INVESTIGATION OF CRAWL SPACE VENTILATION

AND

MOISTURE CONTROL STRATEGIES

FOR B.C. HOUSES

Final Report

Prepared For:

Research Division
Canada Mortgage and Housing Corporation

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June, 1991

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SUMMARY

This report outlines a research project funded by the Canadian Mortgage & Housing Corporation (CMHC) Research Division for the purpose of investigating problems related to crawl space construction in British Columbia. Research was carried out between June/1990 and February/1991. A number of groups, including the Technical Advisory Committee of the B.C. Canadian Home Builders Association (CHBA), the CMHC Regional Office, and the New Home Warranty Program (NHWP), had identified problems with crawl space moisture control and ventilation strategies. Causes of the problems included uneven code enforcement and general failures in local building practices.

The widespread use of passive crawl space vents has long been seen as an effective defence against moisture build-up in crawl spaces. However, because these vents are often left open in the winter, and have inoperable or loosely fitting covers, they cause excessive cold air movement through the crawl space. This translates into a high energy penalty in heat loss from piping, forced air ducting and through ground floors. Ambiguous wording in the building codes has forced many building inspectors to prescribe the use of these vents in all situations - including heated crawl spaces. To some extent, vents were seen to be a solution to high moisture loading caused by a lack of proper moisture barriers over wet soils or by blocked or inadequate drainage systems.

Research included a literature review, a survey of present crawl space construction practices in B.C., and the selection and investigation of 10 case study houses in Greater Vancouver and the Fraser Valley. The ten house sample included crawl space constructions of similar types, with different types of heating and crawl space ventilation systems (ie. vented or non-vented, forced-air or radiant heated). Four of the houses investigated had experienced some degree of moisture problems which had required expensive remedial measures. Field investigation revealed that 3 of the 4 problem houses had inadequate moisture barriers. Moisture incidence was directly attributable to the lack of an effective moisture barrier, despite the presence of a 50 mm concrete slab.

A procedure previously developed for testing airtightness of attic spaces, was employed on crawl spaces in 9 of the case study houses. Test results showed that crawl space air leakage, excluding installed ventilation, was high enough to assure natural air change of 0.35 ACH with only a small temperature differential and slight wind. In most cases, there was a large difference (up to 500%) in the ground floor or "interface" airtightness between forced-air heated houses and radiant heated houses, because of the physical link created by the air-ducting system. It was also discovered that none of the vented crawl spaces had sufficient number of vents to meet the code requirements for installed vent area of 0.1 $m^2/50\ m^2$ of plan area.

Inspections of crawl spaces revealed extensive cracking of the concrete skin coat in all houses. Cracks did not reveal damage to polyethylene moisture barriers where they were present. The absence of concrete curbs for interior support walls has lead to structural decay in two of the houses. High wood moisture content was commonly measured in areas behind the joist header insulation.

It was concluded that some revision of the national and regional building codes would be required to reduce incidence of crawl space moisture problems. Such revisions would have to address the crawl space issue in a more comprehensive manner. To some extent the use of crawl space vents in B.C. housing has been an attempt to compensate for inadequate or ineffective drainage systems and moisture barriers. A better approach may be to eliminate the vents in heated crawl spaces, and apply any cost savings towards improving drainage systems and moisture barriers.

Some residential building sites require more effectively designed moisture control systems in order to control high ground water levels. Perimeter drainage tiles should be designed for easy testing, and clean-out, and should be connected to the floor slab area through drains installed in the footings. Fine granular sand presently used under slabs in the lower mainland does not provide an effective capillary break and could be substituted for coarse granular fill with no additional cost. Better application of insulation materials on the interior wall surfaces of crawl spaces is required to raise thermal efficiency and reduce surface condensation. Heat radiation and air leakage from duct work in a typical forced-air crawl space should be credited when calculating heating requirements.

More information is still required to fully define the minimum requirements of a crawl space moisture control system, including research into such issues as; moisture-proofing tops of foundation walls, air mixing systems for crawl spaces in houses lacking forced air duct work, the impact of crawl space vents and construction techniques on soil gas entry, and the airing-out of crawl space moisture in new houses during the building dry-out period.

RÉSUMÉ

Introduction

Les maisons neuves des basses terres continentales de la Colombie-Britannique sont couramment aménagées sur des vides sanitaires contrairement aux autres régions du pays où la majorité des maisons disposent d'un sous-sol pleine grandeur. À l'heure actuelle, les codes national et provinciaux exigent la ventilation des vides sanitaires afin d'y réduire au minimum le taux d'humidité. Cette exigence entraîne un gaspillage d'énergie considérable lorsque le vide sanitaire abrite des conduits de chauffage et des registres. Le comité consultatif technique de l'association canadienne des constructeurs d'habitations de Colombie-Britannique a reçu de nombreuses demandes de renseignements quant à la façon de concevoir et d'inspecter les vides sanitaires. Ce comité a donc demandé à la SCHL de déterminer si la ventilation pouvait contribuer à réduire le taux d'humidité des vides sanitaires.

Programme de recherche

L'entrepreneur s'est d'abord adressé aux principaux intervenants de la scène du bâtiment de la Colombie-Britannique (inspecteurs, bureaux du programme de garantie des maisons neuves, etc.) et a dépouillé la documentation existante pour connaître l'étendue du problème et les solutions déjà proposées. Il a choisi dix maisons de styles variés, toutes construites au cours des huit dernières années, et a relevé le taux d'humidité, l'étanchéité à l'air, la composition du sol, etc. de leur vide sanitaire respectif. Comme l'entrepreneur a eu de la difficulté à trouver des maisons pour mener ses essais, l'échantillon n'est probablement pas représentatif du parc résidentiel. Les propriétaires qui savaient que les chercheurs voulaient examiner les problèmes de vides sanitaires étaient plus enclins à soumettre leur maison à l'examen. Deux de ces maisons ont subi des essais de renouvellement d'air effectués au moyen d'un gaz traceur. Des mesures correctives ont été prises pour quatre maisons, mais l'entrepreneur a tout de même pu évaluer l'état du vide sanitaire avant et après l'application des mesures.

Résultats

- Le vide sanitaire de cinq des dix maisons ne comportait pas d'aérateur, bien que l'on en ait ajouté par la suite dans quatre d'entre elles. Les aérateurs de trois maisons étaient fermés et remplis d'isolant en matelas. Aucune des maisons ne disposait d'aérateurs conformes aux exigences du code et il n'y avait aucune corrélation particulière entre le nombre d'aérateurs et le taux d'humidité des vides sanitaires.

- La surface de fuite accidentelle des vides sanitaires correspondait approximativement à la surface de fuite créée par les aérateurs. Dans les maisons où le vide sanitaire était traversé par des conduits d'air pulsé, la surface de fuite vers la maison était habituellement importante. C'est là un indice qu'un vide sanitaire aéré ventile généralement la maison. Par ailleurs, la surface de fuite vers le vide sanitaire l'était beaucoup moins dans les maisons dotées d'une installation de chauffage par rayonnement (donc sans conduits). Les détails de conception des maisons chauffées par rayonnement et des maisons munies d'une installation à air pulsé devront donc différer.

- La teneur en humidité des éléments en bois des vides sanitaires était habituellement inférieure à 28 p. 100. L'entrepreneur a soulevé le problème de la lisse d'appui d'un mur nain, reposant sur des semelles insuffisamment élevées.

- Les panneaux de mousse isolante appliqués sur les murs étaient souvent arqués parce qu'ils avaient été mal fixés, compromettant ainsi leur efficacité.

- Les problèmes d'humidité des maisons s'accompagnaient d'un mauvais écoulement de l'eau souterraine ou d'autres anomalies du même genre. Le vide sanitaire des maisons reposant sur un sol bien drainé, pourvus ou non d'aérateurs, ne présentaient pas de problèmes d'humidité. Il est difficile de remédier après coup aux problèmes occasionnés par une mauvaise préparation du terrain. Une membrane de polyéthylène bien installée sous la dalle pour faire obstacle à l'humidité pourrait contrecarrer l'ascension capillaire de l'eau souterraine et le taux élevé d'humidité qui s'ensuit dans le vide sanitaire.

Conséquences pour l'industrie de l'habitation

Voici quelques-unes des conséquences possibles pour l'industrie :

- Les codes en vigueur ne font pas l'objet d'une interprétation uniforme. Ils n'avaient été respectés dans aucune des maisons visitées. Les codes devraient être clarifiés et modifiés de telle sorte qu'il soit plus facile de les faire respecter. La ventilation n'est pas nécessaire dans un vide sanitaire bien drainé bénéficiant du chauffage à air pulsé. En d'autres termes, si le vide sanitaire est construit comme un petit sous-sol, il pourra se passer de ventilation additionnelle vers l'extérieur.

- Les constructeurs ne peuvent compter uniquement sur la ventilation du vide sanitaire pour régler les problèmes d'humidité. Les aérateurs n'assurent pas nécessairement une ventilation appropriée et, de toute façon, il est fréquent que les occupants ferment les aérateurs à lames ou bloquent les ouvertures. Il serait donc préférable et plus efficace de bien contenir les eaux souterraines. L'entrepreneur suggère certaines méthodes.

- D'autres aspects des vides sanitaires pourraient profiter de recherches additionnelles : ventilation du vide sanitaire des maisons dépourvues d'une installation de chauffage à air pulsé; comment rendre étanche à l'humidité le haut des murs de fondation; temps nécessaire pour évacuer l'humidité après la construction.

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1.0 INTRODUCTION

1.1 Background

Problems with crawl space construction in B.C. houses have been identified by a number of groups, including the Technical Advisory Committee of the B.C. Canadian Home Builders Association (CHBA), the Canadian Mortgage & Housing Corporation (CMHC) Regional Office, and the New Home Warranty Program (NHWP). Despite the widespread use of crawl space vents as dictated by building code, crawl spaces have experienced high wood moisture levels. In some cases, crawl space moisture has resulted in excessive humidity and condensation in living areas. Passive crawl space vents are suspected to be a source of considerable heat loss from houses, particularly when the crawl space contains forced air heating ducts. Ambiguous wording in the Building Code, and uneven enforcement of ventilation requirements by municipal inspectors, has lead to frustration and complaints from builders, and a continuing series of appeals to the B.C. Building Standards Branch.

The building code has required the installation of passive vents in all enclosed crawl spaces, except those that are used as a "warm air plenum[1]" (section 9.18.3.5). Strictly interpreted, this wording has required the venting of all heated crawl spaces since warm air plenums the size of crawl spaces are never used in B.C.. Builders have complained and appealed because in some municipalities they are required to install exterior wall vents, despite the presence of return and supply openings from the forced air duct work into the crawl space. In non-forced air houses municipal inspectors have frustrated builders by requiring them to install and operate electric baseboard heaters in the crawl space all winter.

Part of the problem lies with builders who want the best of both worlds. For lower cost insulating and plumbing, they choose to treat the crawl space like a shallow basement, insulating the walls and not the slab or floor. This also creates useful storage area. But for heating and ventilating purposes it is easier to treat the crawl space like wall or attic cavities, and simply ignore any distribution or delivery of heat and air.

A number of recent research reports have indicated that alternative crawl space construction techniques may be warranted, and that passive ventilation may often be unnecessary or ineffectual. The

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[1] *Plenum* is defined as a chamber forming part of an air duct system. A warm air *plenum* is a crawl space acting as an supply air duct for a furnace without ducted distribution.

principal reason for vents in a heated crawl space is to ensure adequate drying during the non-heating season. However ground-level air moving through passive vents in the summertime may supply little heat and drying, and on cooler days and nights may actually contribute to condensation in crawl spaces. In any case, most householders in B.C. have never been informed that passive vents are to be opened in spring and closed each fall. Vents are frequently found to be inoperable (due to distortion by sunlight, poor installation, or settlement of structural members), or permanently plugged with insulating material.

Aside from occupant lifestyles, the most common reason for moisture problems in new houses is reported to be moisture loading from crawl spaces[2]. There are many factors that can lead to moisture loading, including poor drainage systems and ineffective moisture barriers. At present, building codes and the building inspection process do not properly address such factors.

In response to these concerns about crawl space construction in B.C., the Research Division of CMHC issued a request for proposal on March 2, 1990, for the purpose of conducting research into the ventilation and moisture levels of crawl spaces.

1.2 Objectives

1. To investigate the extent of problems now occurring with heat, moisture, air and soil gas flows in crawl spaces in B.C. housing.
2. To identify trends in construction that may impact on the effectiveness of current and proposed crawl space moisture control strategies.
3. To develop, demonstrate and describe new ventilation and moisture control strategies for crawl spaces that are likely to be convenient and economical for both builders and householders over the foreseeable future, and that are suitable for incorporation into the building code.

[2] Discussion with N.H.W.P. personnel.

1.3 Prior Research

Prairie Moisture Problems: One of the few Canadian research projects into crawl space design was conducted for CMHC by I.B.I. Group in 1987[3]. This study was a response to indoor moisture problems in houses in Norway House, Manitoba. The study failed to identify a strong relationship between crawl space humidity and indoor moisture problems. However it did expose a large number of moisture problems inside crawl spaces resulting from inappropriate construction practices. Because sill plates and headers are difficult to insulate and seal, these areas had suffered from condensation and structural deterioration. Opening vents in the spring to dry out the crawl space actually increased crawl space moisture levels, since at this time outdoor air is quite moist and crawl space walls quite cold. Although the Norway House research was limited to remote, cold-climate, bungalows, it emphasizes the need for re-evaluating current building practices and crawl space design.

Nazaroff Radon Entry Study: Another report of special relevance to this project is "Radon Entry Into Houses Having a Crawl Space", W. Nazaroff et al, 1984, which describes research undertaken by Lawrence Berkeley Labs (LBL). This study, which involved many tests similar to those conducted as part of this project, implies that as much as 50% of the radon released into the crawl space, enters the living space. Although the focus was on radon infiltration, the results are also valid for some aspects of moisture entry, and for other types of soil gases. The study points to the ineffective performance of vents because they rely on meteorological conditions. The report also emphasizes the difficulty of preventing soil gases from entering crawl spaces and, subsequently, living areas of a house. The paper compares radon entry rate into the house with crawl space vents closed and open and shows a 50% greater incidence rate when the vents are sealed.

S. Quarles Crawl Space Study: Another recent report of special interest to this project is "Factors Influencing the Moisture Conditions in Crawl Spaces", S. Quarles. This study, sponsored by the USDA Forest Products Laboratory (FPL), indicated that a reasonably effective moisture barrier was adequate to control moisture, without any crawl space ventilation. Quarles also states that the critical factor in maintaining low wood moisture content with reduced ventilation is maintaining adequate ground cover. A follow-up survey by Energy

[3] Prairie Moisture Problems: Crawl Space Investigations in Norway House. I.B.I. Group, for CMHC, 1987.

Design Update[4] revealed that many other researchers agree that non-vented crawl spaces are best, if moisture barriers are properly designed and installed.

<u>PIRF System:</u> Of special interest to this study is the research that has taken place by Dow Chemical Engineering Division to develop the Perimeter Insulated Raised Floor (PIRF) system for crawl space insulation and ventilation. The intention of the PIRF system is to employ an extremely effective moisture barrier, sealed to Styrofoam SM R5 board insulation. According to the PIRF research, the use of such an effective barrier allowed builders to reduce to 1/10th of the ventilation requirements in the California Uniform Building Code (which is presently $0.1m^2/17\ m^2$ of floor area). The vents designed for and recommended for this system are temperature controlled using a bimetallic coil to open and close between 5 °C and 20 °C. PIRF is a comprehensive approach to crawl space construction that resolves a number of the current complaints about vents. Nevertheless PIRF is not practical in B.C.. The system is designed for warmer climates ranging from 800 HDD's to 2750 HDD's (heating degree days below 18 °C).

2.0 INVESTIGATION PROCEDURES

2.1 A Survey of Industry Practices and Concerns

A letter and summary of the proposed work was sent to chief inspectors throughout B.C., and to other selected individuals, to invite their participation in the research.

Many individuals were also contacted by phone and interviewed about crawl space construction practice and inspection procedures - including inspectors in four regions of the province, and experienced builders throughout the lower mainland. Concrete specialists were interviewed, including John Timusk, University of Toronto and Kathy Gissing, Canadian Portland Cement Association (CPCA). Ralph Moore and others at NHWP shared insights from there work on numerous houses with crawl space moisture problems.

Meetings and seminars were arranged with the New Home Warranty Program, and with the Technical Advisory committee of the B.C. Home Builders Association. Builders were invited to a preliminary presentation of the project findings, which included a photographic review of ten case studies.

[4] Energy Design Update; Vol 8, 12; December 1989: Moisture in Non-vented Crawl Spaces.

2.2 Case Study Test Protocol

A protocol was developed for testing and inspecting houses in the lower mainland. The work plan involved the selection and testing of 10 houses, and some experimentation with remedial measures where warranted. A brief explanation of the field investigation protocol is provided below:

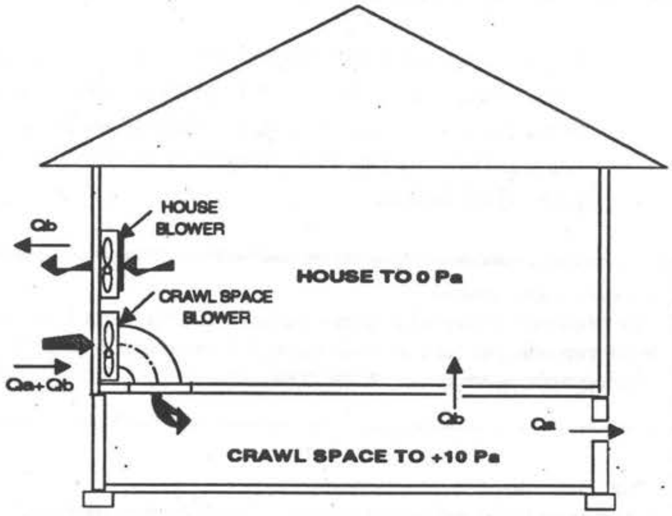
General Information
The house characteristics, dimensions, heating system type, and crawl space construction type, were recorded as part of walk-through inspections and an interview with the homeowner. Photographs were taken of the house, crawl space, vents, and any problem areas.

Test Conditions
Wind speed was estimated on site. Humidity measurements were made using an aspirated hygrometer (Psychrodyne) outdoors, in the house and in the crawl space. Crawl space humidity measurements were made immediately after the crawl space hatch was opened.

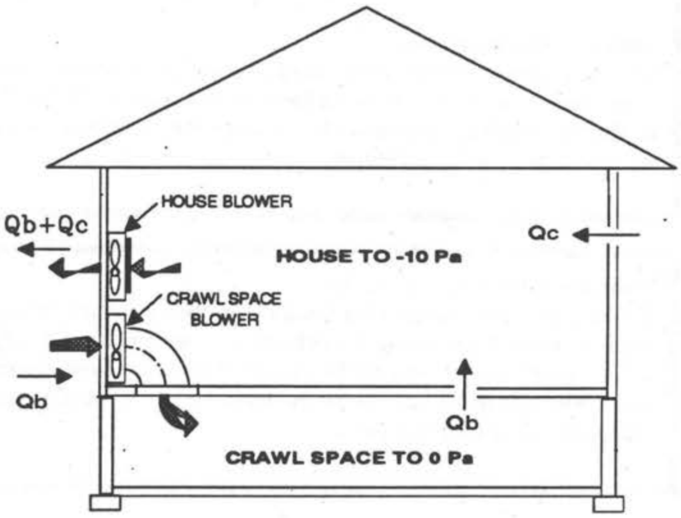
Moisture Measurements
Moisture measurements were taken using a Delmhorst resistance meter at several points in the crawl space. In cases where surfaces were suspected be by dry and no problems were evident in the crawl space, only spot checks were made. Otherwise multiple testing was carried out, at locations recorded on sketches.

Vent Air Flow Measurements
If the crawl space vents were installed in the house an attempt was made to measure air flow through these vents using a mock-up duct test rig capable of measuring flows from 5 - 100 L/s. Unfortunately, low air flows and alternating flow directions made it difficult to obtain good readings in all but one of the test houses. Typically, the direction of air flow was recorded using a smoke pencil.

Air Leakage Measurements
The procedure for testing the air leakage of the crawl spaces was adopted from Attic Air Tightness Testing Procedure previously designed by Sheltair and involved two tests which are illustrated in Figure 1. The procedure requires two blowers, arranged so that the crawl space blower supplies air directly from outdoors. Depending on the location of the crawl space hatch, a length of 500 mm flexible ducting acts as a plenum between the outdoors and the crawl space. The house blower is arranged to draw air from the house. Three leakage quantities can be derived from two tests but a modification of test 1 can also give vent-only leakage. The tests are explained briefly below.



CONFIGURATION FOR TEST No 1



CONFIGURATION FOR TEST No 2

Figure 1: Air Leakage Test Configurations

Test 1a: Crawl Space to +10 Pa and House to 0 Pa - vents open:
This test reveals the leakage of the crawl space through cracks in the wall sill joint and through the installed vents (Qa) if any are present. The house blower at the same time measures the interface leakage (Qb) between the crawl space and the main floor.

Test 1b: Crawl Space to +10 Pa and House to 0 Pa - vents closed:
This optional test is the same as Test 1a except that vents (if they have operable shutters) are manually closed. This was performed in two of the houses.

Test 2: Crawl Space to 0 Pa and House to -10 Pa
This test gives the approximate ELA of the building envelope above the crawl space (Qc) and serves as a second check of the interface leakage (Qb). For a better approximation, the average of Qb is taken from Tests 1 & 2.

2.3 Selection of Case Study Houses

It was intended that the sample of houses should represent the range of construction types for crawl spaces built in the Lower Mainland. From the limited sample of ten houses, ideally 2 or 3 were to have experienced problems with moisture build up and of the remainder, 3-4 vented with forced air heating, 2-3 vented with radiant gas or electric heat and 2-3 non-vented with either type of heating system. The breakdown of the actual types of houses tested did not perfectly satisfy the criteria but provided a good sample nonetheless. Of the ten houses, 4 were moisture problem houses; 6 were forced air heated with ducting in the crawl space, 3 had gas hydronic heating systems, and one was radiant electric heated. Six of the ten houses had installed crawl space vents.

Finding appropriate houses was difficult. The municipal building inspectors contacted seldom information about actual homebuyers, and only 3 houses were obtained from their sources. Some builders did not want the research group to approach their customers for fear of repercussions (eg. the builders could be liable for any problems uncovered). Three of the houses tested were referred by representatives of NHWP. These houses (Houses #1, #2, and #6) had experienced crawl space moisture problems and NHWP was in the process of designing and trying out remedial measures.

2.4 Tracer Gas Air Change Measurements

In an attempt to characterize air exchange between the crawl space, the ground floor and the outdoors, tracer gas air change tests were performed on two houses. House #2 represented a typical forced-air heating with passive vents and House #5 a gas radiant heated house with no installed passive vents.

In both cases, the crawl space only was seeded with tracer gas, and a five-point computerized gas analyzer was used to measure and record concentrations. Sensors were placed in the crawl space at different location and on the ground floors.

In House #5, tracer gas was mixed in the crawl space and allowed to decay overnight by natural means. The data was logged in 3 minute intervals by the equipment. The results are presented in House #5 case study.

House #2 was subjected to a similar tracer gas test, except that the furnace blower was energized for the first part of the test. In the latter part of the test, air change by natural means was monitored. Two of the six installed crawl space vents remained open while the remainder had been blocked previously with insulation by the homeowner. Data was logged at one minute intervals. Results are presented in the House #2 case study.

2.5 Monitoring of Crawl Space Remedial Measures

An initial investigation of House #6, had revealed serious moisture problems. Ground water was entering through a slab that had been poured over an earthen floor without a moisture barrier. NHWP and the builder of the house had made several attempts to solve the problems. These attempts included re-installing sections of drain tile, stripping insulation off the walls, and installing a dehumidistat controlled fan to vent excess moisture. The problems persisted.

The case study offered an excellent opportunity for evaluating the effectiveness of a polyethylene moisture barrier when properly applied. It was expected that, because of the extremely high moisture levels present in the crawl space of House #6 at the time of testing, the impact of remedial work would be dramatic and relatively easy to quantify.

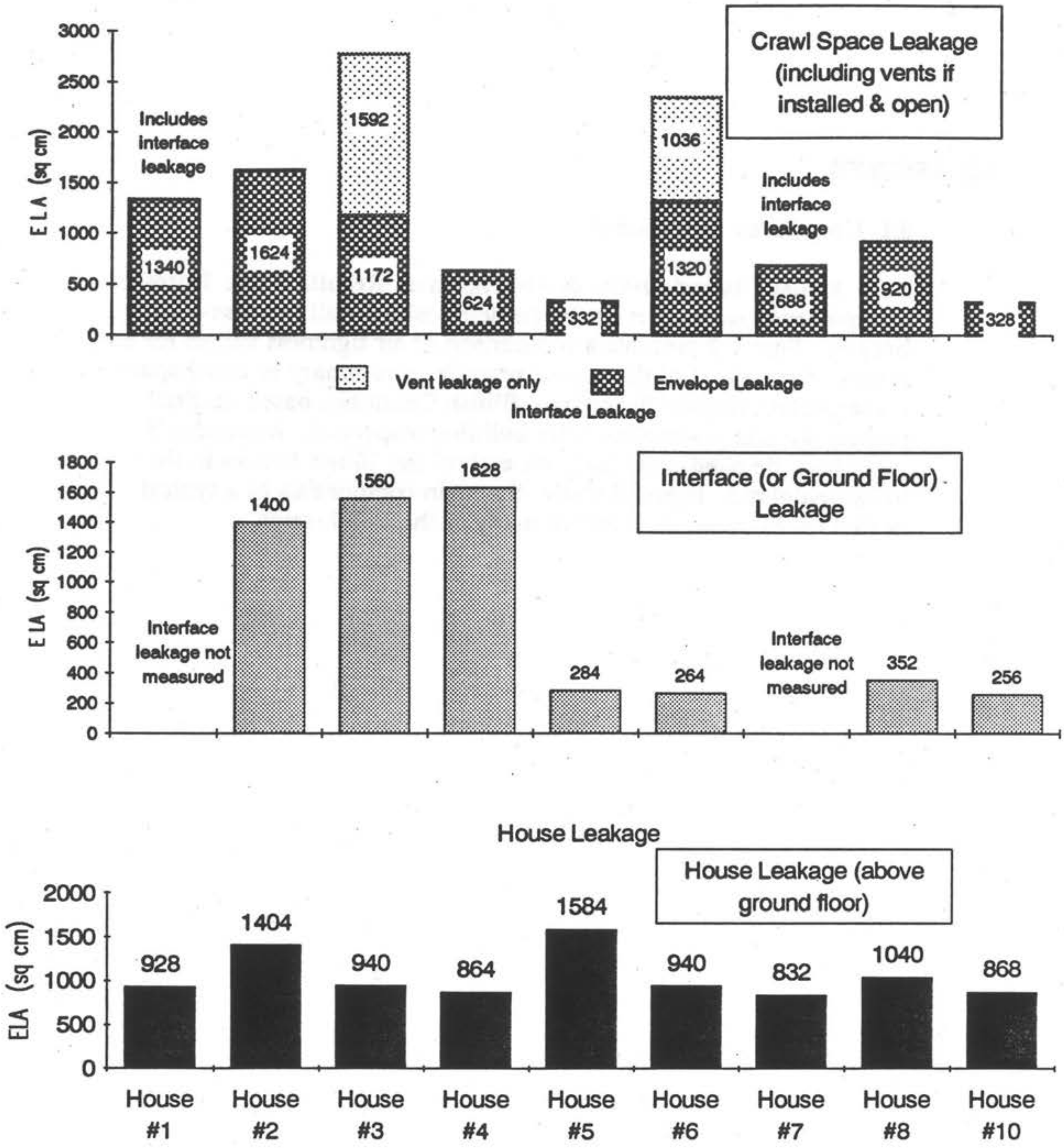
The research team installed a Campbell Scientific CR21 data logger measuring indoor, outdoor and crawl space absolute humidity and temperature. After 3 days of monitoring, a 0.015 mm polyethylene moisture barrier was installed on top of the existing concrete. Within three days of applying the poly, an additional 50 mm concrete skin coat was applied to the existing slab, sandwiching the new poly.

The moisture levels were monitored for a further 40 days until conditions were quite stable. An option was left to seal the poly barrier to the perimeter walls, at the base of the foam board insulation. (Poly sheets were cut oversized so that enough material extended to join to the board insulation terminating 25 cm from the floor.) The results are presented in the House #6 case study.

3.0 RESULTS

3.1 Case Study Summaries

3.1.1 House Characteristics & Air Tightness Results: Table 1 presents a summary of data collected in the field visits for all ten case study houses. Figure 2 presents a comparison of air tightness values for each house. Appendix I of this report provides a summary of crawl space construction practices throughout British Columbia, based on field inspections and discussions with building inspectors. Appendix II provides a detailed case study for each of the 10 test houses in the lower mainland. Figure 3 shows the main components of a typical heated crawl space, as found in many of the case houses.



Air Leakage Measurements in sq cm @ 10 Pa

	House #1	House #2	House #3	House #4	House #5	House #6	House #7	House #8	House #10
Heating System	forced air	forced air	forced air	forced air	radiant	radiant	*radiant	radiant	forced air
C. S. envelope	1340	1624	1172	624	332	1320	688	920	328
Vents only	-	-	1592	-	-	1036	-	-	-
Combined	-	-	2764	-	-	2356	-	-	-
Interface Leakage	-	1400	1560	1628	284	264	-	352	256
House Leakage	928	1404	940	864	1584	940	832	1040	868

Figure 2: Air Leakage Results for Case Study Houses

Table 1: Data Summary for Case Study Houses

House	1	2		3	4	5	6	7	8	9	10
Month visited	July	July	October	September	September	September	October	January	January	January	January
Municipality	Chilliwack	Surrey		Surrey	Mapleridge	Vancouver	Surrey	Surrey	Langley	Surrey	Langley
House age (yrs)	2	2		4	new	new	3	8	1	2	7
Number of Occupants	2	4		2	0	0	2	3	2	4	4
Main floor area (m2)	160	115		120	125	135	250	197	152	124	61
Heating system type	forced air	forced air		forced air	forced air	radiant	radiant	*radiant	radiant	forced air	forced air
Number of C.S. Vents	0	6		6	0	0	4	4	5	5	0
Air Leakage Measurements (L/s @ 10 Pa)											
C. S. Leakage	335	406		691	156	83	589	172	230	not done	82
C.S.; with vents closed	-	-		293	-	-	259	-	-	-	-
C.S. vent leakage**	-	-		398	-	-	330	-	-	-	-
Interface Leakage	***	350		390	407	71	66	-	88	-	64
House Leakage	232	351		235	216	396	235	208	260	-	217
Absolute Humidity											
Indoor (gm/kg)	15	12	7.3	7.8	m	6.5	7.8	8.6	5.8	6.4	7.5
Outdoor (gm/kg)	14.4	13.1	5.5	7.6	m	5.8	5.2	5.2	3.5	3.5	5.8
Crawl Space.(gm/kg)	14.2	12.5	6.6	7.6	m	7.6	9.3	6.7	4.5	6	6.3
Temperatures											
Indoor	28	28.5	19	18	m	15.3	21	21	19.8	19.5	19
Outdoor	27.5	29.5	8.4	12	m	16	10.5	7.2	0	0	9
Crawl Space	21.5	22	15	16	m	15.8	16	13	18.2	11	14.5
Moisture Content MC (%)											
Perim. walls (concrete)	65%	m	60%	45%	m	55%	60%	45%	40%	60%	65%
C.S. Floor (concrete)	85%	m	85%	55%	m	85%	85%	45%	60%	100%	80%
Sill Plates (wood)	18%	m	32%	10%	m	12%	26%	10%	10%	15%	20%
Joists (wood)	15%	m	12%	10%	m	10%	22%	10%	10%	20%	12%

* Combination of electric radiant heating panels (ESWA) & baseboard.

** Vent leakage = Vents open leakage - Vents closed leakage

*** C.S. leakage includes Interface leakage

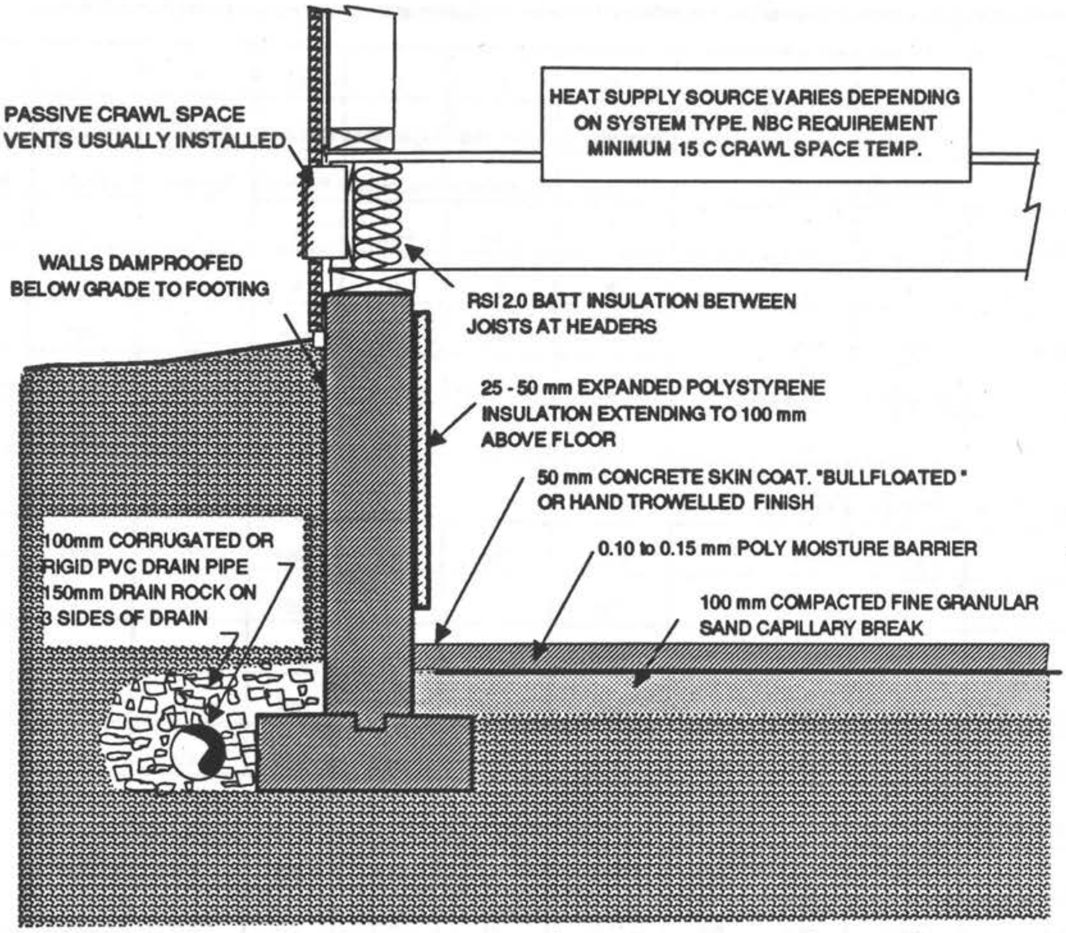


Figure 3: Typical Construction for Heated Crawl Spaces in B.C. Houses

3.2 Case Study Highlights

3.2.1 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, our research into site conditions literally 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. We speculate that a residual layer of clay was left below creating a *perched* ground water table higher than the neighbouring 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 the homeowner believed that a failure in the piping system may be causing the ground water levels to be high. This would explain the absence of problems in the houses on neighbouring lots. At House #9, flooding occurred as ground water tables rose 150 mm above the crawl space floor level. Some of the reasons for this include; run-off from the neighbouring lot located at a higher elevation, the possibility of an underground spring passing under the slab, and a drainage system blockage.

Run-Off Water Retention - Many sites were found to have low permeability in the upper soil regions and rainwater run-off can be retained on the lawn surfaces for more than 12 hours after a rainfall.

3.2.2 Drainage

Foundation Drainage - Foundation drainage systems were similar in all but 1 of the houses visited. They generally consisted of a single 100 mm plastic flexible perforated drain tile placed at or below footing height, terminating at a collection box or sump. In House #5 the dual system - with rain water run-off carried away in a separate pipe 100 mm pipe - was employed and rigid PVC used. No special measures were taken in any of the houses at the initial building stage to avoid potential drainage problems. None of the sites had clean outs or risers located so as to easily test or service foundation drains.

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 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. Sheltair determined that the water pooling was a result of condensation on the cold masonry and metal surfaces in the chimney cavity, caused by the migration of moist crawl space and house air into the back of the fireplace opening. 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. Fine soils can travel with the flow of groundwater through coarse fill and into the perforated tile, eventually causing blockage.

3.2.3 Floor & Curb Wall Construction

All of the houses studied had concrete ground covers typically 50 mm in thickness. In four of the houses no poly vapour barrier was installed beneath the concrete. Not surprisingly, these were 4 of the 6 houses with reported problems. In two of the houses, House #8 and #10, concrete was observed to have thinned to nothing in some locations, exposing poly and sand. At House #10 (with no poly), the area where the thinning was observed was noticeably wet compared to other areas.

Extensive cracking of the skin coat was common to all houses. House # 6 and House #8 slabs were most severely cracked. These were also the driest crawl spaces. In House #8, examination of a long 12 mm wide crack in the slab permitted a visual inspection of the poly vapour barrier. The integrity of the polyethylene had been maintained, despite the cracking of concrete.

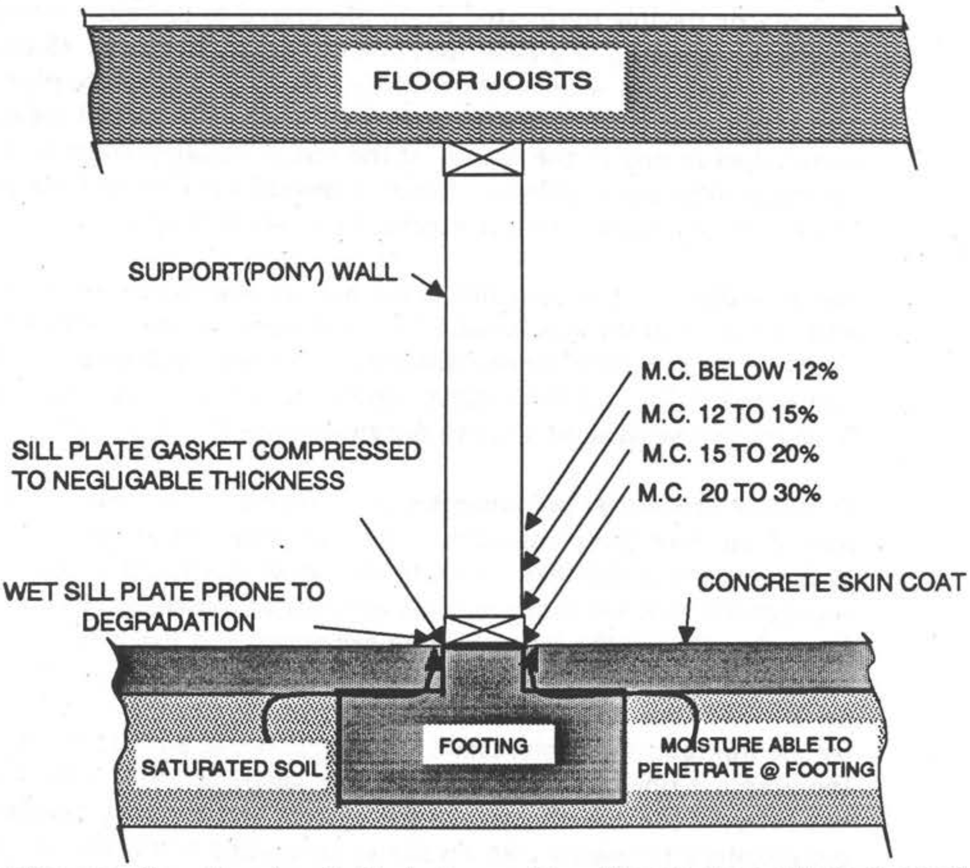


Figure 4: Typical Moisture Gradient for Slab Level Support Walls

The absence of concrete curb walls for interior support walls may cause structural damage in many houses built in this manner. Three of the houses visited had support walls built at floor level and of these, two recorded wood MC's of greater than 20 % at the sill plates. Moisture moving horizontally through the floor slab saturates the sill plates. Figure 4 illustrates the typical moisture gradient of sill plates resting on a slab located in region where the soil may be saturated.

3.2.4 Insulation

Perimeter Walls: Poorly applied rigid insulation leaves more opportunity for condensation along concrete walls above grade, especially if humidity is high as in the three NHWP problem houses, where insulation was removed to dry out the concrete surface. A good practice for insulation of foundation walls was used in House #5, where insulation was applied from the outside at grade level. Insulation in the other nine houses was applied from the interior, typically with 35 to 50 mm expanded polystyrene board. In most cases the insulation extended from sub floor level to approximately 700 mm or 300 mm above the crawl space floor. The minimum requirements are for insulation to extend to below the frost line, which in the lower mainland is 300 mm below grade. The common method of fastening insulation to the walls is to use 2 concrete nails per 60 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 - reducing the effectiveness considerably.

Crawl Space & Sub-floors: None of the houses had perimeter insulation installed below the concrete. House #8 and #10 had floor insulation above the crawl space, (installed as a retrofit in Home #1).

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 moisture content was measured in areas behind the joist header insulation.

3.2.5 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 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 showed that, without a supplemental heat source, a temperature of approximately 14 °C was maintained when outdoor temperatures were 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 this was probably 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. Duct tape used to seal the duct work had failed in many areas.

3.2.6 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 (Houses 1, 2 and 9). Of the six forced-air heated houses, four are now vented[5]. 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, ranging from 0.36 ACH in the non-vented House #5 to 0.59 ACH in House #2 (where 2 of 6 vents had been blocked with insulation).

3.2.7 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:

1) **Crawl Space Vent & Total Leakage Area:** The average vented crawl space leakage area was 1920 cm^2 including the installed vent leakage area and the accidental leakage area around the sill plate and other penetrations to the outdoors below ground floor. The

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

non-vented house leakages averaged 428 cm^2. The greatest leakage area, House #4 at 2764 cm^2, was 15 % greater than the code required ventilation of .1 m^2 / 50 m^2 though the installed ventilation area in House #4 was actually 67% of the code requirement. All other houses measured well below the code requirement including accidental leakage.

2) **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[6]. The largest interface leakage was House #3 at 1628 cm^2 and the smallest was House #10 at 256 cm^2. The latter seems inconsistent with the other houses. However the plan area of House #10 is small, ducts are well constructed, and the single supply air opening was closed during the test.

3) **House Leakage:** House leakage includes only leakage above the interface. The average house leakage was 1045 cm^2. House #2 and House #5 have the largest envelope areas and were also the leakiest; House #7 was the tightest.

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

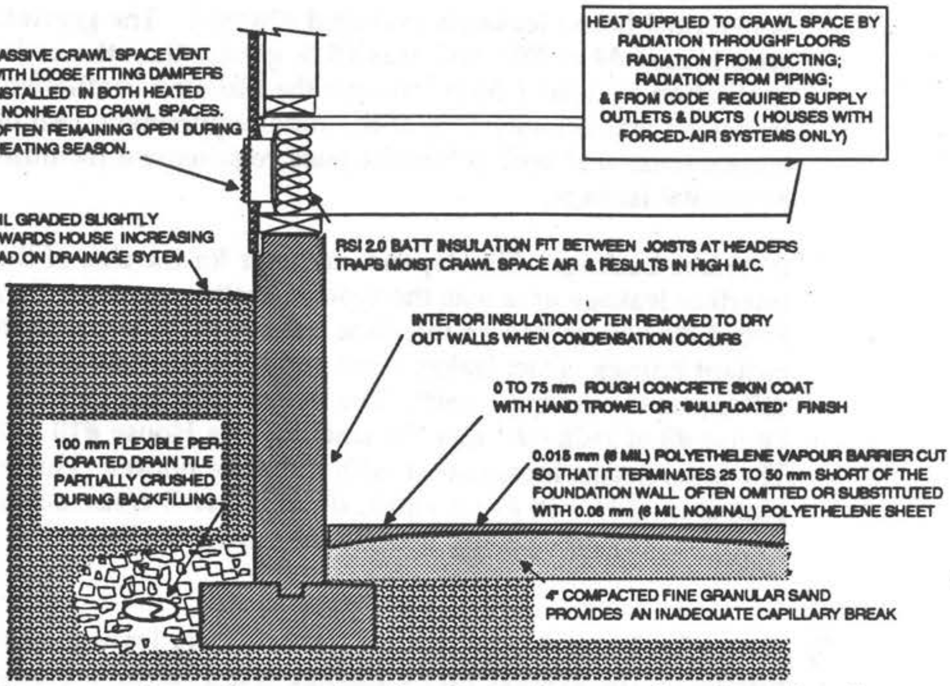


Figure 5: Conceptual Drawing of Crawl Space Construction Showing Typical Problems Encountered

4.0 DISCUSSION OF RESULTS

The following discussion covers many of the general issues related to the performance of crawl space moisture control systems in B.C.. The discussion is based on case study observations and information obtained from builders, and inspectors. Figure 5 illustrates, quite realistically, the kind of problems that can occur with a poorly designed crawl space system. Figure 6 on the other hand, illustrates what an effective crawl space moisture control system should look like for a heated crawl space.

4.1 Drainage Systems

- *Definite problems exist with current drainage systems in the Lower Mainland.* Outside the Lower Mainland and in some parts of Vancouver Island, problems seem to be much less frequent. For reasons of cost effectiveness, it is probably necessary to prescribe types of drainage systems according to drainage characteristics of the region or building site and to require more effective drainage designs in the Lower Mainland and in other areas where water tables may be high. Geotechnical services may be required to deal with the exceptional situations.

- *Some residential building sites require a comprehensively designed moisture control system that can control ground water levels that are above the height of the crawl space floor.* Considering the slow rate at which ground water typically travels through soil, an effectively designed drainage system can actually draw down the water table to the drain tile height. Although this has not been verified in our research, it is common practice to control high water tables with adequately installed and sized foundation drains. In commercial drainage systems, an *interceptor drain* may be placed in the path of moving ground water at some distance away from the building. This reduces the demand on the buildings' foundation drainage system. This practice could theoretically be adopted to residential situations as a retrofit control method.

- *An investigation of site conditions in order to assess drainage requirements is highly recommended in regions where water tables are known to be high. However, this may only be economical for multi-residential sites.* In many areas where groundwater is known to be a problem, an inadequate drainage system can create endless problems for homeowners. The estimated cost for an engineer to perform a preliminary site investigation would be $300 to $500. Further sub-surface testing requires machinery for test pit drilling and operators, at an approximate cost of $100/hr.

- *Wherever possible, sites should be graded so that rain run-off is diverted away from the foundations.* This is and always has been a key element of good drainage, but is not always addressed. In some vicinities, where sites are flat and excavation depth is limited, sloping the site to drain surface water is very difficult.

- *Crawl space foundation drainage systems should have clean-outs placed so as to provide easy maintenance.* This would ensure that if heavy silting results in blockage of the system, flushing of the drains will be easy and less costly to the homeowner.

- *Fine granular sand used under slabs in the lower mainland does not provide an effective capillary break.* Some builders and drainage contractors in the area insist on the use of clean granular fill or torpedo gravel (10 mm nominal diameter) under slabs in basements and crawl spaces. Many areas of the province however, including the north and the interior, simply compact the existing ground cover prior to pouring slabs, and experience no "wicking" or capillary rise of moisture into the crawl spaces because ground water levels are well below the surface. Gravel and sand are similarly priced items and economy is not an issue that would hinder a conversion from sand to gravel. The ineffectiveness of sand to form a capillary break is not well understood by trades or inspectors contacted in the study.

- *The use of flexible foundation drains in B.C. is declining due to the problems with low strength and blockage.* Poor experience with flexible drain tile in a number of municipalities, including Victoria and West Vancouver, has resulted in the requirement of only rigid drain pipes. Many drainage professionals and have voluntarily switched to rigid from flexible drain tile. The problem with the flexible pipe is its low crushing strength and it is often damaged during backfilling. The elimination of flexible piping as a foundation drain system would make such damage, and also the task of cleaning silted or blocked drains far easier.

- *A drain through the footing to the foundation drain should be provided in combination with a coarse granular layer beneath the slab.* 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.

4.2 Moisture Barriers

- *The 1990 code requirements for polyethylene underneath slabs has been justified* as a radon protection measure in much of British Columbia, but is even more justifiable as an effective moisture barrier.

- *As a moisture barrier system, it is not crucial that the poly be welloverlapped or sealed at the edge, or that it be free of puncture holes.* A 95% ground cover can be 95% effective as a "moisture barrier". However, as a "vapour barrier" it is important that the ground cover remain intact. An issue that has complicated the adjudication of a vapour tight ground cover is the current practice of concrete contractors to purposely puncture the polyethylene so that bleed water will be absorbed in the sand or soil beneath. Punctured poly should remain effective as a "moisture barrier", but is probably no longer effective as a "vapour/soil gas barrier".[7] Conversations with excavators suggest that this water retention has the effect of doubling the time required before the concrete surface can be finished, (travelled). In the case of crawl space skin coats however, the concrete does not require finishing after the initial placement and rough "bullfloating". It is likely that many contractors are puncturing the poly for skin coat slabs despite the absence of a good rationale. Some education of contractors may be needed to break them of this habit - at least for crawl spaces.

- *Dampproofing of slab-edge and inside of foundation walls is impractical.* Considerable extra effort is needed to attach poly around the perimeter and to keep it hanging during the pouring of slab. The benefits of lapping poly around edges have not been well demonstrated at this time.

- *Dampproofing of the inside of crawl space foundation walls would reduce crawl space moisture production.* With current construction practice in B.C., is highly likely that wet concrete footings below foundation walls are contributing to the moisture load in crawl spaces, since moisture will be wicking up through the foundation wall and evaporating off the interior surface of the crawl space wall and top. Ideally, such a moisture entry route can be eliminated by placing the concrete footings on a gravel bed, or by placing a moisture barrier between the footing and the foundation wall (eg. hot tar), or by spraying both the interior surface and top of the foundation wall with a dampproofing concrete sealer in a similar fashion to the

[7] See "The Airtightness of Concrete Basement Slabs"; Work in progress by G.K. Yuill & Associates for CMHC, 1991.

exterior of foundation walls. Unfortunately all such measures are costly, awkward and messy to implement, and are likely to fail for these reasons.

- *Dampproofing of the tops of foundation walls is important because of capillary water rising through the unprotected footing.* Moisture wicking through concrete foundation walls contributes to high moisture content in the header and band joist area. This area contains wood members that can be subject to rapid moisture absorbtion and rot. Fortunately, this is an entry point for infiltration air from outdoors which will usually have a drying effect on the sill plate. The sill plate gaskets presently used may be only partially effective in this respect. More research is required to establish the relevant merits of different gasket materials as capillary break and vapour seal.

- *Better application of Foam board insulation materials on the interior wall surfaces of crawl spaces would reduce the occurence of surface condensation.* If the boards are fastened properly and caulked along the seams, moist crawl space air would be prevented from entering between the wall and insulation and condensing on the cold surface.

- *Internal support walls resting on crawl space floor at slab level absorb high amounts of moisture at the sill plate and are not properly protected.* The common practice of building supporting walls and crawl spaces that sit directly on the concrete slab, has lead to moisture problems in the supporting wall, despite the use of asphalt impregnated papers, or foam gaskets beneath the bottom sill. Field tests revealed that the support walls resting on a low concrete curb wall, 50 to 100 mm above slab height did not measure high moisture content even in problem houses. Promoting this practice would resolve most of these problems.

4.3 Crawl Space Vents

- *Application of the building code requirements for crawl space vents has not consistent.* None of the crawl spaces visited in this project achieve the minimum code requirements for open area of crawl space vents. Not all of the vents were equipped with operable dampers or louvres. Because most louvred vents are poorly constructed, closing the dampers only reduces the open area by 60 to 70 %.

- *Crawl space vents are an inappropriate moisture control system compared to a effective poly vapour barrier.* The application of polyethylene beneath slabs as part of the adoption of the NBC 1990 code, creates an excellent opportunity to re-evaluate and, if warranted, completely eliminate the use of crawl space vents.

- *Accidental air leakage in crawl spaces provides enough ventilation through infiltration and wind pressure.* Most of the crawl spaces tested in this project revealed almost as much accidental air leakage through the sill plates at the top of the crawl space walls, as had been installed through crawl space vents. Of course, greater emphasis on airtight construction by builders may reduce this accidental leakage area by 10 to 20 % over the next few years.

  Tracer gas testing revealed that good air change rates (0.4 ACH) were achieved in the non-vented crawl space of House #5 even in moderate weather (10 °C). Open crawl space vents result in greater air change rates (eg. 0.5 to 1.0 ACH), with associated higher heating costs.

- *Operable crawl space vents are not always properly used.* Homeowners are extremely unlikely to operate the crawl space vents correctly, and are more likely to completely block off these vents if they become aware of them.

4.4 Heating of Crawl Spaces

- *Crawl spaces used as warm-air plenums are rare in B.C. and code references to them have caused unnecessary confusion among builders.*

- *Crawl spaces with forced air duct systems are significantly different than crawl spaces in radiant heated houses, due to the additional air change and heat loss caused by ducting.* The measured interface area between crawl spaces and houses in forced air heated homes, is sufficient to ensure adequate mixing of crawl space air with the rest of the house, and also to dilute additional moisture content generated in the crawl space.

- *Heat radiation and leakage from duct work in a typical forced-air crawl space is sufficient to keep crawl space warm during cold weather in a Vancouver climate.* The addition of supply air outlets into the crawl space in this case is not necessary.

- *In a radiant heated home without installed venting, a floor grille(s) or a duct could be installed in the ground floor to ensure adequate mixing of air in the crawl space with air in the rest of the house.* The "ground floor" or interface leakage is often very small in radiant heated houses (200 to 300 cm^2) and if elimination of vents is considered, adequate heat and air exchange with the crawl space must be ensured by physically increasing the leakage, or installing a mechanical ventilation system. Installing a dummy grille in the crawl space hatch is one option, if the hatch is located inside the house.

- *Additional heat supply to crawl spaces in radiant heated homes does not appear to be essential based on the limited testing undertaken in this project (House #6).* Even with vents in place, temperatures close to the heating design temperature in Vancouver did not reduce crawl space temperatures below 14°. Elimination of vents would help keep crawl spaces warmer, as would the provision of the connecting grilles between crawl space and occupied floors.

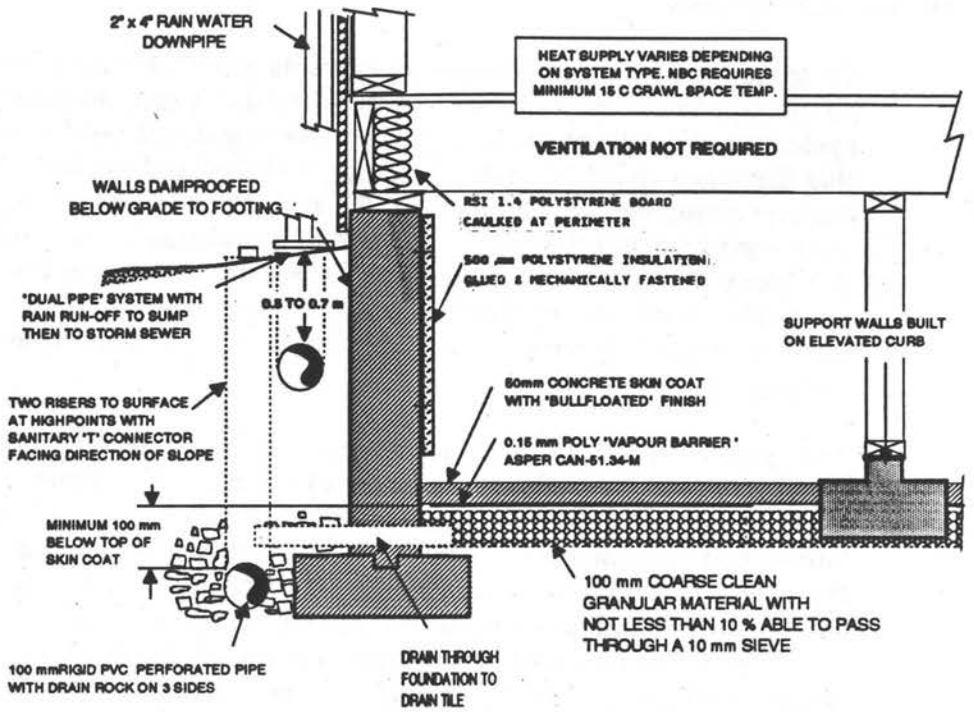


Figure 6: Effective Moisture Control System for Heated Crawl Spaces in B.C. Houses

Heat loss from radiation and convection from supply duct and sub-floor can provide 2 to 5 kW (175 to 225 W/m of length from a standard size [175 X 350 mm] supply plenum in a crawl space[8]) of heat when at steady state temperatures, depending on the amount of ducting in the space. With typical crawl space heat losses less than 2 kW this is ample to maintain 15 °C at design temperatures as low as -10 °C.

[8] Based on equations for duct heat loss from 1985 Ashrae Fundamentals.

6.0 CONCLUSIONS

To some extent the use of crawl space vents in B.C. Housing has been an attempt to compensate for inadequate or ineffective drainage systems and moisture barriers. Field surveys and test results indicate that the crawl space vents are not being installed and operated in a manner consistent with building codes, and that even where vents have been used correctly they are ineffective as a moisture control strategy. It is likely that a better approach would be to eliminate the vents, and apply the capital and operating costs associated with the installation and use of crawl space vents towards improving drainage systems and moisture barriers.

The greatest single factor influencing the generation of moisture in B.C. crawl spaces is the presence (or absence) of an effective moisture barrier. In three of four problem cases investigated, the moisture barrier had been omitted under the concrete floor. The second factor is the height of the ground water table and some additional testing or construction techniques may be warranted - especially for wet sites. The third factor influencing moisture problems is the design and condition of the foundation drainage system. For a small additional cost, it should be possible to greatly improve the performance and longevity of foundation drainage systems.

More information is still required to fully define the minimum requirements of a crawl space moisture control system, including research into such issues as moisture proofing tops of foundation walls, air mixing systems for crawl spaces in houses lacking forced air duct work, the impact of crawl space vents and construction techniques on soil gas entry, and the airing-out of crawl space moisture in new houses during the building dry-out period.

7.0 REFERENCES

1. Nisson, J.D., Energy Design Update, p.4, December 1989.

2. Western Regional Technical Service and Development and City of Fairfield, Building Inspection Department, The Moisture Performance of the Perimeter Insulated Raised Floor, 1985/1986.

3. J.Oldengarm, TNO Institute of Applied Physics, Field Experiences of Airborne Moisture Transfer in Residential Buildings, September 1988.

4. Forest Products Journal, Factors Influencing the Moisture Conditions in Crawl Spaces, Vol. 39, No. 10, 1989.

5. Health Physics, W.W. Nazaroff and S.M. Doyle, Radon Entry Into Houses Having A Crawl Space, Vol. 48, No. 3, pp. 265-281, 1985.

6. Concrete Information, Portland Cement Association, Repairing Damp or Leaky Basements in Homes.

7. J. Oldengarm and P.A. Elkhuizen, TNO Institute of Applied Physics (TPD), Heat, Moisture and Air Transport in Crawl Spaces.

8. Olle Aberg, University of Lund, Department of Building Technology, Design Consequences for the Crawl-Space Foundation, Reducing Moisture Problems.

9. Associate Committee on the National Building Code, National Research Council of Canada, Canadian Housing Code 1990, Printed in Canada, First Edition, 1990.

10. David F. McCarthy, Essentials of Soil Mechanics and Foundations, Third Edition, 1988.

11. J.Patrick Powers, P.E., Construction Dewatering: A Guide to Theory and Practice, 1981.

12. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., ASHRAE Handbook, Fundamentals, SI Edition, 1989.

13. The IBI Group, Prairie Moisture Problems: Crawl Space Investigations In Norway House Manitoba, February 1987, CMHC.

14. Ministry of Municipal Affairs, Province of British Columbia Building Code, September 1988.