing the interface between the soil and the occupied space, so far as is reasonably practicable.

Sections 9.13 and 9.18 include requirements for dampprooofing of slabs and ground covers in

There is a safe range for the interior pressure in a house. The upper limit is primarily due to the need to minimize outward leakage of the warm, moist interior air through leaks in the building envelope. The lower limit depends on the type of combustion heating equipment present in the house. It also follows from the need to avoid drawing in soil gas, as discussed in Appendix Notes A-9.13 and A-9.33.

Controlling the entry of soil gas by house or basement pressurization is therefore problematic, since it could lead to exfiltration-caused condensation problems in the building envelope. This leaves the option of reducing the pressure outside the envelope as the most practical method of achieving the desired outward pressure difference. The remainder of this note describes how this may be accomplished.

At least in areas which are prone to higher than normal radon levels, or other ground pollutants, the practice described below should be followed:

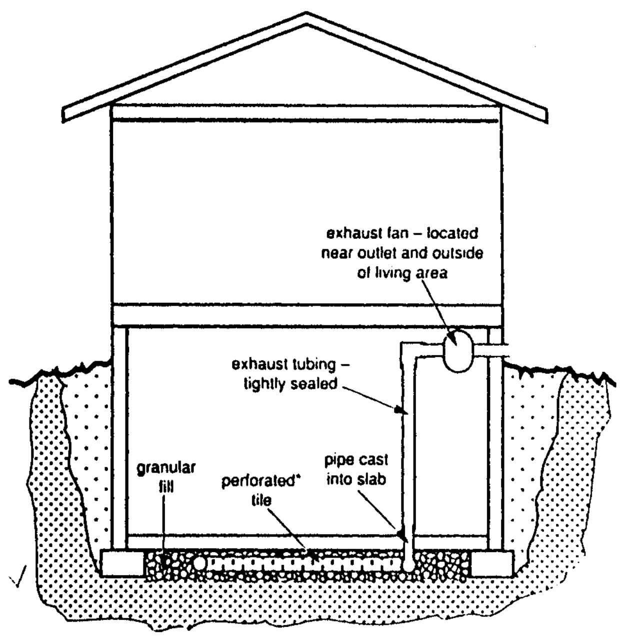
(1) Any slab-on-ground should have not less than 100 mm of coarse granular fill beneath the slab (as required in Article 9.16.2.1.) if no perforated tile is laid within the fill. If tile is used, not less than 50 mm of fill is required and no point in the filled area should be more than 3 m from the tile. The tile should not be connected to any drainage tile.

(2) A short length of pipe, of not less than 100 mm diameter, should be cast vertically into the slab. If no tile is used, this pipe should be located near the centre of the slab and the fill around the pipe location should not be less than 150 mm deep for a radius of 300 mm. If tile is used, the bottom end of the pipe should connect to the tile at its lowest point. The top end of the pipe should have a removeable cap.

(3) When the house is completed, a test should be carried out to determine the radon concentration. (Local health authorities can provide guidance as to whether the test results indicate the need for remedial measures.)

(4) If radon concentrations are above guideline levels, the sub-slab space should be ventilated. This requires that the pipe connection to the sub-slab space be uncapped and connected to a ventilation system exhausting to the outside. Exhaust pipes passing through unheated spaces should be insulated. The fan should be located where noise will not be a nuisance and outside the occupied space. It is also best to locate the fan as close to the final outlet end of the ventilation system as possible so that the pressurized portion of the system downstream of the fan will not be located in or adjacent to the living space. If the pressurized portion of the system were to pass through the living space, then any leak in the system would have the potential to spill high radon concentration soil gas into the living space, thus exacerbating the situation the system was intended to correct. The fan should be of a type suitable for the application and capable of continuous operation. This sub-slab ventilation system is illustrated below.

(5) The house should be re-tested for radon after completion of the ventilation system.



One type of sub-slab ventilation system

*suggested for radon-prone areas

A-9.16.2.1.

City of Vancouver

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SUPERVISOR,
PLUMBING INSP.

August 24, 1987

SEPARATION OF ROOF DRAINAGE AND FOUNDATION DRAINS

Over the years, the Plumbing Inspection Branch have become inundated with complaints of flooding neighbouring property after rainstorms. This is especially true where roof drainage water was allowed to pass through the foundation drainage system before reaching the City stormwater connection or sump.

This situation becomes aggravated as the spaced out or perforated foundation drains become clogged with roots or increase in friction due to entry of soils and sand into the pipe and unduly affects the innocent neighbours.

Therefore, in order to comply with the new Vancouver Building and Plumbing Bylaws, we will enforce the national standards for storm drainage which are in the new Plumbing Bylaw.

Effective on October 1st, 1987, all new storm drainage systems (including one- and two-family dwellings) will be required to convey stormwater from roof and paved areas to the sump in approved solid pipe in conformance with Plumbing Bylaw No. 5964.

The past practice of conveying such stormwater through the subsoil drainage system and permitting a basement floor drain to discharge into same subsoil system will no longer be permitted.

Where external downspouts are used to convey roofwater from outside gutters, they will be permitted to discharge into approved solid stormwater piping at grade level providing piping is intercepted by a sump. Storm drainage piping shall be an approved type for outside/underground installation, properly sloped with cleanouts installed as required in the Plumbing Bylaw, and laid in well-tamped trench before inspection and backfilling. Piping shall be sized in accordance with Plumbing Bylaw No. 5964.

Note - A 100 mm pipe will drain up to 460 sq.m. if graded at 2%.

The current regulations for installations of sumps (see attached sheet) will remain as before but will now intercept both storm drainage piping and subsurface drainage water through separate inlets with inverts a minimum of 100 mm above outlet to City storm sewer.

If the builder chooses to use a continuous layer of crushed rock to drain subsurface water as per Subsection 9.14.4 of the Building Bylaw, a 1 m section of approved, rigid, perforated drain tile pipe shall be installed with invert of inlet a minimum of 100 mm above outlet to storm sewer. This section of pipe shall extend out into the continuous layer of crushed stone, thereby allowing subsurface water to flow into the sump.

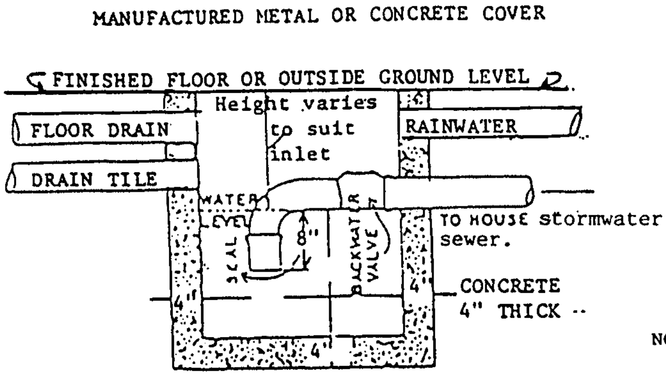
All subsurface drainage (either drain tile or continuous layer of crushed stone) shall be installed in accordance with Vancouver Building Bylaw Section 9.14 "Drainage".

R. V. Hébert, P. Eng.
DIRECTOR and
CITY BUILDING INSPECTOR

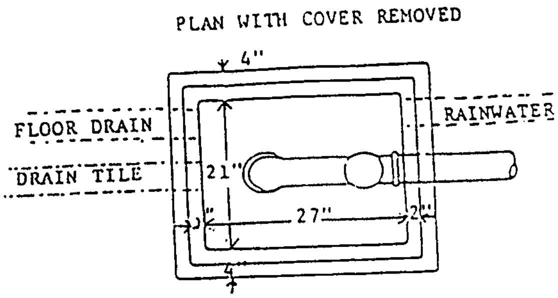
RVH:lc
Attachments

Contd.../2

STORM SEWER SUMP



CROSS SECTION OF SUMP



NOTE: The hinge pin of the backwater valve should be greased periodically. Sediment must be kept well below the level of the backwater valve inlet.

MEMORANDUM REGARDING DRAINAGE SUMPS

The concrete sump shown above must be installed where drain tile, roof conductors, basement drains & area drains (deck & patio) are being led to the storm sewer connection. A permit for this installation will be required from the City, and the plumbing inspector will inspect and pass it before use.

*For a round sump with a 4" discharge pipe to Storm Sewer the following diameters are acceptable:

24" up to 4 ft. depth from backwater valve to surface
30" up to 5 ft. depth from backwater valve to surface
36" with ladder required if depth greater than 5 ft. from backwater valve to surface.

For roof areas which are large enough to require a 6-inch sewer connection, when designing to Article 11.10.10 of the Plumbing Bylaw, the sump is to be 30 inches long inside, the width and water depth being 24 and 18 inches, respectively. For larger buildings or those with areas which require an 8" Storm Sewer connection or larger, please refer to list on back of this page.

No object or covering shall be placed over any sump which would interfere with free access for inspection and for removal of sediment or floating matter.

Location of the sump must be on the owner's property and owners, Architects, and Contractors are required to see that provision is made for installing them on the property when the plans are prepared.

All sumps must be water-tight and extended to the surface of the ground or the floor of a building.

A sump must be at a depth to effectively drain the lowest floor level of the house by gravity flow. The drainage line entering the sump must be above the maximum sump water level (See Drawing).

Rainwater conductors need not go to a sump if they are installed in accordance with Article 12.6.5(3) of Plumbing Bylaw 5964.

Warning: No garage waste, trade waste, or other objectionable liquid or solid can be led direct to the sewer connection for the property or to the standard sump which is shown above. All such prohibited wastes shall be led to special sumps, of which particulars may be obtained from the Industrial Waste Control Branch, City Hall, Telephone No. 873-7567.

SUGGESTED MINIMUM SIZE FOR SUMPS WITH BACK-WATER VALVES

PIPE SIZE	RECTANGULAR CONSTRUCTION	WALL THICKNESS	PIPE CONSTRUCTION	LIQUID DEPTH
4"	2'-0" X 2'-0"	4"	30"	17"
6"	2'-6" X 2'-0"	4"	36"	18"
8"	3'-0" X 4'-0"	6"	42"	24"
10"	3'-6" X 4'-0"	6"	48"	30"
12"	4'-0" X 5'-0"	6"	54"	30"
15"	4'-0" X 6'-6"	6"	72"	36"

Contd.../3