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Performance Guidelines for Basement Envelope Systems and Materials

Final Research Report

Michael C. Swinton, IRC/NRC
Dr. Ted Kesik, University of Toronto

Institute for Research in Construction
National Research Council Canada

October 2005

This publication is dedicated to achieving satisfactory basement performance in cold climates.

Preface

These guidelines were developed by the National Research Council of Canada (NRC) under the guidance and review of a Steering Committee formed by representatives of industry associations and government agencies. This committee was formed to oversee the development of the Guidelines and to ensure that they reflect the best collective knowledge of Canadian industry and related public and private agencies . The following were members of the Steering Committee:

Mike Swinton	Project Manager, Institute for Research in Construction, NRC
Al Houston	Chair of the Committee (retired from Canada Mortgage and Housing Corporation)
David Atkins	Regional Municipality of Ottawa-Carleton
Stephane Baffier	Canadian Plastics Industry Association
Brent Barnes	Canadian Plastics Industry Association
John Bickley	Network of Centres of Excellence on High Performance Concrete, Concrete Canada
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Michael Shirlaw	Canadian Portland Cement Association
Frank Szadkowski	NRCan, Energy Efficiency Division
John Timusk	Trow Consulting Engineers Ltd., retired from the University of Toronto
James Whalen	Plasti-Fab Ltd.
Ron Waters	Canadian Construction Materials Centre, NRC
Keith Wilson	Owens Corning Canada Inc., Canadian Association of Man-made Vitreous Fibre Manufacturers

As well, participation in the survey by the following New Home Warranty Agencies:

Greg Cormier	Formerly with the Atlantic New Home Warranty Corporation
Gordon Huolt & Ted Wiatt	The Alberta New Home Warranty Program
André Gagné	Association Provinciale des Constructeurs d'Habitation du Québec
Jerry Kondi	New Home Warranty Program of Manitoba, Inc.
Ralph Moore	New Home Warranty Program of BC and the Yukon
Glenn Silliphant	New Home Warranty Program of Saskatchewan, Inc.

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- Roxul Inc.
- Cellulose Insulation Manufacturers of Canada
- Canadian Home Builders Association
- Canadian Portland Cement Association
- Ready Mixed Concrete Association of Canada
- Network of Centres of Excellence on High Performance Concrete
- Canadian Wood Council
- Natural Resources Canada
- National Research Council

Authors who have contributed to the writing of the guidelines include Dr. Ted Kesik, University of Toronto and Mike Swinton, IRC/NRC, with extensive inputs and review by the Steering Committee. Our thanks to Marianne Manning for incorporating Steering Committee comments.

A special acknowledgement to Dr. John Timusk, whose expertise in the physics of basement performance and contributions to the field of knowledge, both inspired and informed the authorship of this publication. It would not have been possible without his insights and collegial support.

Audience

These Guidelines were written primarily for the technical decision-makers in the home building industry. They have been written to appeal to a broad audience, including people involved in the following sectors of the industry:

- home builders and contractors
- materials manufacturers
- codes and standards developers
- warranty agencies
- materials evaluators
- regulators
- building officials
- educators and trainers

Organization

The Guidelines have been organized into six parts:

Part 1 - Performance Requirements for Basements
Part 2 - Basement Envelope System Selection
Part 3 - Selection of Materials and Equipment for the Basement System
Part 4 - Critical Design Details
Part 5 - Quality Assurance
Part 6 - Basement System Cost/Benefit Analysis

The role of the basement envelope is reviewed in Part 1. Our general expectations of what basements are for and how they are expected to perform in what circumstances are laid out – these are the performance objectives of the basement envelope. From these follow the technical performance requirements – the structural requirements, the environmental separation functions, and the qualitative properties of the envelope system: buildability, durability, etc.

Part 2 reviews the main construction approaches – the basement envelope systems that can be selected to address the performance requirements. The combination of environmental conditions (inside and out) and occupant expectations, combined with the selected envelope system determines the performance requirements of the materials to be used within the construction system.
Part 3 identifies the roles of the materials within the envelope system and indicates what performance characteristics have to be met by those materials for their given roles.

Part 4 addresses some key detailing issues, and the special requirements put on the design detail and the materials used; e.g., the wall-soil interface, window well detailing, etc.

Part 5 reviews various quality control tools available to the Canadian construction industry. Quality control is an essential element of achieving envelope system performance targets. Its role is to ensure that performance objectives laid out at the design stage are satisfied throughout the production chain: material manufacturing or site forming, assembly and finishing.

Part 6 introduces the concept of cost/benefit analysis as a planning tool for achieving a balance between long-term basement envelope system performance and first cost, for a range of scenarios and locations.

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INTRODUCTION

The basement can be a challenging environment in which to build livable space. By its very nature, it is the lowest location in the house, and often the coolest, the most humid and the darkest. It is surrounded by earth that can be dry, moist, wet or frozen, and sometimes all of these at the same time. As a result, the envelope components are subjected to greater structural, water and moisture loads than the above-grade portions. And although it is generally agreed that from a thermal standpoint, the above-grade components are subjected to more extreme loads, the duration of the below-grade heating season can be longer and is out of phase with the rest of the house and the outdoors.

As well, the context in which the basement system is expected to operate varies from site to site. It is affected by local climate, site grading conditions, a seemingly infinite variety of soil conditions – some of which represent a challenging environment for materials and the structure. On the inside, the basement interior is often allowed to run cold and damp, and the envelope can be isolated from the interior air by storage boxes, cold storage spaces, etc.

In these conditions, the basement envelope has some difficult and often contradictory functions to perform, and these are generally not well understood.

Most envelope systems used in Canadian house construction have evolved into present-day practice through a sequence of improvements based on trial and error. When a particular system and its materials become recognized (often marked by a reduction in the overall cost of construction, including cost of 'errors' or call-backs) the approach becomes mainstream practice. It may eventually be incorporated into the National Building Code or officially recognized by evaluation agencies, if it meets the intent of code requirements. With this 'evolutionary system,' we know the functions of the building envelope are addressed if there are no problems – but we don't know which functions and why. This leads to problems when systematic errors start to occur.

On occasion, the cost of 'errors' becomes excessive for builders, homeowners, manufacturers and warranty programs alike. Recently, symptoms have been emerging for insulated wall systems for applications below grade. The symptoms appear to be varied and sporadic, with some being localized regionally and others being more widespread. In both older and new homes, problems created by moisture seepage through the basements walls are reported. Excessive moisture in walls may, in addition to structural problems, cause mold and mildew, which are currently associated with potential health risks. In some locations, difficult soil conditions have been the cause of major problems that have entailed costly repair.

The guidelines recognizes that there are any number of design solutions that can be applied to address particular conditions and circumstances, but that some may be more appropriate than others to achieve the intended performance at least overall cost to the consumer. In many cases, the applicable code, which is a minimum standard, can represent a good solution. Even in these circumstances, it is not always clear what role, or how many roles, each material or system of materials is expected to play within the envelope – conventional approaches to basement design just seem to work on average and fail in certain circumstances. Not knowing why some basement systems work and others fail makes innovation of materials and systems difficult to introduce to the industry.

Innovative materials and existing materials used in innovative ways need a set of rules against which performance requirements are to be assessed.

In more difficult environmental conditions (both interior and exterior), it is not clear whether commonly used basement materials can be expected to take on more than their primary function, and may even require special formulation even to address their primary function. Some circumstances may require that a material, which normally plays many roles in the envelope system, give up some of those other roles to more specialized materials designed for that purpose. When this happens, additional construction costs may occur. Does the improved performance; i.e. reduction in numbers of failures and associated repair or replacement costs, warrant the additional expenditure? In what circumstances? The means of making such assessments are the central focus of this guide.

Main Messages Contained in this Document

- Performance expectations for environmental separation have become more demanding as basements are used as living space.
- The National Building Code of Canada and applicable provincial counterparts, being documents of minimum requirements, can't anticipate all of the variations in conditions for which a basement is expected to perform. Nor can the NBC force everyone to build to those conditions. As yet, regionally/site sensitive requirements have not been proposed. This leaves considerable decision-making and responsibility to the designer/builder.
- The tools available for this task are: builders' experience, builders' guides, material standards and application standards, evaluation guides, engineering manuals, engineering/architectural services from consultants and municipal offices. These guidelines are intended to facilitate the process of accessing these tools – a pathfinder – to promote performing basement envelopes.
- Basement envelopes featuring multiple materials must generally be specified to make sure that all of the functional requirements expected of the envelope are covered by at least one of those materials or system of materials, and that all of the materials are working together to achieve satisfactory performance – the 'basement as a system.'
- There are many different approaches to building a basement envelope and more are emerging every year. All should be capable of functioning as intended, if performance requirements are satisfied for the existing environmental conditions.
- An understanding of the intended role that is to be played by the materials and systems is needed by the people designing and constructing the envelope and the people responsible for inspecting the assembly process, to ensure that assembly techniques don't defeat the intended properties or function of the materials and systems.
- There is a balance to be achieved between first cost, cost of repair (including warranty work), and cost of maintenance and operation. That balance changes with conditions. Approaches to achieving a good balance are proposed.

Intent

The ultimate objective of these guidelines is the specification of basement envelope and material systems that perform better and last longer, within the broad range of Canadian climates, soil conditions and indoor environments.

The guidelines are intended to be a communication tool between construction materials manufacturers and designers, specifiers and builders involved in the construction of residential basements. It is a given that materials manufacturers know the business of making their products and builders know the business of building houses. The key intermediate step between

the activities of materials manufacturing and house construction is the specification of the appropriate material for the appropriate task within the envelope system.
The following questions can be asked:

- what turns a material or a product that is available for many applications, e.g. plastic film, into a specialized building product destined to play a key role in the envelope systems of houses; e.g. the polyethylene sheet playing the dual role of the vapour barrier and an integral part of the air barrier system?
- how is the right material chosen and installed to form an integral part of an envelope system?

Designers and builders generally know the answers to these questions but specific answers for specific materials and envelope systems may be less clear cut. For example, the decision to select a particular product may be influenced by a combination of:

- long-term conventions generally used by the home building community
- individual builder experience and preference
- product performance characteristics, cost, product availability and consumer appeal
- product literature
- product track record
- applicable standards
- current and past codes requirements
- warranty issues
- materials evaluations criteria for assessing conformity

The link between material performance properties and their selection for envelope systems is therefore not necessarily a simple matter of cause and effect. As well, with evolving materials and methods of construction, the rationale for specifying a particular material and using it in a particular way may become lost or obsolete.

These guidelines record the technical rationale for specifying particular basement envelope materials and systems based on the best information available today. This is to promote a greater level of coherence in the process of specifying appropriate envelope systems and materials for basements and foundations. This will be achieved by reviewing the performance requirements of the envelope and its related systems, reviewing the performance capabilities of available constructions systems, and finally, sorting out the host of regulatory requirements that must be met by the building materials and the systems in which they are incorporated.

Once the technical link is clearly made between material performance characteristics and intended function within the basement envelope system, then the host of other factors affecting the process of material selection can enter into play.

Overview of the Problems

The National Building Code of Canada, being universally applicable, has to strike a balance between first cost and probability of basement failures and expensive repairs. Forcing everyone to pay a premium because someone else is going to develop a problem down the road, leading to possible health and safety issues, may not be good economics. On the other hand, having a consistently large number of homeowners (or warranty claims) pay for repair bills that are many times the original cost of prevention is not good economics either. A sound economic balance is needed.

Unfortunately, in many cases we are not good at predicting where the problem areas are: ‘minimum basement configurations’ get built in less than ideal situations – these show up as failure statistics. Sometimes the situation is too challenging for the ‘minimum basement configuration.’

Sometimes site assembly practices defeat the intended functions, resulting in a poorer envelope than is expected with a ‘minimum basement configuration.’

These guidelines try to fill the gap between minimum-code basements and what is actually needed or desirable for a given set of client expectations, site considerations, materials availability, and cost.

Approach to Basement Systems and Material Selection

The selection of basement systems and materials through design involves the following process:
- Understand the building physics.
- Identify the environmental constraints.
- Select the appropriate basement system.
- Review all functions expected of the system and identify the roles that materials have to play within that system.
- Select the appropriate materials to satisfy the needs of the system.
- Review both the envelope system and the materials for durability criteria.
- Review the material Evaluation Reports and applicable Codes & Standards to ensure that compliance is achieved.
- Review the initial material and labour costs, cost of operation, maintenance and repair, and weight as appropriate for builder, client and societal needs.
- Refine the design as needed.
- Set up and follow a quality assurance program to ensure that the product meets the specs and the expectations.

These Guidelines are formatted to accommodate this design process.

PART 1 - PERFORMANCE REQUIREMENTS FOR BASEMENTS

1.0 Overview

Based on numerous past studies dealing with basement performance problems, and the latest periodic reporting of defects by new home warranty organizations,[1] it is widely recognized that our conventional, *"inherited"* basement technologies do not consistently deliver the level of performance expected by today's consumers. In Canada, consumers now commonly expect basements to potentially perform as livable spaces, offering the same quality environment as the rest of the dwelling. The *"basement as a system"* concept implies the need for rigorously assessing basement performance.

Unlike many parts of the U.S. and other warmer countries, where the basement is considered to be outside the building envelope, in Canada the basement is presumed to be inside the envelope: it is not only usable space, it is often considered to be livable. Although not necessarily lived in, the basement spaces (and heated crawlspaces) are connected to the above-ground spaces through passageways (and air circulation ducts in houses with forced air systems). Indoor air, including its relative humidity, temperature, and its contaminants, is shared with above-ground space. The National Building Code of Canada, which governs minimum requirements for basement spaces, recognizes this feature. These minimum requirements reflect constructions that can provide acceptable performance with some site conditions. These do not, however, always correspond to the actual, and often less favourable, conditions under which many basements are currently constructed.

Building codes provide requirements to address only those issues, and building configurations, materials, components, assemblies and systems that the construction community agrees require regulation. Consequently, current prescriptive building code requirements for basements do not necessarily explicitly preclude combinations of sub-systems, components and materials that may be incompatible or do not address all performance parameters effectively. As new components and materials are introduced without reference to the overall system, the likelihood of over- or under-designing basements increases.

A comprehensive framework of performance parameters is key to the successful design, construction and development of basement systems that will provide acceptable performance. Listing requirements of the basement envelope to provide livable space is not straightforward, and is even controversial in the sense that there is no universal agreement on which functions are essential for a basement to be considered usable or livable.

Functions of the Basement System

In these guidelines, it has been assumed that contemporary residential basements must satisfy two primary functions:

1) to provide a foundation for the house superstructure; and
2) to provide a usable/livable indoor environment.

The list in Table 1.1 reflects the realities of the housing industry by organizing envelope functions according to three related sets of considerations: *performance*, *construction* and *marketability*.

PERFORMANCE RELATED	CONSTRUCTION RELATED
• provide structural support	• be economical
• provide earth retention	• be buildable in a timely fashion, with available labour and materials
• control of heat flow	• be resistant to the rigours of the construction process, including weather, site storage and handling
• control of air leakage including soil gas	• accommodate services - electrical, plumbing, HVAC, etc.
• control of surface emissions	
• control of surface condensation	**MARKET RELATED**
• control of interstitial condensation	Provide market value by
• control of moisture flow into the envelope from the interior	• being aesthetically pleasing
• control of moisture flow into the envelope from the exterior	• creating usable and livable space
• control of embodied moisture	• providing serviceable finishes (e.g., flat, cleanable, and supportive of furnishings and contents)
• control of rain water, snow melt and ground-water	
• control of sewer water	
• control of light, solar and other radiation	
• control of noise	
• control of fire	
• be durable (i.e. provide the above functions without premature failure over the service life of the envelope)	

Table 1.1 List of functions of the basement envelope system.

These guidelines focus on the performance-related functions of the basement envelope, but exclude the control of surface emissions, lighting and solar radiation, noise and fire. These are specialized subject areas that are usually treated in the context of the entire building, and may not warrant additional consideration from the basement envelope design viewpoint.

Organization of Functions

The functional requirements of the basement envelope can be organized according to the principal functions that they are intended to meet. Chart 1.1 organizes these in terms of an overall hierarchy of functions, sub-functions, functional requirements and components of the basement system. It should be noted that these terms reflect currently available basement technologies; updating and revisions may be required as innovation occurs.

The top portion of Chart 1.1 relates to the structural support considerations, which are primary. These must be addressed by all designs. Although most of the structural requirements are handled directly by the structural elements, protection from ground water, frost action and the effects of expansive soils can be addressed through other elements of the system. For example, controlling surface water, local drainage, and selective control of heat flow patterns around the foundations may be addressed by other *sub-systems* of the envelope.

The chart clearly differentiates between the structural support function, which can be addressed without providing usable space (e.g., using piers and posts), and the function of providing a usable and livable indoor space, involving effective environmental separation. The latter is more the focus of these guidelines.

Like the structural support functions, the provision of environmental separation cannot be completely achieved by the envelope system on its own, so that complementary measures, such as provision of a heating system, are part of the overall basement system (the lower part of the chart).

Difficulties arise when one tries to determine which measures are essential for a basement to be usable and livable, and to what degree. As well, occupant expectations may vary according to building use and location (e.g., homeowners with finished basements have very different needs and expectations than owners of unfinished basements situated in a flood plain where periodic flooding is a fact of life).

Another complicating factor is the ability of materials and components to fulfill more than one function. For example, when a material or component in a proven assembly controls both heat and moisture flow, care must be exercised when substituting that material or component with another. If the substitute material does not provide the same level of performance with respect to both functions, then an additional or existing material may have to be specified to make up the difference.

FUNCTION	SUB-FUNCTION	FUNCTIONAL REQUIREMENTS	COMPONENTS INVOLVED
Provide a foundation for the house superstructure	Superstructure support and anchoring	Resist vertical and lateral (wind and sesimic) loads ; transfer load evenly to soil.	Structural elements of the walls, columns and footings.
	Protection of the superstructure from differential movement due to frost action and soil expansion	Frost penetration control; provision of soil drainage; soil/wall adhesion control; resist or accommodate soil movement due to frost or moisture	Footings, foundation insulation and wall soil interface, backfill and drainage system.
	Isolation of moisture-sensitive superstructure from groundwater	Break capillary action, and provide surface water drainage	Dampproofing or waterproofing or air gap system, and drainage system
Provide a usable & livable indoor environment in the basement (while satisfying criteria for health, safety, and quality of indoor space)	Effective environmental separation	Structural contribution to environmental separation: earth retention, resistance to bulk water, self-support & support or back-up of other components of the envelope system	Walls, slab, lateral supports
		Control of heat loss	walls, slab, insulation, air barrier system and related supporting, protective, and finishing elements
		Control of air leakage including soil gas	Air barrier system including soil gas barrier or soil gas control system
		Control of interior and exterior moisture flow, & surface condensation	Vapour barrier, dampproofing, insulation and structural elements air barrier
		Control of embodied moisture	Structural elements, vapour barrier, dampproofing, insulation
		Control of: rain water, snow melt & groundwater	Above-ground components, ground/wall interface, backfill, drainage layer, drain tile, connections to sewer or sump
	Indoor Environment Modification	Heating	Heating system, distribution & control
		Cooling	Air conditioning systems, distribution & control
		Ventilation	Ventilation systems, sub-slab ventilation & flues
		Air circulation	Fans and ducts
		Humidification, dehumidification	Equipment & controls
		Control of water sources	Gutters, slab slopes & materials, drains, pits or sumps
		Control of Pollutants	Control of off-gassing, Selection of surface finishes, Ventilation

NOTE: Control of lighting, solar radiation, noise and fire are not dealt with here, but are key functions of the envelope that must be addressed in whole building system design.

Chart 1.1 Organization of functions, sub-functions and functional requirements of the basement envelope – HVAC beyond this scope.

Proposed Classification System for Basements

Chart 1.1 depicts a comprehensive list of requirements that must be satisfied to ensure adequate performance of a basement intended for use as a livable space. It is important to recognize that in some cases, certain control functions may not be feasible (e.g., flood protection or sewer backup) or desirable in a particular housing market (e.g., fully finished basements).

During the development of these guidelines it became apparent that in Canada, there exist distinct regional approaches to, and expectations of, basement construction. Ideally, recognition of the diverse use of basements and expectations would be best served by a classification system based on intended use and the intensity, duration and frequency of environmental loads.

Table 1.2 proposes a basement classification system, which reflects the types of basements currently constructed across Canada.

- Class A basements (types 1, 2 and 3) represent basements in which all critical control functions for a livable space have been addressed. In many Canadian housing markets, Class A basements are dominant, maximizing the utilization of highly priced land, or adding value to smaller houses where the basement potentially represents nearly half of the livable floor area.

- Class B basements represent conventional practice in many parts of Canada, especially in areas with well-draining soils, where the risk of water leakage is of little or no concern.

- Class C basements represent what was once conventional basement construction up to the 1970s, and continue to be constructed in some parts of Canada where the notion of a livable basement is simply not marketable.

- Class D basements generally employ engineering design and special measures to deal with chronic flooding or sewer backup events.

- Class E basements are purely structural foundations, which provide no environmental separation. These are typically found in permafrost conditions and also for seasonal dwellings such as cottages, which are built on piers, posts or grade beams.

If the proposed classification system were nationally adopted, even informally, designers and builders could properly specify which functions they intend to be addressed, how well and for what circumstances, thereby leading to appropriate specification of systems and materials to address the required functions, according to circumstance. If basements were to be identified according to their class, homebuyers would know their basement’s designed purpose and intended use.

These guidelines are largely focused on Class A-2 and A-3 basements, representing the majority of basements currently being built with new houses. Omitting certain control functions from a basement design is a matter of professional judgement and circumstance; however, it is recommended that all functions should at least be considered in a design.

CLASS	INTENDED USE	SERVICE CRITERIA	LIMITATIONS/ALLOWANCES
A-1	Separate dwelling unit.	• Satisfies consumer expectations for control of heat, moisture, air and radiation. • Access/egress, fire and sound separation, and fenestration meet all Code requirements. • Separate environmental control system. • Hygrothermal comfort comparable to above-grade storeys of the dwelling.	• Not suitable for flood prone areas, or areas prone to sewer backup. • Basement can be finished with materials that are moisture or water sensitive. • Virtually defect-free construction. • Redundancy of critical control measures provided.
A-2	Liveable space (e.g., family room, home office, etc.)	• Satisfies consumer expectations for control of heat, moisture, air and radiation. • Hygrothermal comfort comparable to above-grade storeys of the dwelling.	• Not suitable for flood prone areas, or areas prone to sewer backup. • Basement can be finished with materials that are moisture or water sensitive. • Virtually defect-free construction. • Redundancy of critical control measures provided.
A-3	Near-livable (e.g., unfinished surfaces)	• Satisfies all functions of the basement envelope, except for comfort, and is unfinished (e.g., no flooring nor carpet, paint, etc.)	• Virtually defect-free construction. • Redundancy of critical control measures provided.
B	Convertible or adaptable basement.	• Satisfies minimum requirements for control of heat, moisture, air and radiation (e.g., no explicit wall drainage layer) • Thermal comfort can be upgraded to same quality as above-grade storeys of the dwelling. (e.g., partially insulated wall)	• Not suitable for flood prone areas, or areas prone to sewer backup. • All structural and interior finishing materials (if any) must recover to original specifications after wetting and drying. • Practically free of defects in free-draining soils where adequate site drainage has been provided. • Normal frequency of defects can be expected otherwise.
C	Basement/cellar - convertible or adaptable at significant future premium.	• Unfinished basement with no intentional control of heat, moisture, air and radiation.	• Practically free of defects in free-draining soils where adequate site drainage has been provided. • Normal frequency of defects can be expected otherwise.
D	Basement serving a dwelling in a flood-prone area, or area prone to sewer backup.	• Class A-1, A-2 or A-3, B or C service criteria may apply.	• Interior finishes capable of withstanding periodic wetting, drying, cleaning and disinfecting.
E	Basement acting as a structural foundation only.	• Acceptable factor of safety for structural performance including frost heaving, adhesion freezing and expansive soils.	• Not intended to be inside the building envelope and no finishing intended. • Floor separating basement and indoors is now the building envelope and must address all functions. • Equipment in basement must be rated to operate outdoors or located in a suitably conditioned enclosure.

Note: Minimum requirements for health and safety are assumed for all of the basement classes listed above. In the case of the Class E basement, only the structural safety requirements are addressed.

Table 1.2 Classification of basements by intended use.

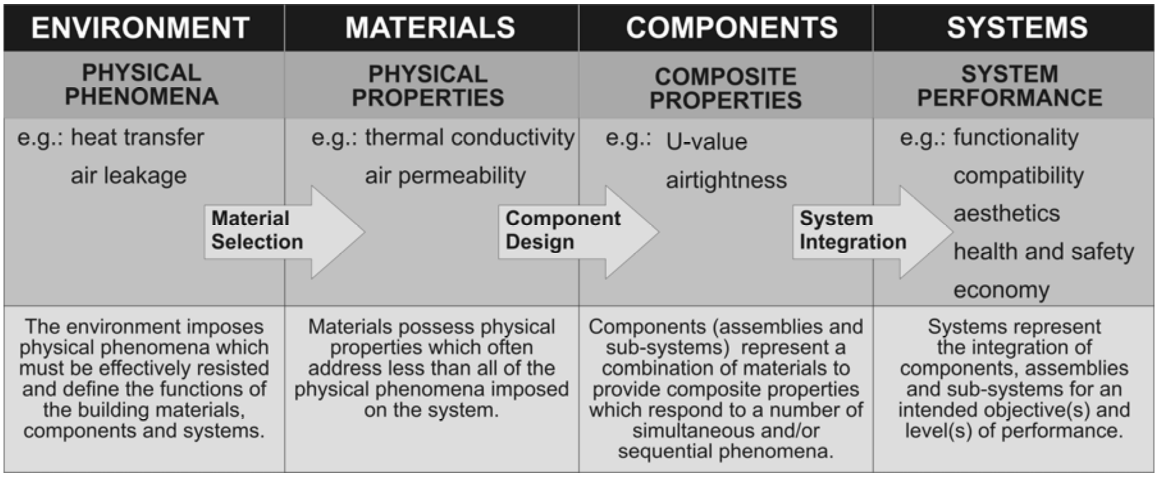
The next section of the guidelines presents the application of the *"systems approach"* to basements within the context of functions as outlined earlier.

1.1 The Systems Approach: Functions, Materials, Components

The systems approach to building performance is derived from general systems theory and is premised on the following definition:

> *A system is an integrated assembly of interacting elements, designed to carry out cooperatively a predetermined function.*

Figure 1.1 depicts the relationship between functions, materials and components within the systems approach to basements, and is equally applicable to buildings in general.



ENVIRONMENT	MATERIALS	COMPONENTS	SYSTEMS
PHYSICAL PHENOMENA	PHYSICAL PROPERTIES	COMPOSITE PROPERTIES	SYSTEM PERFORMANCE
e.g.: heat transfer air leakage	e.g.: thermal conductivity air permeability	e.g.: U-value airtightness	e.g.: functionality compatibility aesthetics health and safety economy
The environment imposes physical phenomena which must be effectively resisted and define the functions of the building materials, components and systems.	Materials possess physical properties which often address less than all of the physical phenomena imposed on the system.	Components (assemblies and sub-systems) represent a combination of materials to provide composite properties which respond to a number of simultaneous and/or sequential phenomena.	Systems represent the integration of components, assemblies and sub-systems for an intended objective(s) and level(s) of performance.

Figure 1.1 Relationship of functions, materials and components within the systems approach.

Within this relationship, it is observed that materials are selected in response to the loads and transfer mechanisms they are intended to resist or accommodate. Physical phenomena affecting buildings are summarized in Table 1.3, which also presents their characteristics and some examples.

Components are an arrangement of materials that address a number of simultaneous or sequential phenomena. A system is composed of components and assemblies (an arrangement of components) to achieve the performance objectives for the basement or building system. Experience and observation strongly indicate that for basements, a key sub-system is the envelope, or the environmental separator.

LOAD	EXAMPLES
Gravity	- structural loads (dead, live, soil and hydrostatic)
Climate	- cold climate - tropical climate
Weather	- wind, precipitation, temperature, relative humidity, barometric pressure, sunlight etc. - extreme instances include hurricanes, tornadoes, etc.
Seismic Forces	- earthquake
Noise and Vibration	- traffic vibration - occupant noise - aircraft traffic noise
Fire	- lightning - electrical
Organic Agents	- insects - rodents - birds/reptiles - fungi/moss/mold
Inorganic Agents	- radon - pollutants and contaminants*

***Note:** Organic substances, such as methane from landfill sites, may be derived from organic processes, but are treated as a pollutant or contaminant.

Table 1.3 Loads on buildings.

In the design process, reconciling functions with materials and components in relation to imposed loads requires careful consideration of numerous factors before material selection. Some of the more important factors are listed in Table 1.4 on the following page. Practically all of the factors apply equally to basements and the whole building system.

It is also interesting to note that almost all of the factors are related to the design of the envelope or environmental separator.

SITE PARAMETERS	FACTORS TO CONSIDER	IMPACT ON BUILDING SYSTEM
Soil	• soil type and bearing capacity • percolation rate	• foundation design • foundation drainage
Topography	• bottom of valley • side of slope • hilltop • level site	• foundation design • foundation drainage • site drainage • site access
Groundwater	• height of water table	• foundation design • foundation drainage
Infrastructure (Services)	• sanitary sewer • storm sewer • potable water supply • energy supply (electricity, gas) • communications • firefighting	• type and quality of building services • service entrance locations • fire routes
Sunlight	• building orientation • seasonal sun paths • shading from adjacent plantings and buildings	• passive solar heating • cooling loads • daylighting • fenestration and shading devices • landscaping
Wind	• seasonal magnitude, direction and frequency • extreme values • building orientation and geometry • arrangement of intentional openings (ventilation)	• structural design • separator design • natural ventilation • pedestrian comfort • landscaping
Rain	• seasonal precipitation • storm intensity and duration	• site grading/landscaping • storm drainage • foundation drainage
Snow	• seasonal precipitation • storm intensity and duration	• snow loads • snow removal • snow melt and runoff rate
Outdoor Temperature Profile	• seasonal temperatures • extreme temperatures	• separator design • heating/cooling systems
Relative Humidity	• seasonal variations	• humidification/dehumidification
Seismic Activity	• magnitude and level of risk	• structural design
Noise and Vibration	• external and internal sources	• separator design • structural design
Fire	• combustibility/flame spread • smoke development	• material selection • separator design
Organic Agents	• insects, rodents, birds/reptiles, fungi/moss	• separator design • landscaping
Inorganic Agents	• radon, methane, heavy metals	• separator design
It is important to recognize that in addition to the above parameters, other special considerations may be involved (e.g., resistance to explosive forces, gunfire, etc., as in the case of an embassy building).		

Table 1.4 Factors to consider in basement system design.

The Basement Envelope System

The central focus of these guidelines, and a recurring theme throughout, is the interactive nature of the roles of each material in the basement envelope system, and the role of the envelope within the basement system.

The primary function of building envelope systems is to provide effective environmental separation and moderation of the indoor environment. In general, building envelopes are passive systems. They do not involve moving parts, except for operable windows, or external inputs of energy to perform their functions. Mechanical and electrical systems are active systems which are not involved in environmental separation. The exception is sump pumps, requiring external inputs of energy. These pumps' primary function is to control indoor conditions by supplementing the passive moderation of the indoor environment provided by the basement envelope system.

The elements of the basement envelope system consist of:
a) the above-ground basement wall
b) the below-ground basement wall
c) the basement floor slab
d) drainage
e) joints and intersections

When basements serve as separate dwelling units, the floor separating the basement from the above-ground dwelling unit(s) becomes an important element deserving special consideration in terms of acoustical and fire safety properties. However, as mentioned earlier, this relatively uncommon situation is not dealt with in these guidelines.

These basement envelope system elements and their associated materials, components and assemblies are listed in Table 1.5. Each element has a particular role which, when combined with all other elements, addresses all of the environmental separation functions highlighted in Chart 1.1. The way in which an envelope addresses these functions is what defines the *basement envelope system*.

A) ABOVE-GROUND BASEMENT WALL	**C) BASEMENT FLOOR SLAB**
✪ Primary separation elements: cladding or parging (rainscreen or face-seal) supported by structure	• Soil
• Exterior insulation (optional)	• Gravel (drainage layer and capillary break)
✪ Supplementary separation elements: airspace with membrane or waterproofing, backed by structural foundation wall	• Insulation (optional)
• Permeable moisture barrier (optional)**	• Air/vapour barrier membrane (soil gas, radon and moisture barrier)
• Framing/strapping (optional)	• Floor-on-grade
• Interior insulation (optional)	• Vapour barrier
• Vapour barrier	• Floor finish
• Air barrier system	
• Interior finish	**D) DRAINAGE**
	• Site and surface drainage
B) BELOW-GROUND BASEMENT WALL	• Wall drainage
• Soil (undisturbed)	• Foundation, footing and floor drainage: drain tile or gravel
• Backfill	• Sump pit or interior drain
✪ Primary line of protection: drainage layer	• Sewer connections
• Exterior Insulation (optional)	• Storm sewer, swale, ditch or dry well
✪ Secondary line of protection: dampproofing or waterproofing, backed by structural foundation wall	
• Moisture barrier	
• Framing/strapping (optional)	**E) JOINTS AND INTERSECTIONS** All materials and techniques involved in the joining of materials and intersections that form part of the:
• Interior insulation (optional)	• Above-ground precipitation protection (including penetrations and junctions with other assemblies)
• Vapour barrier	• earth retention
• Air barrier system/ membrane / soil gas barrier	• Below-ground water control (if present)
• Interior finish	• air barrier and soil gas barrier
	• thermal barrier
*** NBC - 9.13.3.3 (3) - currently requires that impermeable moisture barriers (<170 ng/(Pa.s.m^2)) not extend above ground level, to allow the interior, if any, to dry. This requirement continues to be investigated.*	

Table 1.5 Elements of the basement envelope system to address all separation functions to a performance level appropriate for A-2 and A-3 basements.

One of the important characteristics of the envelope system is that not all of the materials have to address all of the roles – but at least one has to. As a result, the envelope system only becomes fully defined once all of the materials are specified in a 'package.' The 'package of materials' put together to form a system has to be evaluated as a whole, not just in terms of the individual materials. The same holds true for the envelope sub-systems, such as the air barrier system, which is made up of many joined materials, not just one.

Roles of Materials within the System - Addressing the Functions

Material selection is governed by the loads on the basement system and the intended use (class) of the basement. These two major factors define the functions and sub-functions, which subsequently translate into particular material properties. There are also generic requirements for materials, which are often implicit in design.

In general, the materials chosen for the basement envelope have to:

1. Satisfy at least one of the performance-related functions listed in Table 1.1;
2. Satisfy all of the construction-related requirements, for the material to be used;
3. Be compatible with other, adjacent materials used, both chemically and dimensionally, for the exposure regimes to which basements are subjected; and
4. Be durable in the *basement envelope environment*. That is, the material must effectively address its intended function over the *service life* of the basement envelope, within the *basement envelope environment*. That environment is dictated by factors outside the envelope (e.g., soil conditions, precipitation, RH and temperature, etc.) by how well the control of those factors is achieved by the specialized materials selected for that function, and by the interior environment (temperature, RH, etc.).
5. As well, materials can contribute to market value.

Materials that contribute to market value have a better chance of being used. Contributing to market value may play an important role in the selection of materials, especially for visible elements of the envelope. Nevertheless, long-term performance of invisible elements of the envelope should also have a recognized market value, for fulfilling their functions – hence the notion of classifying basements according to intended function, which would give consumers an indication of the how each function is addressed for that basement.

Some materials are specialized to address a single function; for instance, thermal insulation placed on the interior of the structure is designed to control heat loss. (Thermal insulation may also control noise transmission, which illustrates the point that most materials address several functions, some intended, and some inadvertently.)

An example of a material used in multiple roles is the polyethylene sheet, which may be chosen as the vapour barrier material, and may also be part of the air barrier system if properly supported and joined to adjacent materials for continuity. It should be noted that the polyethylene membrane cannot address the air barrier function on its own; it is therefore not an 'air barrier.' It is only by being part of the air barrier sub-system, which involves other materials and joining techniques, that this function can be satisfied.

One of the more dramatic examples of multiple roles of a material results from positioning the thermal insulation layer on the outside of the structure. Such a placement has the potential of addressing six of the main functional requirements shown in Chart 1.1. This example will be reviewed in the Part 2 of this guide, once all of the requirements have been defined.

It is even conceivable that one material could address most or all of the functional requirements of the basement envelope, depending on how stringent the requirements are for a particular circumstance. That is not to say that a single-material system would necessarily be the most economical system or the best performing.

Shifting Requirements By Season and Circumstance

One of the key challenges of building envelope design is that the sub-function of "*effective environmental separation*" is a dynamic role that changes on an hourly, daily and seasonal basis. Coming up with a consistent set of performance criteria for the system and its materials can be difficult, and even result in contradictory requirements, depending on the season or the prevailing conditions. For example, the role of the vapour barrier is generally accepted in cold climate design. Nevertheless, during the warm periods of the year, strong temperature gradients may occur in the upper part of the basement wall, and drive substantial amounts of embodied moisture (e.g., from construction, leakage or capillary action) into the vapour barrier. This can cause problems due to condensation and pooling water in new basements. These problems have often been incorrectly diagnosed as leakage.

In summer, it may be desirable to have more vapour permeability than is allowed by traditional vapour barrier materials. This has been the subject of much debate for above-ground envelopes in warmer climates, where the issue has taken the form of questions: *Do we need a vapour barrier? Do we need polyethylene? Do we need levels of vapour resistance currently specified by Code?* If one wished to fine-tune envelope assemblies, the real moisture control issue is: *How much permeability should each material have, including recognized moisture-controlling materials, given all properties of those materials and their relative positions in the assembly, to achieve an acceptable moisture balance in the envelope year-round?* This issue gains importance below ground because the envelope often has to handle significant quantities of water at various periods through its service life, by virtue of its below-ground location and the construction methods often used. Furthermore, depending on the materials used, the basement envelope assembly may be able to accommodate a moisture flow without adverse consequences.

The following sections give an overview of performance criteria that need to be addressed to satisfy each functional requirement of the *basement envelope system*.

1.2 Structural Functions

Structural adequacy is a fundamental safety requirement for buildings and basements. Unlike environmental separation, the structural functions do not have options corresponding to an intended use (class) of basements. Chart 1.2 presents the performance criteria for the components involved in fulfilling the structural functions. Factors to be considered are summarized in Table 1.6.

SUB-OBJECTIVES	MAIN FUNCTIONAL REQUIREMENTS (DEFINING THE SUB-SYSTEMS OF THE ENVELOPE)	COMPONENTS INVOLVED	PERFORMANCE CRITERIA OF THE SUB-SYSTEM
Superstructure support and anchoring	Resist vertical and lateral (wind and seismic) loads ; transfer load evenly to soil.	Structural elements of the walls, columns and footings.	Transfer loads such that strength of materials and soil-bearing capacities are within safety limits
Protection of the superstructure from differential movement due to frost action and soil expansion	Frost penetration control; provision of soil drainage; soil/wall adhesion control; resist or accommodate soil movement due to frost or moisture	Footings, foundation insulation and wall soil interface, backfill and drainage system.	Depth of footings; insulation, location and coverage; drainage capacity; backfill type
Isolation of moisture sensitive superstructure from groundwater	Break capillary action, and provide surface water drainage	Dampproofing, or waterproofing or air gap system, and drainage system	Maximum water permeability; drainage capacity

Chart 1.2. Performance criteria for the structural functions.
(expanding on Chart 1.1, for the environmental separation functions)

Gravity – Dead Loads from
- footings
- footing plate on gravel
- walls and posts

Wind Loads (from above-ground elements)
Self-Support (resistance to cracking, deflection or falling over, creep)
Soil Expansion/Contraction due to Frost Action
- adfreezing (uplifting, tensile loads)
- frost heaving (uneven heaving, racking loads)

Seismic Loads
Support
- bottom of the wall
- top of the wall
  - accommodation of structural members serving stories above
- flexural strength, deflection and creep

Hydrostatic Pressure
Construction Loads
- short-term loading due to equipment, material handling and storage
- backfilling

Impact Loads Above Ground
- due to occupant activity
- play and lawn care (repeated impact)

Table 1.6 Loads associated with structural functions for basements.

1.3 Controlling Environmental Factors

The sub-objective of providing environmental separation involves a systems design whereby all functions have to be addressed. These are shown in Chart 1.3, and are discussed below.

SUB-OBJECTIVES	MAIN FUNCTIONAL REQUIREMENTS (DEFINING THE SUB-SYSTEMS OF THE ENVELOPE)	COMPONENTS INVOLVED	PERFORMANCE CRITERIA OF THE SUB-SYSTEM
	Structural contribution to environmental separation: earth retention, resistance to bulk water, self-support and support or back-up of other components of the envelope system	Walls, slab, lateral supports	Transfer loads such that strength of materials and soils are within safety limits
Effective environmental separation	Control of heat loss	Walls, slab, insulation, air barrier system and related supporting, protective, and finishing elements	Effective thermal resistance, including thermal bridging, and 3-dimensional heat transfer and storage in soil.
	Control of air leakage including soil gas	Air barrier system including soil gas barrier or soil gas control system	Air permeability, degree of continuity, structural sufficiency
	Control of interior and exterior moisture flow, and surface condensation	Vapour barrier, dampproofing, insulation and structural elements, air barrier	Threshold moisture contents of all materials, duration and material tolerance
	Control of embodied moisture	Structural elements, vapour barrier, dampproofing, insulation	Threshold moisture contents of all materials, duration and material tolerance
	Control of: rain water, snow melt and groundwater	Above-ground components, ground/wall interface, backfill, drainage layer, drain tile, connections to sewer	accumulated water and moisture contents of all materials, duration and material tolerance

Chart 1.3 Performance criteria for the environmental separation functions.
(expanding on Chart 1.1, for the environmental separation functions)

Structural Contribution to Environmental Separation

As pointed out earlier, certain elements or components of a system may serve multiple roles. In fulfilling the structural functions, the basement structure also contributes to environmental separation functions. This is because the structural sub-system is part of the envelope sub-system, and in addition to its house-support role, it also retains the earth and potentially bulk water - a fundamental first step in providing usable space. The structural sub-system has to support or back up all other elements of the envelope system, as well as furnishings, equipment and occupants.

Like the house-support role, the essential performance criterion of the sub-system is to distribute the loads through the structure in such a way that the stresses developed in the envelope materials are within serviceability limits dictated by the strength of those materials.

A key element in basement wall design is to ensure that the top and bottom of the wall are secured laterally to resist earth pressures. If the top and bottom are not secured, then the edges of the wall become the lateral supports resulting in relatively long spans, and high tensile stress on the inner part of the wall. As well, this may result in large deflections inward, which may not be accommodated by building envelope components such as framing, insulation, and drainage membranes. In cases of very large deflections, even structural members such as steel beams supporting floors above may punch laterally through the foundation wall, compromising both envelope and structural integrity.

Control of Heat Loss

Control of heat loss is an essential element of environmental separation, especially for basements in cold climates. Although the soil and snow cover present a 'modified' thermal environment to the below-ground basement envelope, by providing some thermal resistance and thermal lag, these effects are not generally enough to eliminate the need for insulation below ground. For instance, Ottawa may experience mean daily air temperatures of -20°C, while the soil may reach 2°C at a depth of 0.6m, and 4°C at a depth of 1.8m, next to the basement wall.[2] These soil temperatures are similar to mean monthly air temperatures in many parts of Canada during the heating season, where above-ground insulation is considered essential.

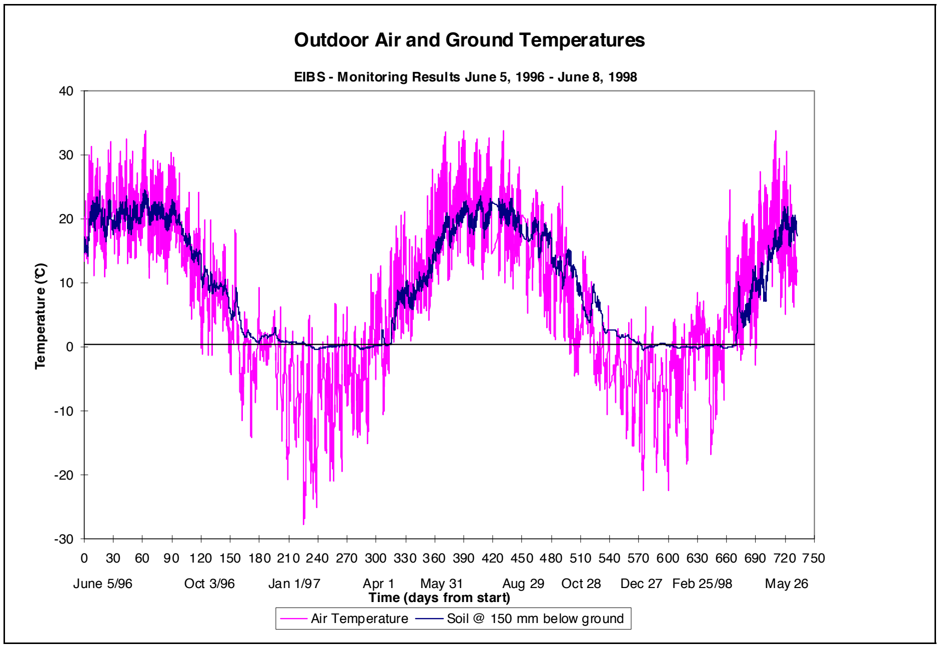


Figure 1.2 Outdoor air versus soil temperature profiles – Ottawa.

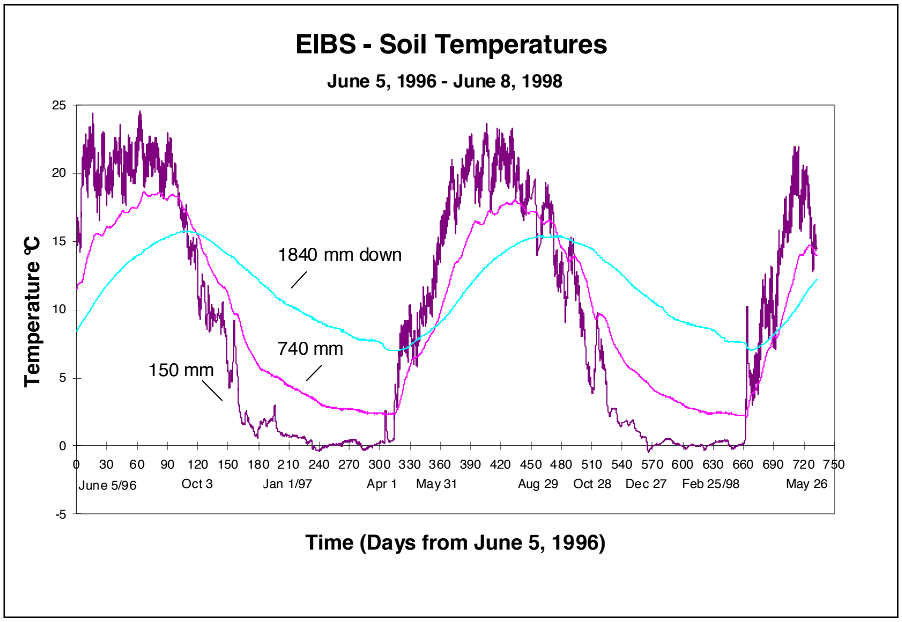


Figure 1.3 Variations in soil temperatures – Ottawa.

The duration of the below-ground heating season also lags behind that of the above-ground by virtue of the mass of the earth, which often results in the thermal envelope being the only means of providing appropriate indoor temperatures in the late spring and early fall, when heating systems are inactive or turned off. Basements in cold climates can account for between 20% and 30% of the total building space heating energy demand, and there may also be economic incentives to adequately insulate the basement envelope (see Part 6).

Given these perspectives, it is reasonable to conclude that thermal control in basements is both justifiable and desirable. The essential performance requirements needed to achieve thermal control are: provision of adequate and effective thermal resistance over as large an envelope surface as is economically practical, and in a continuous fashion.

R-Value of the Assembly vs. R-Value of the Insulation

The thermal barrier sub-system consists of all the elements of the envelope assembly, since all of these are involved in heat transfer. Key within these are the thermal insulation elements, but these can rarely be treated in isolation of other components. The distinction is made between thermal resistance of the insulation material, which is a material property, and the *effective thermal resistance of the assembly,* which also accounts for the thermal bridging of framing members, and the thermal resistance of all other elements of the envelope, including finishes, the interior air film, and air leakage. The former is the performance criterion for the material (further discussed in Parts 2 and 3), while the latter is the performance criterion for the sub-system, the topic here. Although the proper performance of the insulation material is essential, it is not sufficient on its own to deliver the desired performance of the thermal sub-system. Structural and framing material, dimensions and spacing all influence the effective thermal resistance of the assembly, and therefore need to be specified for the system performance to be known.

The other performance criterion is coverage – how much of the envelope is actually covered by the insulated assembly. Traditionally, insulation is extended from the top of the wall down the wall to:

- 600 mm below ground
- or covering the full wall
- or covering the full wall and a width of board insulation inward from the perimeter,
- or covering the full wall and slab

Effective thermal resistance of the assembly and coverage fully define the thermal performance requirements.

Control of Air Leakage and Soil Gas

The control of air leakage is addressed by the *air barrier sub-system*. Soil gas ingress control can be complemented by sub-floor ventilation. The air barrier sub-system is composed of several air-impermeable membranes or rigid materials, supported by the envelope structure, joined at the edges, corners, wall-to-wall and wall-to-floor intersections, and sealed at penetrations. The basement air barrier system is also joined with the above-ground air barrier system to form a whole-house air barrier system.

The air barrier system serves as a soil gas and radon barrier below ground to control ingress of radon, methane, airborne water vapour, and insects.

The main performance criteria for air barriers in general are:

- airtightness
- continuity
- structural sufficiency

Generally, the above-ground portion of the air barrier sub-system in the basement is not subjected to full wind loads. The structure itself (e.g., cast-in-place concrete, concrete masonry units, or sheathing on a permanent wood foundation), is thought to provide at least part or all of the resistance to wind load. Wind loads are not an issue below ground, although there are induced pressure differences between the room air and soil that can induce soil gas ingress. As well, most materials that might be used in the *air barrier sub-system* below ground are relatively air impermeable (e.g., polyethylene, gypsum, treated plywood, poured concrete or prefabricated concrete panels) so that the air impermeability criterion is generally not considered to be an issue. The key criterion for below-ground air barrier and soil-gas barrier design is continuity of the sub-system.

Control of Moisture in the Vapour State

Moisture can affect basement systems in its many forms – as bulk water, capillary water, ice and water vapour. Experience has demonstrated that dealing with water in its vapour state often addresses control functions for water in its other forms.

Control of Moisture Flow from the Interior and Exterior

When considering moisture flow, a distinction needs to be made between the following:

- moisture flow;
- moisture accumulation;
- condensation; and
- sustained or recurring condensation.

Moisture flow through the basement envelope, per se, is not a problem – like heat flow, it is inevitable. However, an imbalance in moisture flow at a location in the envelope can lead to moisture accumulation at that location.

Moisture accumulation results from:

- excess moisture flowing into the envelope from inside the basement;

or

- excess moisture flowing from the soil or wet surfaces above ground into the envelope.

A balance of incoming and outgoing moisture in the envelope is generally achieved automatically. Accumulation of moisture within the assembly increases the vapour pressure at a given point, which increases outward flow of moisture and may decrease inward flow. Moisture accumulation is not necessarily a problem, if a new balance can be reached at reasonably low material moisture contents or air vapour pressures.

Problems with High Moisture Contents and Condensation
If the vapour pressure required to achieve a balance of incoming and out-flowing moisture is above the *saturation vapour pressure* at that location (i.e., above the maximum sustainable in air or a hygroscopic (hydrophilic) material at a given temperature) - that balance cannot be achieved. The result is sustained accumulation in liquid form: condensation.

If drying conditions are not present (more outward moisture flow than inward) or if the wetting conditions recur, this can lead to sustained or recurring condensation.

This last condition, sustained or recurring condensation, is the one to avoid in an envelope design. Moisture control strategies should focus on avoiding this condition since it can lead to eventual structural damage and the production of moulds. The first three conditions – moisture flow, moisture accumulation, and temporary condensation – are inevitable elements of the moisture flow system, and must be controlled, rather than avoided.

The following design principle emerges:

- **ensure that a balance in moisture flow is achieved at every point in the basement envelope, with vapour pressures that are well below the saturation vapour pressure at that point.**

Applying this principle involves a number of interactive factors: primarily, the thermal resistance and vapour permeance of each material, and the relative location of each of these materials in the assembly. To fine-tune a design, the evaluation of these at a system level involves full-year simulation or testing of a basement envelope (wall and slab under realistic environmental conditions) to ensure that the principle is satisfied.

It should be noted that one of the principal causes of an imbalance in moisture flow in the envelope is an abrupt decrease in vapour permeability of adjacent materials at cold temperatures. When this occurs, that location becomes a candidate for condensation. Paradoxically, most moisture control strategies involve the selection of impermeable membranes to control moisture flow, so that care must be taken to either maintain these at warm temperatures or plan for condensation and drainage. The success and failure of various approaches will be explored in Parts 2 and 3.

Control of Surface Condensation

Surface condensation is just a special, visible case of uncontrolled moisture from the interior. When surface condensation occurs, the above rules of avoiding condensation are not satisfied. Surface condensation is not simply caused by surface temperatures being below the dew point of adjacent air (i.e., moisture at the surface being unable to develop the vapour pressure of the room). It also involves an abrupt change in vapour permeability in the direction of the gradient, such as resulting from glass being next to room air. Alternately, surface condensation may involve a more permeable material that is already at saturation and cannot accept more moisture in vapour form. Either situation causes moisture to come to the surface more quickly than it can evaporate from or be absorbed through the material.

Thus, the same design principle applies to avoid surface condensation as interstitial condensation:

- **ensure that the balance in moisture flow is achieved at the basement envelope surface, with vapour pressures that are well below the saturation vapour pressure at that point.**

A corollary to the above principle is that if the temperature of the surface is above the dew point of adjacent air, then a balance in moisture flow can always be achieved without condensation, regardless of the relative permeability of the adjacent materials. Because of the ease in evaluating this special case – dew point temperatures can be evaluated by direct measurement of temperature and relative humidity – this is the rule that is used by most designers. Nevertheless, for the purpose of finding more alternative solutions to the overall moisture transfer problem in the envelope, this corollary should be set aside for the time being. The overall moisture balance of the envelope must be considered as a whole, rather than just in terms of the inner surface temperature. Accordingly, the same performance criteria involved for achieving balanced moisture flow in the envelope apply to the surface condensation issue.

Release of Construction Moisture

Construction moisture may be defined as the moisture that is contained within the materials used to construct the basement system (e.g., water in concrete), as well as the moisture that is accumulated in the materials during the construction period due to sources such as precipitation and groundwater. Moisture may also be introduced by construction heaters which are typically fossil-fuelled, unvented and produce significant quantities of water vapour among their products of combustion. In summary, construction materials may be:

- inherently wet, as part of their formation (e.g., poured concrete, gypsum board joint compound, wet-spray applied insulation systems);
- wet unless treated and protected (e.g., green lumber, moisture content > 19%); or
- initially dry, but exposed to snow or rain during site storage and the construction process, (e.g., most manufactured wood products, gypsum board, metal products, masonry).

(Materials can also get wet after construction, as a result of a failure of the water-leakage control sub-system, or the plumbing system. The dry-out problem is the same.)

Accommodating the release of this construction or embodied moisture without initiating deterioration of susceptible materials is a special case of achieving a moisture balance. Where an assembly is closed in before the moisture overload is dissipated, the rule is automatically broken. In that case, because the envelope has to handle so much moisture at or near the saturation point of the materials and air, there is little latitude for local vapour pressures to adjust to achieve a balance. The problem is thus compounded, since, while one saturated portion of the basement envelope may be in a favourable position to dry out, its moisture may be causing an imbalance in other locations in the envelope (i.e., the impermeable surfaces).

Figure 1.4 An example of construction moisture accumulation during winter construction.

Best practice would see that time is allowed to permit moisture dissipation before the assembly is closed in. Where this time cannot be accommodated, two principles apply:

- **Ensure that the balance in moisture flow is achieved at every point in the envelope, with vapour pressures that will eventually be well below the saturation vapour pressure at each point; (same as the principle governing the control of condensation) and;**

- **There need to be prolonged periods where high vapour pressure differentials exist between the saturated materials and the envelope surroundings, and a permeable path must exist between the inner wall and its surroundings.**

It is not sufficient to achieve a balance in moisture flow at low vapour pressures; the vapour flow must be substantially outward or inward (or both) from the saturated location, for sustained periods of time.

Thus, the same performance criteria involved for achieving balanced moisture flow in the envelope apply to the embodied moisture issue, but here, critical indoor, outdoor and soil weather parameters need to be investigated to ensure that dry-out conditions prevail for substantial periods of the year.

Control of Interior RH and Temperature

The control of interior relative humidity and temperature is another moisture control strategy to consider in basement system design. This approach represents a secondary guard that is only effective in dealing with short-term fluctuations. Heating during the winter months and dehumidification during the summer months can improve the moisture balance within basement structural materials and basement furnishings. The proper selection, arrangement and installation of materials within the basement envelope assembly should always serve as the primary protection against moisture buildup, because it is passive and inherently more reliable.

Control of Convection Loops within the Envelope

Convection loops within the building envelope must be controlled to avoid undesirable heat loss, moisture flow and frost action problems. The most common errors to avoid in basement envelope design are:

- air space outboard of internally placed insulation; and
- empty cores of concrete masonry units used in structural foundation walls where the walls are insulated on the interior.

It is important to recognize that even the most ideal of material arrangements in basement envelopes can be 'short circuited' by convection loops if materials are not properly installed.

Control of Surface Water and Groundwater - The Drainage Sub-System

The sub-system that controls surface water and groundwater is potentially the most complex of the basement sub-systems, because it involves such a large number of functions and components – many of which are not normally considered as part of the basement envelope system:

- above-ground components – other than the basement wall, (e.g., roof, eavestrough, etc.);
- the above-ground basement wall;
- the ground/wall interface and local landscaping;
- below-ground drainage (exterior insulation, fibrous drainage mats, semi-rigid dimpled polyethylene membranes, and/or continuous granular drainage layer conveying water to perimeter drainage pipe and gravel or continuous granular drainage layer);
- central collection system;
- connection to receptor (municipal storm/combined sewer or sump/drainage ditch/dry well);
- interior drainage pathways for leaks, over the slab to a central drain and the sanitary sewer; or under the slab to the central collection system; and finally,
- isolation of hygroscopic materials.

All these components form a series-resistance flow system, which is only as good as its most flow-resistant component. Each component carries its own set of design criteria to satisfy an overall objective of the sub-system. That overall function is more than keeping the water away from the foundation: it is to achieve an overall water management strategy such that all connected sub-systems, including municipal sewers, do not become overloaded, and maintain their serviceability over the service life of the system.

The topic of urban drainage and basement flooding is beyond the scope of these guidelines. However, there are a number of past studies that may provide designers with valuable insights into the issues and factors to consider.[3, 4, 5]

Requirements of the Municipal Sewer System

Municipal services engineers tell us that, from their perspective, the ideal drainage strategy for lots (and entire housing developments) is one that delays, as long as possible, the flow of water to the storm sewer system during extreme events. This means directing rain or melt water away from the house to backyard swales or ditches at the lot line, which in turn connects to local collection areas, before finding their way to main storm sewers, ditches or streams. The time delay between peak rainfall or melt periods and maximum water flows into the storm sewer system is important. It is preferable that the swales, ditches and local collection areas flood temporarily during extreme events, out of the reach of buildings and sanitary sewers. This frees storm sewers to do their job, which includes handling drainage flows from the *basement drainage sub-system*. Directing all surface water to the storm sewer at the same time during extreme conditions causes an overload, which inevitably leads to basement backup problems. This mechanism of failure is even more critical in some older neighborhoods where storm and sanitary sewers are combined – the backup water being automatically contaminated with sewage. The old practice of connecting eavestroughs directly to the drain tiles also contributes to overloading sewers during peak conditions.

The house foundation drainage system should thus be a last resort, which needs to be effective, but used as little as possible for draining above-ground sources of water. Providing effective site drainage and appropriate surface run-off routes constitutes primary protection for the basement.

IMPORTANT NOTE: For more information on municipal sewer systems consult - Kesik, T. and Kathryn Seymour, *Practical Measures for the Prevention of Basement Flooding Due to Municipal Sewer Surcharge: Final Report*. Canada Mortgage and Housing Corporation, 2003. *(External Research Program Research Report) 95 pages*.

The role of each function and component in the *basement drainage sub-system* is now briefly reviewed.

Above-Ground Components

The roof, eavestroughs and downspouts, and the above-ground wall, shed rain or melt water to the ground, next to the basement. A roof without eavestroughs and downspouts, and walls with non-porous finishes that are subject to wind driven rain, represent large rain collection surfaces that concentrate rainwater and delivered it at potentially high velocities right next to the basement. As a result, the *basement drainage sub-system* often has to deal with large, concentrated volumes of water, and with the long-term effects of the impact of falling water and subsequent soil scouring at the *ground/basement interface*.

Eavestroughs and downspouts are used to moderate scouring, but can also exacerbate the problem, if not properly planned. Eavestroughs accumulate the flows, resulting in more flow in one area (usually at the corners), and often at high velocity, insufficiently directed away from the *ground/basement interface*. (In some cases, the eavestroughs on a neighbouring house are too effective at getting the water away from that house by delivering it too close to the adjacent basement).

Relevant performance parameters are: maximum flow rates as determined by maximum rainfall and surface area of the roof and walls, flow intensity, reduction in water velocity and location of water deposition. If a fail-safe system could be devised to channel this water well away from the ground/*basement interface* (i.e., beyond the area of usual soil depression next to the basement), then maximum flow rates and intensity from the above-ground components would no longer be critical to the design of the below-ground components of the drainage sub-system.

Above-Ground Wall / Basement Wall Interface

The above-ground walls are often designed using the rainscreen principle,[6] which is a good strategy for above-ground walls, but which relies on flashing at the top of the basement wall to complete the defence against water incursion. The interface separating the rainscreen wall from the face-seal basement wall is thus an essential element of controlling water incursion into the basement wall. Its role is to direct all water dripping down the inner layer of the rainscreen to the outside face of the basement wall, in a continuous manner.

Above-Ground Basement Wall

Rainscreen Walls

There is general agreement that, for above-ground wall design, the rainscreen system offers more lines of protection against failure than face-sealed systems. For rainscreen systems, the first line of protection sheds water at the wall surface. The second provides protection against incidental water penetration past the cladding and a drainage plane to permit dissipation to the exterior. The degree to which a wall will rely on the second line of protection depends on the precipitation load the assembly must resist and the effectiveness of the first line of protection. Therefore, the second line of protection may incorporate:

a) a water-resistant membrane or panel with lapped joints flashed to the exterior;
b) an air space behind the exterior finish and a water-resistant membrane flashed to the exterior; or
c) waterproofing; or
d) massive backup.

The face-sealed system has only one line of protection – shedding water at the surface. With this system, crack-free surfaces and durable sealing of all joints and interfaces with other components (e.g., windows, penetrations, etc.) are the only line of protection. This system thus imposes rigid constraints on the materials that make up the system, construction tolerances, and maintenance.

Virtually all above-ground basement walls, as currently constructed, are face-sealed systems – extensions of the below-ground wall.

The above-ground portion of the basement wall also has to deal with ponding surface water, often collected from the downspouts of eavestroughs or from meltwater. This puts even more demands on the materials used in the face-seal system. As well, the potential for heaving soil and splashing from falling rain has to be addressed by the above-ground portion of the wall. This calls for minimum clearances between the ground and moisture-susceptible finishes. Finally, the above-ground basement wall has to isolate the rest of the above-ground construction from ground moisture or surface water that could rise through it by capillary action.

Water Removal at Ground Level

Grading at the ground/basement/wall interface is one of the key points of water control in the *basement drainage sub-system* - the first line of protection. As described above, the objective is to convey water away from the basement wall, to planned areas of water runoff such as swales and ditches. Conveying water directly to the street is preferable to leaving it to pond next to the basement, but can lead to overloading storm sewers during extreme conditions, since this offers such a direct path to the storm sewer. This in turn hastens sewer backup into basements in extreme conditions.

Conveying water away from the basement wall is not always an easy task. Grading at the sides needs to be away from the wall, but also towards the back and front yard if adjacent houses are nearby. Small clearances between houses and walkways often make grading in two directions difficult to achieve. Also, grades next to the basement wall should be more pronounced, to counter the effects of long-term settlement of the soil.

Capping the Wall Drainage System

As indicated previously, the wall drainage sub-system is a second line of protection. To ensure that this system is not over-utilized, some form of surface capping is recommended to prevent direct water flow down the wall. A cap may consist of a low-permeability, fine-grained cohesive soil (e.g., clay). In fact, some form of membrane or board placed just below ground and sloped away from the wall may be required as a more effective and deliberate capping technique.

Drainage Below Ground

Drainage Layer vs. Waterproofing

The debate over what system to use above ground (rainscreen or face-sealed) has its counterpart below ground: drainage layer vs. waterproofing. The arguments are similar. The drainage layer provides two lines of protection:

1. an initial surface that drains water along the soil/wall interface
2. an air space created by a dimpled semi-rigid membrane or a fibrous/granular material that creates an air space between the earth and the wall, backed up by a second water-resistant surface (e.g. dampproofing membrane or coating) that drains any water reaching it to the footing area. Except where the water table rises above the bottom of the wall, the air space prevents hydrostatic pressure buildup, which would otherwise force water further into the envelope.

The waterproofing system has only one line of protection – the continuous, waterproofed surface next to the structure. Again, like the face-seal system, because the waterproofing system is the only line of protection, it places more stringent requirements on the materials and sealing techniques used.

Footing/Wall Interface

The key difference between the above-ground rainscreen and face-sealed assemblies compared to the *basement drainage sub-system*, is that it is possible for ponded water to rise up the below-ground wall (see the discussion on drainage pipe and gravel which follows). Waterproofing of the lower wall and footing intersection may be required in difficult soil conditions unless a more effective, clog-resistant footing drainage system is used.

Below-Ground Drainage

The drainage of water in the ground and surface water that is conveyed to the base of the foundation wall is accomplished through various approaches to below-ground drainage. Key considerations in below-ground drainage are: 1) where the water will be drained, and as a result, 2) what means will be used to convey the water, either gravity or mechanical pumping.

Gravity drainage is the most reliable means of conveying water; however, it is not always possible to connect the below-grade drainage to a receptor (storm sewer, drainage ditch or dry well) which is below the elevation of the weeping tile. When gravity drainage is not possible, or economically feasible, below-grade water must be collected in a sump and then pumped to an available receptor that is higher than the bottom of the basement, and in some cases the ground surface.

There are two predominant approaches to below-ground drainage currently used in Canadian residential basements – perimeter and gravel, or continuous granular drainage layer. Both of these may employ either gravity or mechanical pumping as a means of conveying water in the ground away from the basement envelope.

Perimeter Drainage Pipe and Gravel

The most typical approach to foundation drainage is illustrated in Figure 1.5, and employs weeping tile (continuous, perforated rigid or flexible pipe) installed around the perimeter of the foundation wall footing, and covered with a granular material (gravel) prior to backfilling.

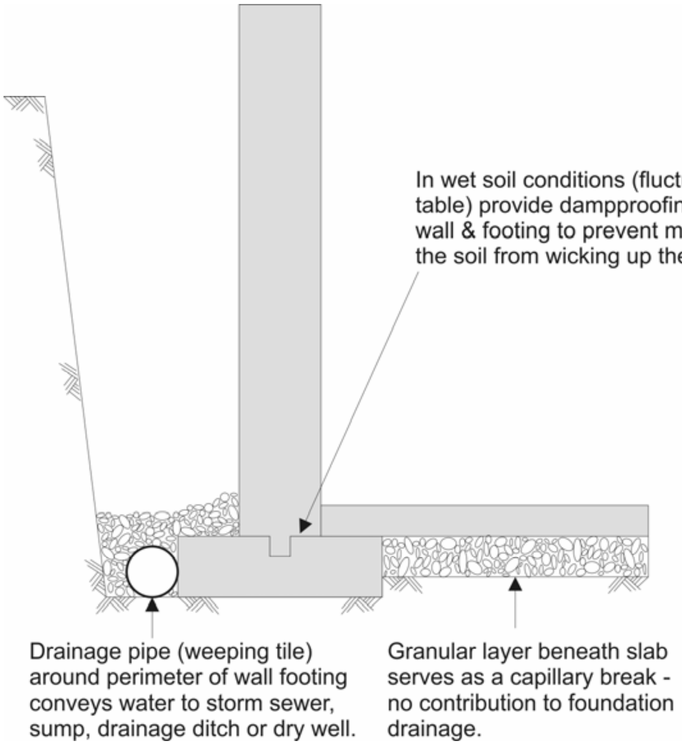


Figure 1.5 Schematic of perimeter drainage pipe and gravel approach to below-ground drainage.

The drainage area around the footings can be viewed as a long, nominally level channel formed by the footing at one side, and the undisturbed ground at the bottom and opposite side. The voids in the gravel provide the space for water to accumulate. The footing defines one side of the water containment area. The drain pipe leads around corners to one or two relatively small openings under the footings, which either connect to the central collection area – a sump pit, or connect directly to the main sewer. As water drains down the wall, it collects here. Hydrostatic pressure develops, promoting flow into the perforated pipe and to a lesser extent through spaces in the gravel. The long distances to the central opening in the footings, or trunk pipe to sewer, dry well or drainage ditch, and the shape of drain pipes results in considerable flow resistance, which in turn requires more height of water to surmount. Corners, constrictions and partial blockage of the pipe result in higher buildups of water. When there is an imbalance between the flow drainage down the wall and the flow out of this channel to the receptor or central collection area (sump), water can back up and result in hydrostatic pressure on the wall.

It should be noted that flow through drain tile or pipe does not constitute conventional pipe flow, since the walls of the pipe are perforated to let water in. These perforations also let water out of the pipe so that hydrostatic pressure cannot develop as a result of the pipe being sloped. Thus, hydrostatic pressure only builds if water rises in the channel, since the walls of the drain pipe cannot sustain water pressure. The uniformly perforated drain tile or pipe merely provides more flow area than conventional gravel, but coarser gravel could conceivably produce the same effect. In this system, the area nearest the central drain outlet would be served first, and the areas around the corners and farthest from the central opening would drain last. This probably leads to differential buildup of water, featuring slow moving water at the extremities, while the area nearest the outlet clears itself. Sedimentation of fine soil particles will occur, depending on flow velocity. This portion of the basement drainage sub-system is fundamentally a low-flow-capacity system, as it is currently conceived. The footings can be expected to be in contact with water on a regular basis. This system may require some form of protection from water buildup at the base of the wall depending on the load that might be imposed by water in the ground. Other systems have perforations or openings that are systematically arranged higher in the drain tile or pipe, thereby allowing open channel flow to develop; but again, the water level in the channel next to the footing must rise to the level of the openings in the pipe before water starts flowing away. With this system, the slope of the pipe has a role to play. All locations around the wall would start being served as the water level reached the perforations. However, the sloped pipe results in more water being collected at the extremities, since the perforations would be higher there. Unlike the uniformly perforated pipe, water does not stagnate, once in the pipe. This system could presumably handle greater capacity flow. The footings would also be in contact with water on a regular basis. This system may also require some form of protection from water at the base of the wall.

The performance criterion is the maximum flow capacity, which is influenced by the channel opening (slope in the case of high perforations) and flow resistance as determined by run length, pipe undulations and roughness, elbows at the corners, constrictions at joints, and size of central collection openings. The flow capacity of this part of the *basement drainage sub-system* should be greater than the maximum drainage rates of the wall drainage system and percolation rates of water through the soil.

Continuous Granular Drainage Layer

The continuous granular drainage layer, as illustrated in Figure 1.6, is commonly used with permanent wood foundation (PWF) construction, and employs a crushed stone or gravel base. This represents a different drainage strategy around the footing plate because the physics and design parameters are different. Since the footing or wall plate rests on the gravel, there are direct flow openings to a central collection area (which may be located within the basement in the case of a sump, or outside of the envelope when other means of conveyance are available). There is thus no channel formed by a footing at the outer perimeter. The resulting spaces in the gravel beneath the footing plate present a very large free area everywhere along the perimeter (compared to the 100-mm opening in a single location, when there are footings directly on the soil).

The slope to the central collection area, and the openings afforded by the gravel are the criteria needed to achieve the design flow capacity when this approach is employed.

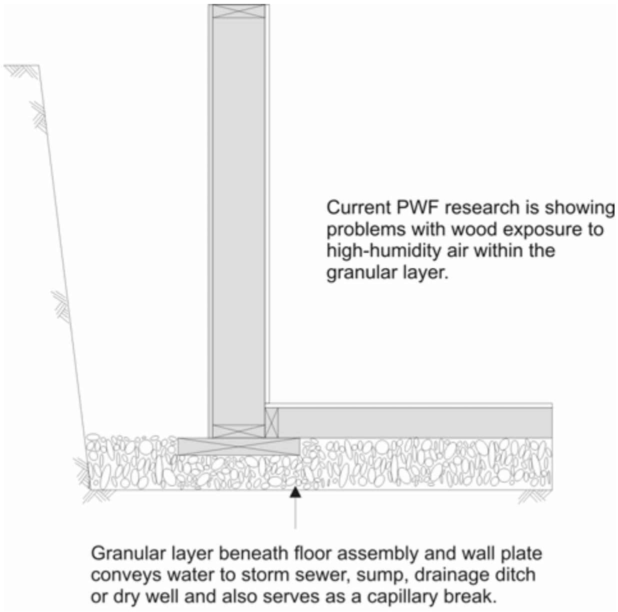


Figure 1.6 Schematic of continuous granular drainage layer approach to below-ground drainage.

Central Collection System

With the exception of basements situated on extremely well-draining soils, below-grade water is normally collected at some point, or points, which may be located within the footprint of the basement or completely outside of the basement envelope. In the case of a perimeter drainage pipe and gravel approach, which relies on gravity drainage, the collector is typically the outlet from the drain pipe loop. Gravity drainage coupled with a continuous granular drainage layer usually employs a sump which is connected by piping to an available receptor, but it is also possible to have one or more outlets discharging into soil strata at a lower elevation via perforated pipe or a 'French drain' (basements constructed on sloped sites are ideally suited to this strategy).

When mechanical pumping of below-grade water is required, irrespective of the approach used, water is typically collected by a sump located within the basement. The location and depth of the sump are critical considerations in design.

The performance criterion for the discharge, with or without collection, is that it must be capable of conveying maximum discharge rates from the *wall drainage sub-system,* without backing-up the below-grade drainage at any point upstream of the collector.

Connection to Receptor

After the below-grade water is conveyed and collected, a connection to a suitable receptor is required (e.g., sewer, drainage ditch, dry well). Key criteria for the performance of this component are:

- the connection must handle maximum discharge rates; and
- backflow valves may be required when the risk of receptor backup is likely (backflow valves which are improperly located, or are not accessible for maintenance and replacement can result in serious moisture and structural problems).

Implicit in these performance requirements is the adequacy of the receptor. In some situations, such as combined urban sewer systems, the adequacy of the receptor must be carefully reviewed. As was mentioned earlier, this issue is beyond the scope of the guidelines.

Interior Drainage Pathways
Interior drainage pathways are the final line of protection regardless of which drainage sub-system strategy is used. This relationship assumes that there is always some probability of drainage sub-system failure or overloading, and also recognizes internal sources of moisture such as a burst or leaking water pipe. If the interior drain is the second line of protection, then it will likely be used over the service life of the basement; hence appropriate strategies for isolating this final means of drainage from the interior are required. This issue is explored in greater detail in Parts 2 and 3.

Isolation of Hygroscopic Materials
Finally, the *basement drainage sub-system* must isolate hygroscopic materials used in the basement envelope system from water handled by that sub-system. Water isolation can be inherent in the drainage sub-system design, or it can be achieved by a continuous and durable dampproofing or waterproofing membrane or coating. Again, first and second lines of protection should be identifiable, or more stringent requirements on the dampproofing materials may be needed, depending on the susceptibility of the materials used and their location in the *basement envelope system.*

Designing to Control All Factors

It is not always possible to control all factors within a satisfactory degree of risk. The probability of failure in a system is significantly reduced by introducing redundancy, but extreme events can and do exceed reasonable levels of safety and performance. Catastrophic failures aside, it is possible to consider all of the factors systematically using the framework that has been presented. The proper exercise of judgment cannot be conveyed within these guidelines; however, a comprehensive list of factors and associated performance criteria can help guide a more rational design process.

Dealing with Exceptional Environments

As indicated earlier, the below-ground environment is a challenging one in itself. However, some areas are even more challenging, being susceptible to frequent, heavy downpours and local flooding. Houses built on flood plains are an example. Here, additional elements of the basement drainage sub-system may be required, including provisions for inevitable flooding, as indicated by the proposed “Class E” basement. Such devices as backflow valves may be seen as an integral part of the drainage sub-system. In such areas, the selection of materials forming the *basement envelope system* would have to be based on the higher probability of failure of the drainage sub-system. It is even possible that in some exceptional environments, any form of basement is simply not feasible, for technical and/or economic reasons.

1.4 Envelope Durability Functions

The *basement envelope system* is not only designed to address all of its functional requirements, but is expected to deliver these at some reasonable total cost (including initial, maintenance, repair and operating costs) over the service life of the basement envelope.

Again, the challenging nature of the basement environment comes into play. Some of the impediments to delivering these functions over the long term are:

- soil settlement, shifting, and differential movement resulting in cracking of structural or other elements that are expected to be continuous, due to internal and external stresses, freeze/thaw action, material aging, etc.
- thermal performance degradation due to moisture or water incursion, sedimentation and freeze/thaw action (exterior insulations), delamination
- soil subsidence next to the foundation, and clogging of the drainage sub-system
- attack from soluble salts (concrete-based systems, in soils with high salt concentrations)
- mould and fungal attack (systems which include untreated wood or paper products)

These lead to durability criteria that should be added to the performance requirements list, as shown in Chart 1.4.

One of the key characteristics of a durable basement envelope system is the arrangement of materials to achieve multiple lines of protection. This multiple-protection strategy has been alluded to throughout Part 1 and it is a ‘system’ strategy to achieve durability. Within the system, there are ‘front-line’ materials taking the brunt of environmental loadings; ‘second-line-of-protection’ materials which are not subjected to full environmental loads but are ready to function when called upon; and finally, the other materials which satisfy the other functions. Because the second-line-of-protection materials are somewhat protected, they can be counted on to perform over a much longer period of time. When there is no second line of the protection, all of the durability requirements are loaded into the front line materials. Thus, not only must these be durable, they must be so in the worst conditions.

Because the durability requirements of the system and materials are interrelated, these factors will be addressed in Parts 2 and 3, in the context of actual systems.

Sub-Functions	Main Functional Requirements (Defining the sub-systems of the envelope)	Components Involved	Performance Criteria of the Sub-system	Durability Criteria
Isolation of the moisture-sensitive superstructure from groundwater	Break capillary action, and provide surface water drainage	Dampproofing, or waterproofing or air gap system, and drainage system	Maximum water permeability; drainage capacity	Maintained impermeability; resistance to cracking, delamination of joints etc. Freeze/thaw resistance of the structure
Superstructure support and anchoring	Resist vertical and lateral (wind and seismic) loads; transfer load evenly to soil.	Structural elements of the walls, columns and footings.	Transfer loads such that strength of materials and soil bearing capacities are within safety limits	Resistance to cracking, shifting and deflection, chemical and biological attack
Protection of the superstructure from differential movement due to frost action and soil expansion	Frost penetration control; provision of soil drainage; soil/wall adhesion control; resist or accommodate soil movement due to frost or moisture	Footings, foundation insulation and wall soil interface, backfill and drainage system.	Depth of footings; insulation , location and coverage; drainage capacity; backfill type	Resistance to lateral and uplifting forces, and freeze/thaw action
Effective environmental separation	Earth retention, resistance to bulk water, self-support and support of other components of the envelope system	Walls, slab, lateral supports	Transfer loads such that strength of materials and soils are within safety limits	Resistance to lateral and uplifting forces, and freeze/thaw action
	Control of heat loss	Walls, slab, insulation, air barrier system, and related supporting, protective, and finishing elements	Effective thermal resistance, including thermal bridging, and 3-dimensional heat transfer and storage in soil.	Control of thermal degradation due to moisture effects and/or exposure (exterior insulation)
	Control of air leakage including soil gas	Air barrier system including soil gas barrier or soil gas control system	Air permeability, degree of continuity, structural sufficiency	Control of cracks, tears, lack of fit at corners & joints
	Control of interior and exterior moisture flow, and surface condensation	Vapour barrier, dampproofing, insulation and structural elements, air barrier	Threshold moisture contents of all materials, duration and material tolerance	Sustained low water vapour permeability
	Control of embodied moisture	Structural elements, vapour barrier, dampproofing, insulation	Threshold moisture contents of all materials, duration and material tolerance	Maintain long-term equilibrium moisture content below critical levels
	Control of rainwater and groundwater	Above-ground components, ground/wall interface, backfill, drainage layer, drain tile, connections to sewer	Accumulated water and moisture contents of all materials, duration and material tolerance	Maintenance of design drainage flow rates, resistance to clogging; resistance to tearing or delamination of waterproofing layer

Chart 1.4 Adding durability criteria to structural and environmental separation performance requirements.

1.5 Mechanical System Functions

As stated previously, mechanical systems actively control the indoor environment, supplementing the level of control provided passively by the building envelope. Performance criteria for mechanical systems are set out in Chart 1.5.

SUB-FUNCTION	MAIN FUNCTIONAL REQUIREMENTS	COMPONENTS INVOLVED	PERFORMANCE CRITERIA OF THE SUB-SYSTEM
Control of indoor conditions	Heating	Heating system, distribution and control	Acceptable control of sensible temperature in all basement zones
	Cooling	Air conditioning systems, distribution and control	Acceptable control of sensible temperature in all basement zones
	Ventilation, sub-slab ventilation	Ventilation systems, fans and flues	Acceptable indoor air quality in all basement zones
	Air circulation	Fans, ducts and louvres	Acceptable comfort and indoor air quality in all basement zones
	Humidification, dehumidification	Equipment and controls	Acceptable control of relative humidity in all basement zones
	Control of water sources	Gutters, slab slopes and materials, drains, pits or sumps	Acceptable control of bulk water within all basement zones
	Control of pollutants	Surface finishes, occupants and habits	Acceptable level of pollutant emissions within all basement zones

Chart 1.5. Performance criteria for the mechanical functions.
(expanding on Chart 1.1, for the environmental separation functions)

The last two functional requirements in Chart 1.5 are not purely mechanical system components, but may be related to items such as potable water, or hydronic heating system fluids. The control of water sources occurring within the basement is a critical consideration, for example, in situations where a water pipe bursts or leaks. Water must be effectively conveyed to an outlet to prevent its accumulation and damage to materials and furnishings within the basement. The control of pollutants involves many factors including materials, surface finishes, combustion equipment, the occupants and their lifestyle (habits). Material and finish selection is within the realm of the designer; however, occupant lifestyles may only be addressed through public education.

Durability functions for mechanical systems are not explicitly addressed within these guidelines, as these have often been addressed through industry standards, competition in the marketplace and manufacturers' warranties. Unlike the building envelope, which is generally expected to remain serviceable throughout the useful life of the dwelling, mechanical systems are typically designed for periodic replacement.

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PART 2 - BASEMENT ENVELOPE SYSTEM SELECTION

2.0 Overview

This part of the guidelines explains the process of selecting an appropriate basement envelope system. A variety of basement system configurations are available to satisfy any given set of performance requirements. In order to select a compatible and well-performing "package" of control function elements, a "systems approach" is advisable. Aside from its efficiency in eliminating unsuitable options from the selection process, this approach ensures that criteria are considered consciously and then integrated explicitly. Figure 2.1 depicts a schematic of the "systems approach" process to basement envelope system selection.

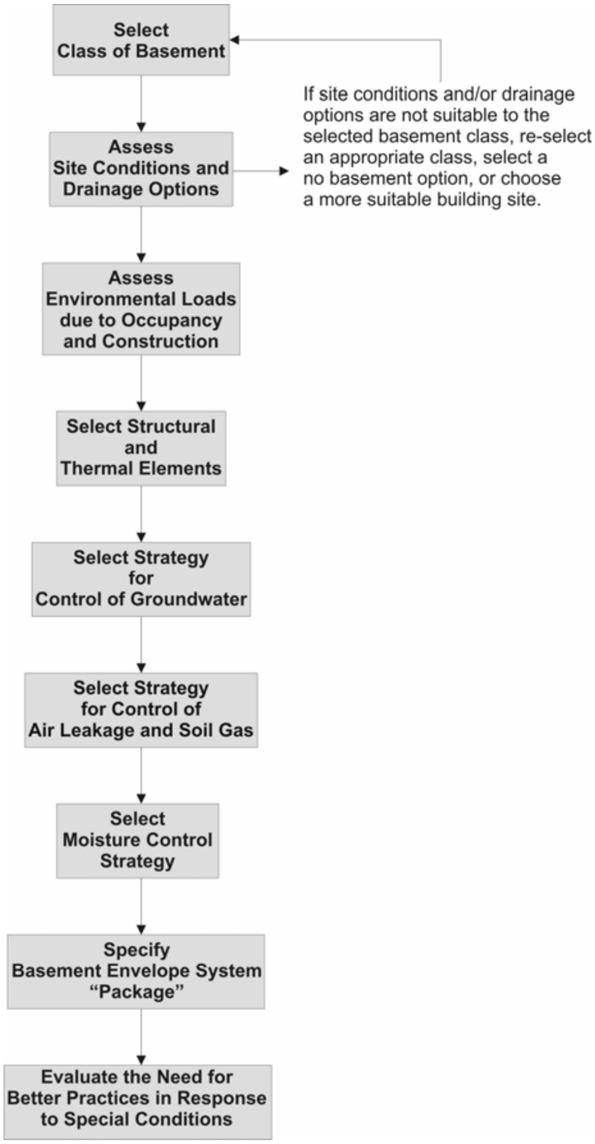


Figure 2.1 Process schematic for "systems approach" to basement envelope system selection and specification.

Before proceeding with a discussion of each step in the process advocated by these guidelines, it is important to review and keep in mind the critical control functions and their role in the basement envelope system.

- ***Structure*** – control of gravitational, lateral (soil), seismic and hydrostatic loads
- ***Foundation Drainage or Waterproofing*** – control of bulk water (groundwater)
- ***Moisture Protection*** – control of capillary water, vapour diffusion and air leakage (air-transported water vapour)
- ***Thermal Protection*** – control of heat flow (conduction, convection, radiation and air leakage)
- ***Contaminant Protection*** – control of soil gas entry into enclosure (coupled to air leakage control)

Table 2.1 summarizes the control strategies available for each of the physical mechanisms associated with critical control functions.

CONTROL FUNCTION	PHYSICAL MECHANISM	CONTROL STRATEGY
STRUCTURAL LOAD RESISTANCE	***Gravity*** ***Active Soil Pressure*** ***Hydrostatic Pressure***	☐ Gravity Load Distribution (footings) ☐ Flexural and Shear Resistance (foundation walls) ☐ Load Sharing (inter-assembly connections)
MOISTURE MIGRATION	***Bulk Water***	☐ Shedding ☐ Shielding ☐ Conveyance ☐ Drainage ☐ “Perfect” Barrier ☐ Pressure Equalization (rainscreen principle)
	Capillary Water	☐ Capillary Barrier ☐ Capillary Break (gap)
	Vapour Diffusion	☐ Vapour Barrier ☐ Thermal Insulation
	Air Leakage	☐ Air Barrier ☐ Thermal Insulation
HEAT TRANSFER	***Conduction, Radiation***	☐ Thermal Insulation
	Convection	☐ Air Barrier
AIR LEAKAGE	***Stack, Wind, and Mechanical Effects***	☐ Air Barrier
SOIL GAS	***Air Leakage***	☐ Air Barrier ☐ Sub-Slab Depressurization
SOLAR RADIATION	***Radiative Heat Transfer***	☐ Orientation ☐ Fenestration ☐ Shading Devices ☐ Thermal Insulation ☐ Glazing Reflectance and Emissivity
	Visible Light Transmission	☐ Orientation ☐ Fenestration ☐ Glazing Shading Coefficient ☐ Shading Devices

Table 2.1 Available control strategies to address control functions and related physical mechanisms.

2.1 Selecting a Class of Basement System

The class of basement system, as described in Table 1.2, is typically selected given the following considerations:

1. Market preferences and demand;
2. Local by-laws, which may restrict certain classes of basement (e.g., separate dwelling unit); and
3. Site conditions that may prove unsuitable for classes of basements intended to provide livable space.

A key consideration in selecting a basement class is the anticipated future use of the basement space and the associated cost of upgrading the basement envelope in the event occupants wish to make the space livable. The Class A-3 basement represents the lowest-cost option that enables homeowners to elect a worry-free upgrade of all or part of the basement into livable space. Class C basements are usually convertible at a significantly higher premium, unless site grading and soil conditions are ideal, and inherently provide many of the control functions associated with specific materials used in Class A basement construction (e.g., drainage layer).

After a class of basement is selected, it is important to carefully review site conditions to ensure that the selection is feasible and economical. This key process is discussed in Section 2.2.

2.2 Assessing Site Conditions

After selecting a class of basement, it is important to assess site conditions and drainage options to determine whether or not the desired basement class is feasible. Conditions which pose a risk of moisture migration (water leakage, flooding or sewer backup) into the basement should generally discourage Class A basement construction unless special measures are applied.

Climate and Weather

Climate describes the long-term, seasonal pattern of weather in a particular location. Canada has six general climatic regions: Arctic, Northern, Pacific, Cordillera, Prairie and Southeastern. Within each climatic region, significant variations in weather can occur. Selected weather data are provided in the National Building Code of Canada, providing a useful summary of extreme temperatures, annual precipitation, and peak rainfall intensities. Further information is available from the Canadian Meteorological Centre, which lists climate normals for most Canadian locations. In many cases, local authorities and practitioners can provide helpful information regarding factors such as depth of frost penetration, particularly in unusual soil deposits. Climate and weather information may be used to anticipate extreme or chronic weather phenomena.

Topography

A building site is affected by the local topography or lay of the land. Building on top of a hill, on the side of a slope, or at the bottom of a depression or ravine all have implications on basement system design. Usually, basements constructed on a height of land enjoy effective drainage of the site. Buildings located on the side of a slope may be exposed to large quantities of runoff during periods of rain or snowmelt. Basements constructed in low-lying areas may experience exposure to water accumulations and difficulty with the effective drainage of the foundation.

Municipal Services

The type and availability of municipal services for conveying storm water impact the design and construction of the basement system. In areas with separate storm sewers located lower than the bottom of the foundation excavation, conventional foundation drainage is permissible. When these are located above the bottom of the foundation excavation, a sump pump may be required to remove water from around the foundation. In older municipalities, with combined sewers (storm and sanitary share one pipe), consideration should be given to sewer backup and to available measures for effectively minimizing the risk where backup is known to occur. Areas without municipal sewers require suitable drainage infrastructure to be provided by the builder. Figure 2.2 depicts several foundation drainage conditions and corresponding strategies.

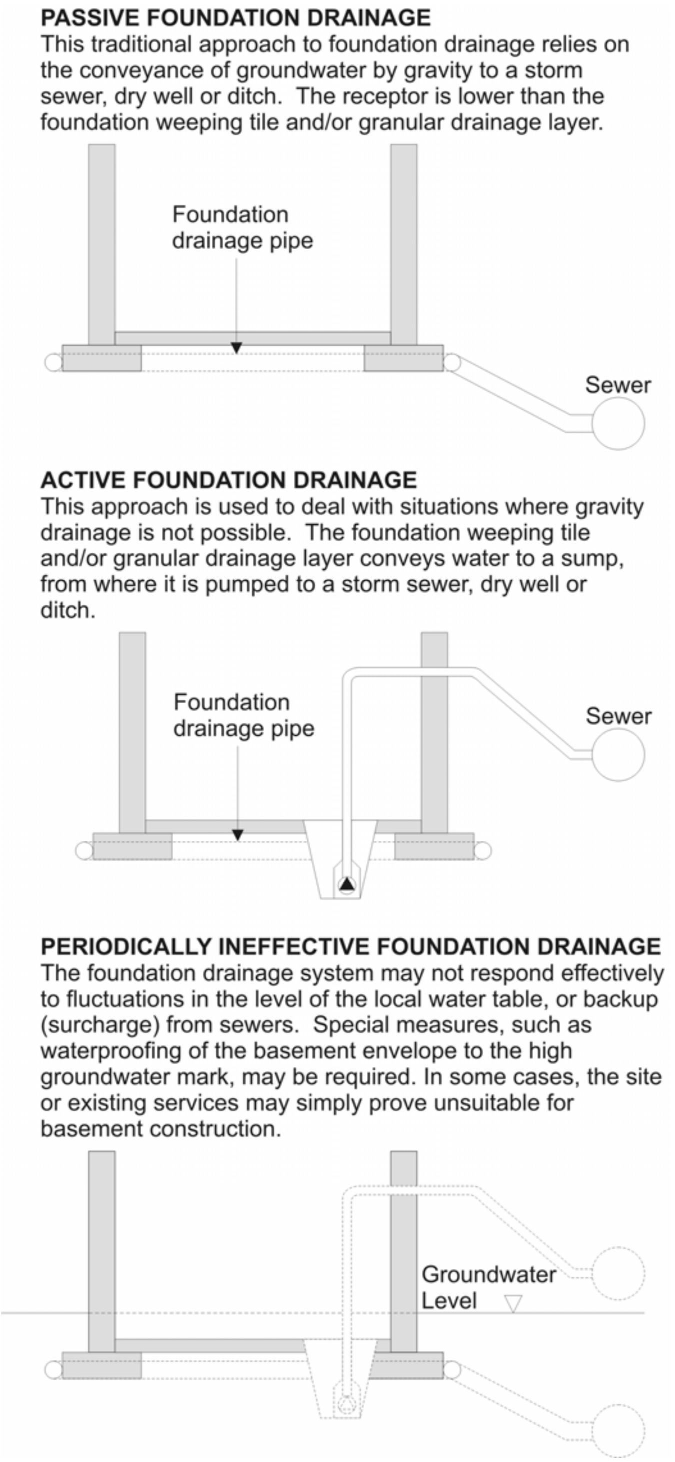
Soil Conditions (drainage characteristics)

In well-draining soils, water in the soil around the basement percolates downward at a rate sufficient to avoid accumulation around the foundation (hydrostatic pressure). In ideal, well-draining soils, the soil surrounding the basement is, in effect, the foundation drainage system. As the drainage capacity of the soil diminishes, water accumulation is possible even when a conventional foundation drainage system is installed. Clay soils may be practically impervious to water, requiring the foundation drainage system to deal with all of the water migrating around the basement. When silty soils are encountered, the risk of fine soil particles plugging the foundation drainage system must be considered. Soil conditions also influence the design and construction of structural elements of the basement system.

High Water Table

Groundwater levels which are constantly or periodically higher than the bottom of the foundation excavation may require waterproofing of the basement envelope, de-watering by sump pumps, or both measures to adequately address this phenomenon. A high water table will also affect the design and construction of structural components of the basement.

Based on the above assessments, special measures may be required, or the class of basement initially selected may have to be revised, to reflect practical and economic constraints.



PASSIVE FOUNDATION DRAINAGE

This traditional approach to foundation drainage relies on the conveyance of groundwater by gravity to a storm sewer, dry well or ditch. The receptor is lower than the foundation weeping tile and/or granular drainage layer.

ACTIVE FOUNDATION DRAINAGE

This approach is used to deal with situations where gravity drainage is not possible. The foundation weeping tile and/or granular drainage layer conveys water to a sump, from where it is pumped to a storm sewer, dry well or ditch.

PERIODICALLY INEFFECTIVE FOUNDATION DRAINAGE

The foundation drainage system may not respond effectively to fluctuations in the level of the local water table, or backup (surcharge) from sewers. Special measures, such as waterproofing of the basement envelope to the high groundwater mark, may be required. In some cases, the site or existing services may simply prove unsuitable for basement construction.

Figure 2.2 Foundation drainage conditions and strategies.

2.3 Assessing Occupancy and Construction-Related Interior Environmental Loads

Environmental loads generated within buildings include heat, moisture, and contaminants, both organic and inorganic. Safety requirements for heating appliances normally deal with clearance of combustibles and hence the shielding of the interior envelope from exposure to extreme temperatures. Code requirements for ventilation are intended to deal with normal rates of moisture production, but, there are no specific provisions for abnormally high moisture loads caused by the occupants or generated by materials used in construction of the basement envelope. The control of contaminants, other than soil gases, is beyond the scope of the code and remains the responsibility of the occupants who should exercise care and take appropriate measures to deal with activities employing corrosive chemicals or generating harmful gases.

Public education regarding responsible occupancy of buildings remains beyond the scope of these guidelines. Hence, this section is confined to occupancy and construction-related moisture loads. Occupancy and construction-related moisture loading of basements can vary significantly and require special considerations in the design of basements.

Designers and builders should carefully consider the following factors when selecting an appropriate basement system to avoid moisture problems which typically occur within the first year of building occupancy, but can be extended when combined with high occupant-related moisture production.

Aspects of occupancy to consider include storage of wet materials (e.g., firewood) and lifestyle facilities. Saunas, steam baths, hot tubs and indoor pools are among the lifestyle facilities that can result in unusually high rates of moisture production within the basement space. In some cases, frequently used cooking, laundry and bathing facilities can also contribute to high moisture levels in the basement. Many of these occupant-related sources of moisture cannot be predicted at the design stage. There also exists a high likelihood that occupancy will change with household demographics and ownership. The provision of adequate mechanical ventilation and non-absorptive surface finishes represent reasonable preventive measures.

Construction-related moisture is a “one-shot” affair. It is more predictable than ongoing occupancy-related phenomena, and can be more effectively addressed through the proper selection of materials and assemblies. In general, cast-in-place concrete foundations have the potential to impose the highest initial moisture load on the interior basement environment unless the path for drying to the outdoors is of much less resistance than the path for migration to the indoors. Studies indicate that cast-in-place concrete basements can liberate significant quantities of water as the concrete continues to cure during the one-year period after construction. The use of concrete masonry units (CMUs) can significantly reduce this condition provided the units are properly stored and the foundation does not experience prolonged exposure to precipitation. It should be noted that grouted CMUs may be assumed to behave in a similar manner to cast-in-place concrete in terms of moisture production.

Permanent wood foundations, precast concrete panels, insulating concrete forming systems and structural insulating panels are considered to have a very low, if any, contribution to construction-related moisture loading of the basement indoor environment. However, factors such as improper storage and protection from the elements, along with construction during wet weather conditions can render these assemblies significant contributors to moisture loading.

The selection of thermal and moisture measures to address these concerns is further discussed in following sections.

2.4 Selecting the Structural and Thermal Elements (Full Basements)

Function: *To support the structure, resist all vertical (gravity), lateral (soil), seismic and hydrostatic loads, and control heat transfer.*

Although it may be customary to make separate, independent decisions when selecting the structural and thermal components of the basement envelope system, these basic decisions have such an impact on one another that they should be made jointly in a single step. Several basement construction systems currently on the market are clearly based on the fundamental recognition that these two sub-systems together define, to a very large degree, the external forces to which the structural and thermal materials can be subjected. This decision also influences the role of other components needed to satisfy all control functions.

Factors affecting the selection of the structural and thermal elements include: availability of materials; availability of appropriately skilled labour; time of construction (seasonality); market preference (class of basement); and local practices.

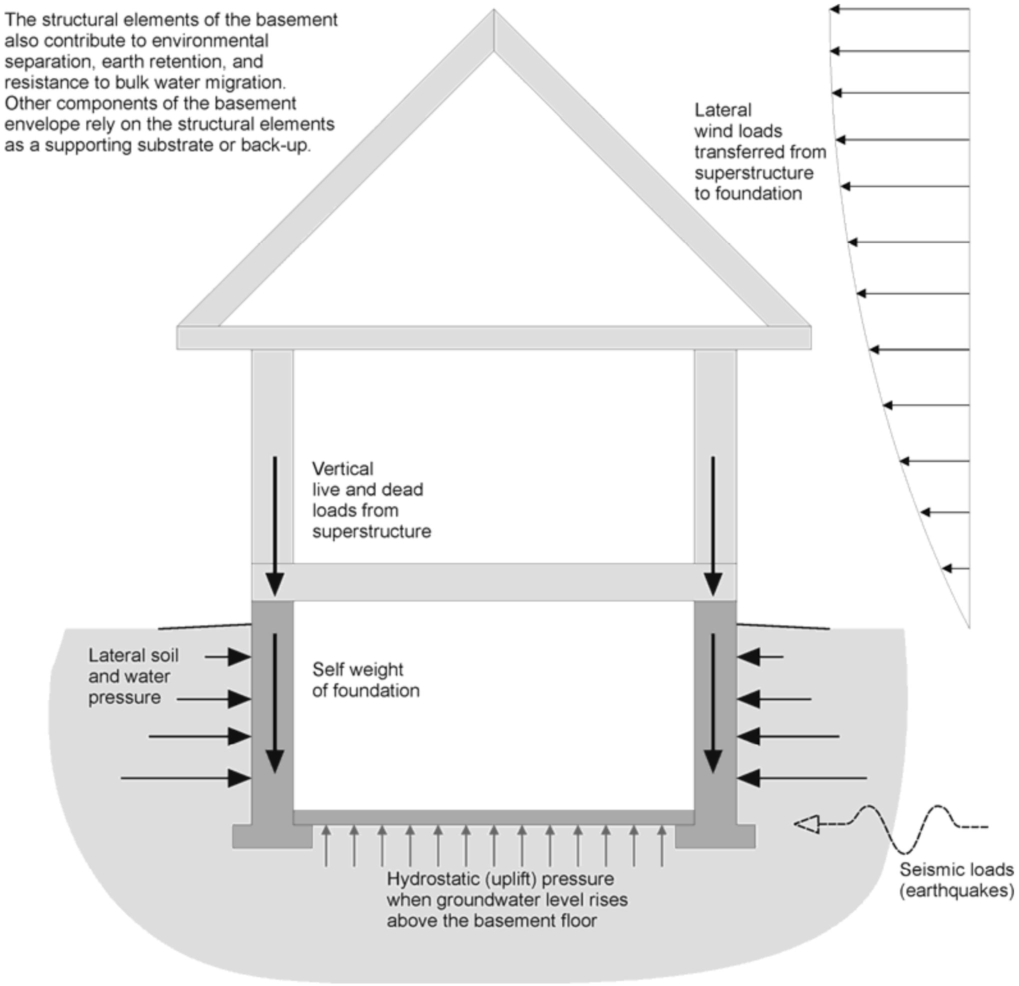


Figure 2.3 Role of the basement structural elements.

Traditionally, basements fulfilled the structural roles depicted in Figure 2.3. In modern practice, basement envelope systems are usually described according to their structural and thermal elements. For example, the generic term "*cast-in-place concrete foundation with full-height, interior insulation,*" describes numerous alternatives for basement envelopes of this type. Figure 2.4 depicts the currently available structural and thermal element combinations for residential basement construction in Canada.

Typical arrangements of structural and thermal elements currently available for residential basements are depicted below. These may be constructed with or without insulated floor-on-grade assemblies.

The basement structure may comprise:

- cast-in-place concrete;
- concrete masonry units;
- precast concrete panels
- extruded or expanded polystyrene insulating concrete forms (ICFs);
- conventional permanent wood foundations (PWFs); or
- structural insulating panels (SIPs).

Note that the uninsulated basement is not depicted. For partial height insulation options, only the exterior arrangement (below-grade only) and the interior arrangement (typically above-grade to 600 mm or 2 feet below-grade) normally apply.

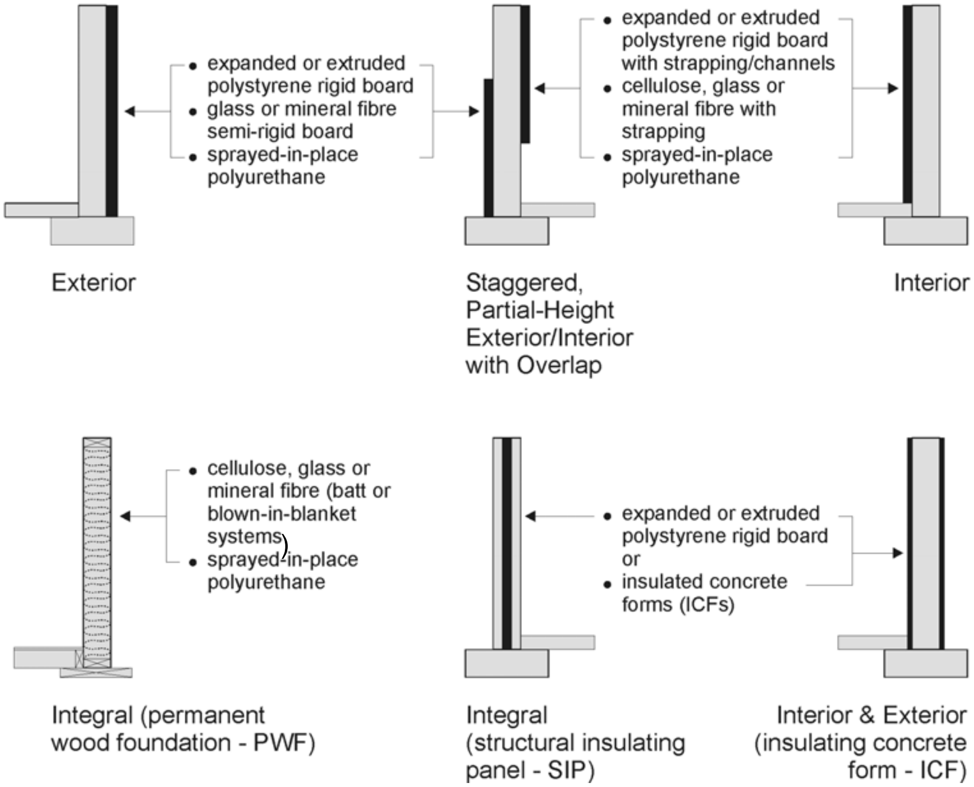


Figure 2.4 Generic combinations of structural and thermal elements for basements.

From Figure 2.4, it is noted that currently six generic combinations of structural and thermal elements are available in Canada.

1. Exterior – insulation on the outside of the structural element;
2. Interior – insulation on the inside of the structural element;
3. Staggered – partial height insulation on the inside and outside of the structural element, typically with an overlap;
4. Integral PWF – permanent wood foundation with insulated cavity;
5. Integral SIP – structural insulating panel (permanent wood or precast concrete) with an insulated core; and
6. Interior and Exterior ICF – insulated concrete forming system with insulation on both sides of the structural element.

A seventh option consists of an uninsulated foundation structure, which does not explicitly address the thermal control function. In the six combinations described above, thermal insulation coverage options include:

a) All of the wall (full coverage);
b) Almost all of the wall (e.g., a gap of 200 mm is left uninsulated at the bottom, typically for interior insulation placement); and
c) Part of the wall (insulated to 600 mm below grade, typically for interior insulation placement).

An additional factor to be considered is the initial wetness of construction materials used. The term “dry construction” refers to the use of materials in the construction process that have already substantially reached their equilibrium moisture contents (e.g., precast concrete panels, PWF and other kiln-dried lumber, etc.). Practically speaking, “wet construction” refers to systems containing water in excess of the equilibrium moisture content (e.g., cast-in-place concrete, concrete masonry units with grouted cores, conventional lumber, wet-spray insulation applications, etc.). When planning for a properly functioning envelope, conventional lumber is presumed to be “wet” because it often is. This fact should be considered when other control elements are being addressed.

The available combinations of options have been summarized as columns in the following table, including labels for use in the selection of the basement system ‘package’.

STRUCTURE	INSULATION PLACEMENT	INSULATION COVERAGE	CONSTRUCTION MOISTURE
CIP – cast-in-place concrete	**EXT** - exterior	**F** – full coverage	**W** – wet construction
CMU – concrete masonry unit	**INT** - interior	**FG** – 200-mm (8-inch) gap uninsulated at bottom of otherwise fully covered wall	**D** – dry construction
PCP – precast concrete panel	**STG** – staggered interior and exterior	**P** – partial coverage, typically above grade and extending to 600 mm (24 inches) below grade	
PWF – permanent wood foundation	**ITG** – integral (PWF & SIP only)	**N** – no insulation provided	
SIP – structural insulating panel	**ICF** – insulating concrete form		

Table 2.2 Available options for control functions associated with structure and insulation.

It is important to note that not all combinations of column options of the above four parameters are practical or feasible. Some combinations are exclusive and/or imply default parameters. For example, any cast-in-place concrete structure implies wet construction, unless the concrete is allowed sufficient time to cure. PWF structures may be dry construction if the wood is properly protected from moisture in storage and during construction, but could otherwise be wet. Structural insulating panels by default employ integral insulation placement, full-depth coverage and dry construction. When an ICF system is selected, cast-in-place concrete (wet construction) is implied along with full coverage. The rational combination of these options is further discussed in Section 2.8.

Examples of how the labelling system is used to describe various structure/insulation combinations is demonstrated below.

CIP/INT/F/W – cast-in-place concrete structure with interior, full-height insulation, wet construction

PWF/ITG/FG/D – permanent wood foundation with integral, full-height insulation (except for gap at bottom), dry construction

PCP/STG/F/D – precast concrete panel, staggered, full-height insulation (exterior insulation below grade, interior insulation above grade to 600 mm below grade), dry construction

To select one of these approaches, a builder must ultimately be satisfied that the selected system will meet the construction and market-related functions mentioned in Table 1.1. However, the selection of the system sets the stage for the selection of materials in order to address all of the performance-related functions listed in Table 1.1. These must be evaluated in turn before an informed assessment can be made.

To select one of the six (and in some cases, seven) available approaches, a designer/builder must ultimately be satisfied that the selected system will meet the construction and market-related functions outlined in Table 1.1. In turn, each of these generic combinations implies additional measures to satisfy the performance-related functions listed in Table 1.1. The following sections deal with available options for achieving the critical control functions corresponding to site conditions, occupancy and construction-related environmental loads and the class of basement system initially selected.

2.5 Options for Control of Groundwater: Drainage Versus Waterproofing

There are currently two available strategies for dealing with surface and groundwater around the basement:

1. Continuous and effective wall drainage, interconnected to a planned and compatible drainage system, to prevent accumulation of water against the outer surfaces of the envelope (walls and floor slab): exterior drainage and dampproofing.
2. Full and continuous barrier to water penetration: waterproofing.

(**Note:** *Interior drainage systems which deal with water once it has fully penetrated the envelope are under development and demonstration, but do not represent significant market uptake to warrant inclusion at the time of guidelines publication.*)

Each one of the two approaches requires specialized materials and design details to make them work. What differentiates these approaches are the materials chosen to make up three optional layers that form part of the envelope system: the *drainage layer*, the *dampproofing layer* and the *waterproofing layer*.

Drainage Layer

Function: *To drain surface and groundwater away from the envelope, and ultimately away from the property.*

DRAINAGE	
EDR	Explicit exterior drainage, handled by air spaces formed by fibrous or rigid materials, backed by a continuous structural element (2 lines of protection – the space, and envelope/drainage medium interface).
IDR	Implicit exterior drainage, handled by backfill (draining soil). The dampproofed, continuous structural element is the single line of protection (i.e., a 'face-seal' system).
NDR	None (i.e., waterproofed instead).

Table 2.3 Available options for control functions associated with drainage.

Dampproofing Layer

Function: *To isolate water-absorbing materials from contact with water.*

DAMPPROOFING	
FDP	Full below-ground wall, exterior and interior coverage (the interior layer is a 2nd line of defence for other materials within the envelope)
EDP	Full wall, exterior coverage only, below ground
PDP	Exterior wall coverage, 300 mm up from the footing only (this is a new option being proposed)
NDP	None (e.g., no water-absorbing materials are in direct contact with ground or water)

Table 2.4 Available options for control functions associated with dampproofing.

Figure 2.5 depicts the drainage approach to the control of groundwater. This is a more traditional means of dealing with groundwater, and involves careful consideration of water shedding, shielding and conveyance to minimize the loads on the foundation drainage system. However, site conditions, such as those depicted earlier in Figure 2.2, and factors such as fluctuating groundwater tables must be considered when this approach is selected. It is not a recommended approach in areas with high water tables and poorly draining native soils.

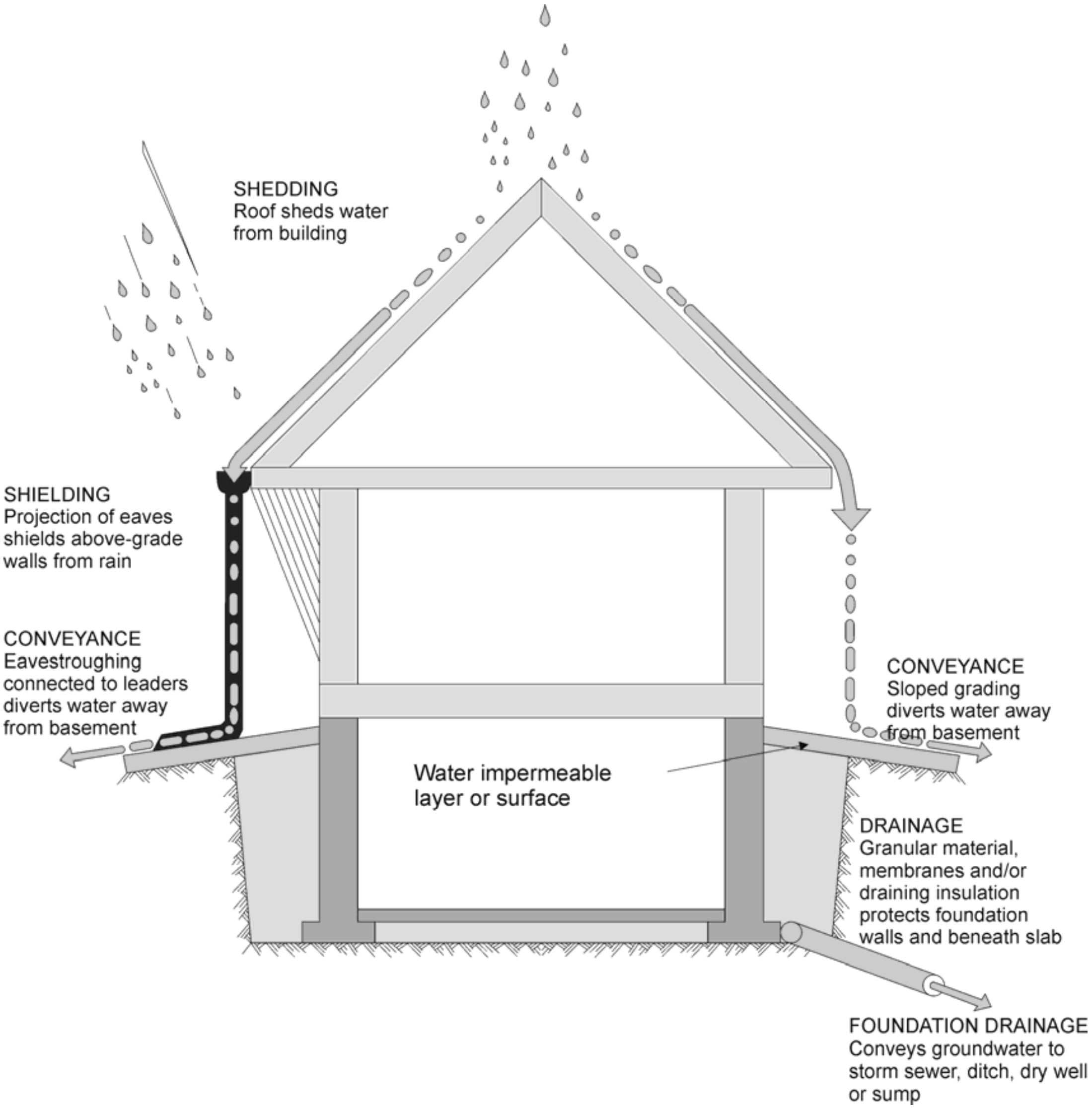


Figure 2.5. Drainage approach to control of groundwater.

Critical aspects of the drainage approach include:

- **Surface Drainage** – conveying water away from the foundations of the basement and any attached structures, such as garages or cold cellars.
- **Drainage Pipe Systems** – ensuring that drain pipes are provided with a positive grade so they will not become plugged with fine soil particles over time.
- **Connection to Municipal Sewers or Surface Water Discharge** – properly connecting the foundation drainage system to the municipal services, or providing appropriate infrastructure on site.

When some of these aspects prove problematic, a waterproofing approach may be advisable.

Waterproofing Layer

Function: *To keep surface and groundwater out of the envelope and livable space. Implicitly, drainage will also occur with this option. However, it is assessed that the particular conditions are challenging and that the drainage will be defeated on a regular basis, and hence the need for waterproofing.*

WATERPROOFING	
FWP	Full and continuous waterproofing of below-grade elements.
PWP	Waterproofing to a specified distance above footing only, in combination with the drainage option.
NWP	None (i.e., drainage and appropriate dampproofing provided instead).

Table 2.5 Available options for control functions associated with waterproofing.

The waterproofing approach to the control of groundwater is preferred when the site conditions result in periodically or chronically ineffective foundation drainage. Typically, waterproofing is performed by specialty contractors employing proprietary systems and is not recommended for installation by unqualified persons. From a designer or builder perspective, it is important to ensure that structural allowance for hydrostatic pressures has been considered and appropriate measures have been taken during construction of the structural elements.

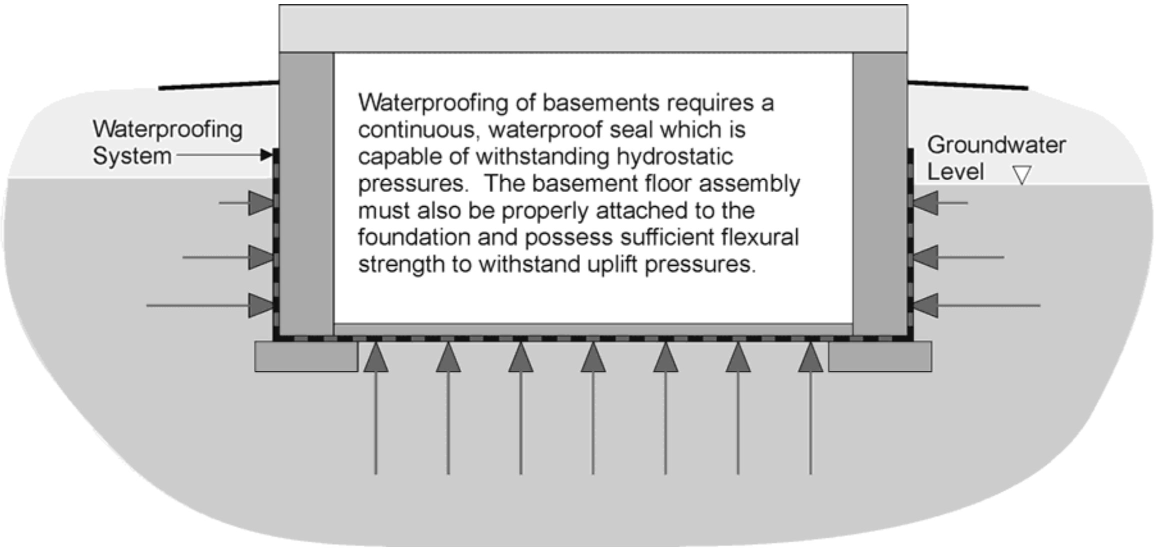


Figure 2.6. Waterproofing approach to control of groundwater.

2.6 Options for Controlling Air Leakage and Soil Gas

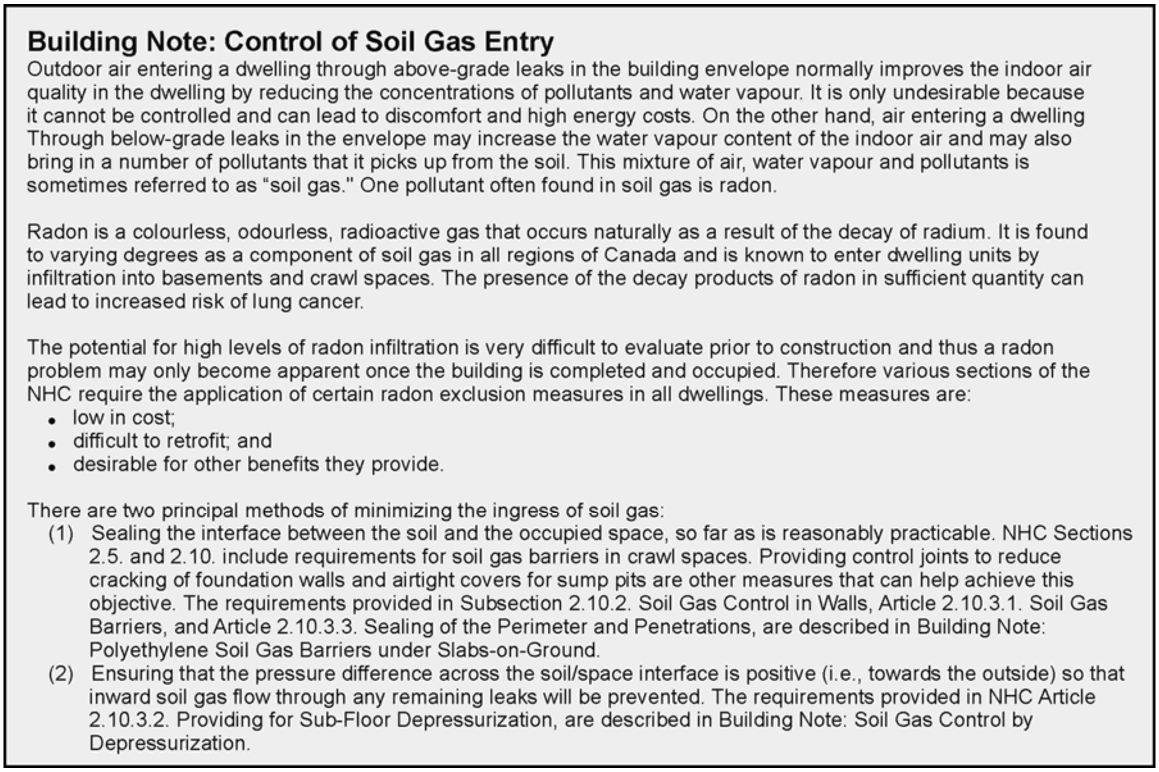
Function: *To control air leakage and soil gas flow across the envelope, and to control interstitial air convection.*

Some of the options available to control soil gas are listed below. The degree of complexity chosen to effectively control soil gas will depend on local soil conditions identified by the authority having jurisdiction.

AIR LEAKAGE AND SOIL GAS CONTROL	
IAB	Continuous system of air-impermeable sheets, membranes or rigid elements of the envelope joined at all edges, corners and penetrations – placement interior of the insulation.
EAB	Continuous system of sheets or membranes or rigid elements of the envelope joined at all edges, corners and penetrations – predominant placement exterior of the insulation.
HAB	Hybrid air leakage and soil gas barrier combining interior and exterior placement of seals.
NAB	No explicit air leakage and soil gas control provided.

Table 2.6 Available options for control functions associated with air leakage and soil gas control.

The following information on the control of soil gas entry has been excerpted from the *National Housing Code of Canada 1998 and Illustrated Guide*.



Building Note: Control of Soil Gas Entry

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 and can lead to discomfort and high energy costs. 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 that 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 the NHC require the application of certain radon exclusion measures in all dwellings. These measures are:
- low in cost;
- difficult to retrofit; and
- desirable for other benefits they provide.

There are two principal methods of minimizing the ingress of soil gas:
(1) Sealing the interface between the soil and the occupied space, so far as is reasonably practicable. NHC Sections 2.5. and 2.10. include requirements for soil gas barriers in crawl spaces. Providing control joints to reduce cracking of foundation walls and airtight covers for sump pits are other measures that can help achieve this objective. The requirements provided in Subsection 2.10.2. Soil Gas Control in Walls, Article 2.10.3.1. Soil Gas Barriers, and Article 2.10.3.3. Sealing of the Perimeter and Penetrations, are described in Building Note: Polyethylene Soil Gas Barriers under Slabs-on-Ground.
(2) Ensuring that the pressure difference across the soil/space interface is positive (i.e., towards the outside) so that inward soil gas flow through any remaining leaks will be prevented. The requirements provided in NHC Article 2.10.3.2. Providing for Sub-Floor Depressurization, are described in Building Note: Soil Gas Control by Depressurization.

Building Note: Polyethylene Soil Gas Barriers under Slabs-on-Ground

Floors-on-ground serving all types of occupancies other than garages must be constructed to reduce the potential for entry of radon or other soil gases. In most cases, this will be accomplished by placing 0.15 mm (6 mil) polyethylene under the floor.

Finishing a concrete slab placed directly on polyethylene can, in many cases, cause problems for the inexperienced finisher. A rule of finishing, whether concrete is placed on polyethylene or not, is to never finish or "work" the surface of the slab while bleed water is present or before all the bleed water has risen to the surface and evaporated. If finishing operations are performed too early, such as before all the bleed water has risen and evaporated, surface defects such as blisters, crazing, scaling and dusting can result. This is often the case with slabs placed directly on polyethylene. The amount of bleed water that may come to the surface and the time required for this to happen is increased from that of a slab placed on a compacted granular base. The excess water in the mix from the bottom portion of the slab cannot bleed downward and out of the slab and be absorbed into the granular material below, because of the polyethylene. Therefore, all bleed water, including that from the bottom of the slab, must now rise through the slab to the surface. Quite often in such cases, finishing operations are begun too soon and surface defects result.

One solution that is often suggested is to place a layer of sand between the polyethylene and the concrete. However, this is not an acceptable solution for the following reason: it is unlikely that the polyethylene will survive the slab pouring process entirely intact. Nevertheless, the polyethylene will still be effective in retarding the flow of soil gas if it is in intimate contact with the concrete; soil gas will only be able to penetrate where a break in the polyethylene coincides with a crack in the concrete. The majority of concrete cracks will probably be underlain by intact polyethylene. On the other hand, if there is an intervening layer of a porous medium such as sand, soil gas will be able to travel laterally from a break in the polyethylene to the nearest crack in the concrete and the total system will be much less resistant to soil gas penetration.

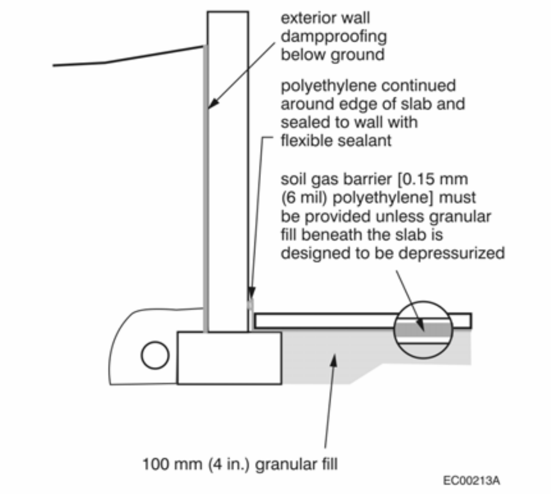


Figure 2-37
Soil gas barrier for concrete walls

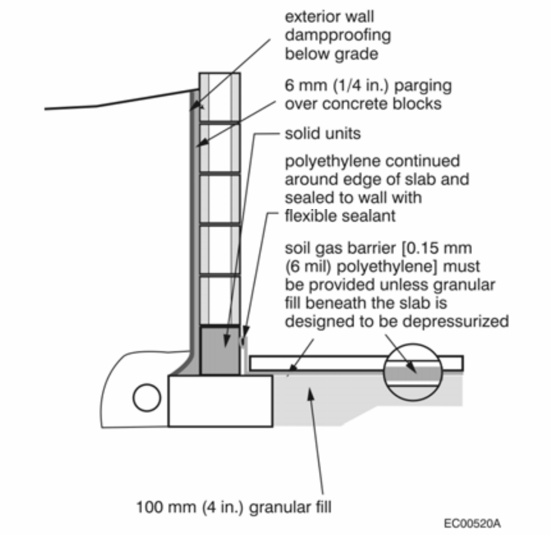


Figure 2-38
Soil gas barrier for unit masonry walls

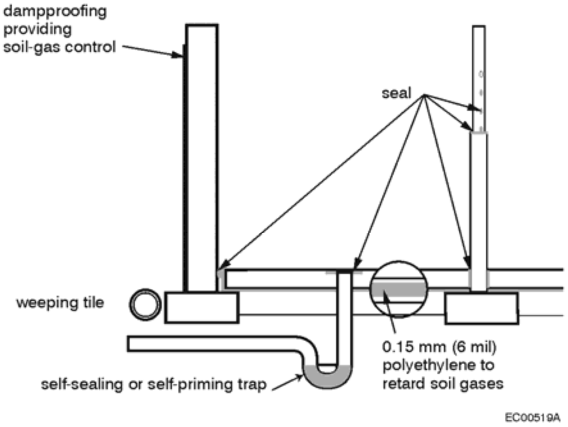


Figure 2-39
Sealing floor perimeter and penetrations

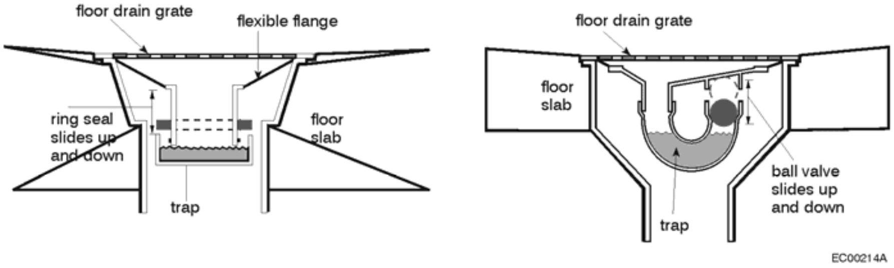


Figure 2-40
Floor drains

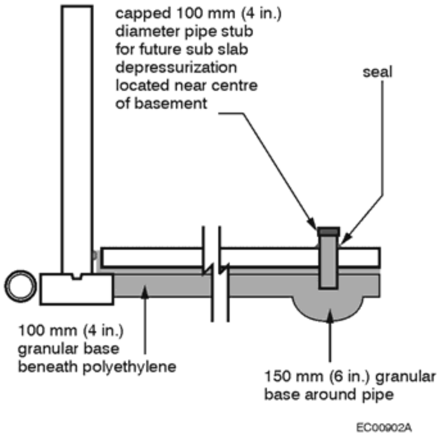


Figure 2-41
Sub-floor depressurization

Building Note: Soil Gas Control by Depressurization

As noted in Building Note: Exclusion of Soil Gas, one method of excluding soil gas from below-grade living space is to ensure that the pressure difference across the soil/space interface is positive (i.e., towards the outside) so that inward soil gas flow through any leaks will be prevented. This requires consideration of the air pressure on the inside of the envelope and the pressure within the soil. Each is affected by quite different factors.

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, as discussed in Building Note: Combustion Air and Tight Houses, in Section12.1.of this Guide. It also follows from the need to avoid drawing in soil gas, as discussed in Building Note: Exclusion of Soil Gas.

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.

Sub-floor depressurization systems have been found to be very effective for controlling soil gas entry into houses. At least in areas that are prone to higher than normal radon levels, or other ground pollutants, this practice is recommended.

NHC Article 2.10.3.2. provides for depressurization as an alternative to the installation of polyethylene below floor slabs. Using this option, a vent pipe for use with a sub-floor depressurization system is installed through the floor but is only connected if soil gas levels are found to be excessive.

Radon testing must be performed on the house and copies of the results provided to the homeowner and the authority having jurisdiction. Since the radon level in a house can vary significantly during the year, the test should be of sufficient duration to provide a reasonable indication of the concentration. The minimum period for testing should be three months or as recommended by the authority having jurisdiction. The preferred testing location is centrally in the basement or the main floor for houses without basements.

The current Canadian Action Level for radon, as specified by Health Canada, is 800 Bq/m3 (see H49-59 "Exposure Guidelines for Residential Indoor Air Quality"). If the results of the test indicate a concentration exceeding the Canadian Action Level, the rest of the sub-slab depressurization system must be installed. (It may be noted that Canadian and U.S. action levels are likely to differ.)

Installation of the sub-slab depressurization system requires that the pipe cast through the slab 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 exhaust fan should be located outside the occupied space where noise will not be a nuisance. It is also best to locate the fan as close to the external 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 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.

Since radon concentration of the vent gases can become quite high, soil gases collected by the sub-slab depressurization system should be vented at the roof level. Therefore, it may be desirable to take some simple steps to facilitate future installation of the system. This could include locating the slab vent pipe below a suitable interior wall, through which the vertical riser could be run, and pre-drilling the wall top and bottom plates, particularly those not accessible from a basement or attic.

The house must be re-tested for radon after completion of the depressurization system.

2.7 Options for Moisture Control

Function: *To manage the flow of moisture such that a balance in moisture flow is achieved at every location in the envelope, with vapour pressures that are well below the saturation vapour pressure at each location throughout the year.*

Options

MOISTURE CONTROL	
VBMC	Inboard of the thermal insulation: vapour barrier, type I (with permeability more or less matched to interior dampproofing).
BMMC	Inboard of the thermal insulation: breather type membrane, 180 - 250 ng/m^2.s.Pa (with permeability more or less matched to interior dampproofing); (control of indoor humidity is essential with this option).
NMC	No explicit moisture barrier membrane (thermal control strategy instead; i.e. exterior basement insulation in combination with the concrete wall. The first impermeable surface either has adsorptive capacity and/or is usually warmer than the interior dew point temperature).

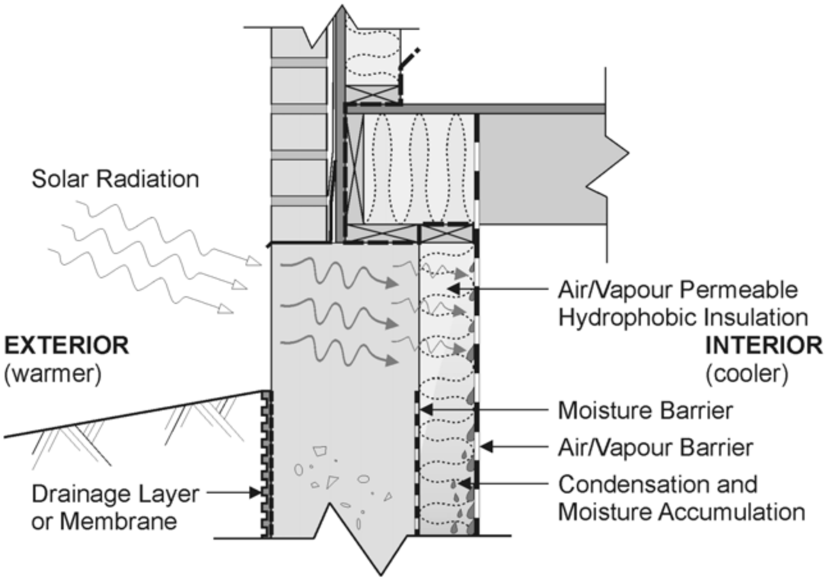
Table 2.7 Available options for control functions associated with moisture control.

For above-grade envelopes, the *moisture control sub-system* generally employs combinations of temperature control by use of thermal insulation and selective permeability of each material in the envelope system. Low-permeability materials are used in conjunction with thermal insulation, i.e., the vapour barrier is kept warm at all times by outboard insulation. At each layer outward through the envelope as the temperature through the wall decreases, designers select materials of higher permeability than the vapour barrier and try to minimize any abrupt decreases in permeability. Relatively impermeable insulations can be used as sheathings (within limits, see NBC 9.25.1.2) because their thermal characteristics encourage warmer temperatures on the inner face, which in turns allows these materials to meet the above principle most of the year. Impermeable claddings, or claddings which feature impermeable finishes, break this rule. Thus, they should only be used in conjunction with open air spaces behind them to minimize the occurrence of condensation and to provide drainage and air drying.

Below-grade envelopes do not enjoy the same luxury: soils do not necessarily present the outer portion of the envelope with drying (low vapour pressure) conditions on a recurring basis, and impermeable materials are generally used to isolate hygroscopic materials in the structure (concrete, wood) from water in the soil.

Special Conditions During Concrete Curing

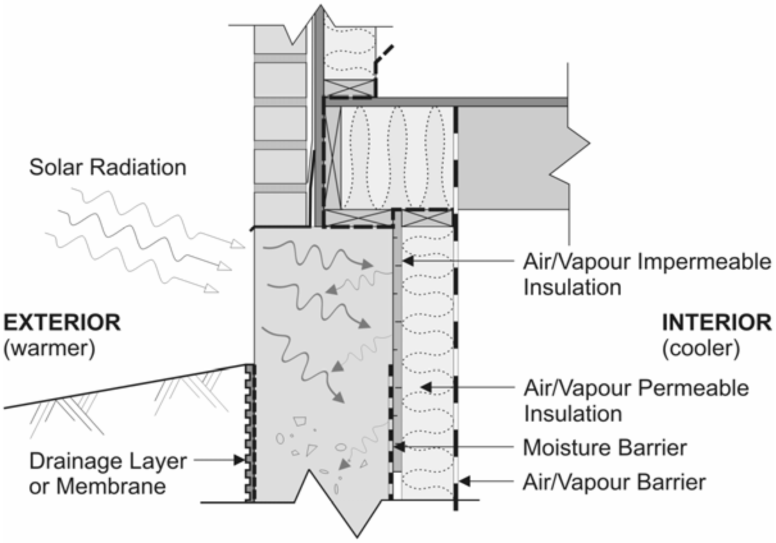
In many cases, construction moisture presents the most difficult challenge to the design of appropriate moisture control measures. A common problem, as depicted in Figure 2.7, involves cast-in-place concrete foundations with air/vapour permeable insulation installed inboard of the foundation wall at the above-grade portion (Note: this arrangement represents the predominant approach to basement construction across most parts of Canada).



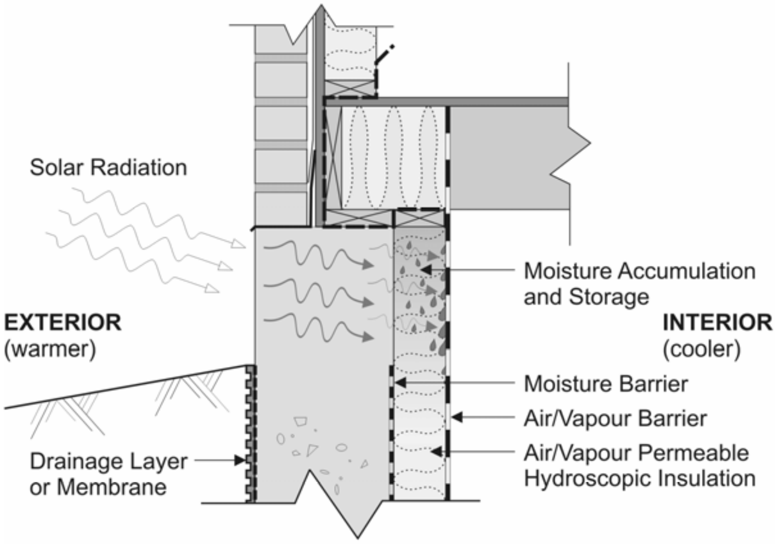
The dominant temperature gradient during summer months drives moisture entrained in the foundation wall inward, where it condenses on the outboard face of the air/vapour barrier. Much of the insulation and strapping normally reach saturation, and in some cases, bulk water runs out the bottom of the interior finished wall assembly (often mistaken for leakage).

Figure 2.7. Common condensation problem associated with concrete curing.

The problem is known to abate within one full heating season following construction, after the concrete has fully cured and the entrained water has dissipated. One obvious solution is to allow the concrete to fully cure before applying the above-grade insulation assembly. However, in many markets, construction takes place during the late fall or winter months and the concrete does not have sufficient time to cure before the interior work is completed for delivery to the homebuyer. Figure 2.8 presents two possible approaches to dealing with this construction moisture-related problem.



The placement of air/vapour impermeable insulation outboard of the air/vapour permeable insulation layer reduces construction-related moisture problems. Moisture driven inward by temperature gradients will tend to move downward through the concrete foundation wall toward the footing, as this now represents the lowest accessible vapour pressure within the basement envelope assembly. The impermeable insulation may be placed partially below grade (as shown above), extended full height, or thickened to replace the permeable insulation altogether.



Another approach to managing construction moisture in above-grade portions of the basement wall assembly involves the substitution of hydrophobic, air/vapour permeable insulation with hydroscopic insulation. The hydsroscopic insulation must be able to absorb and store the construction moisture without becoming supersaturated during the first summer season, and then subsequently release it to the surrounding materials and environment .

Figure 2.8 Isolation and absorption/storage strategies for concrete curing problems.

2.8 Specifying the Basement Envelope System ‘Package’

Considerable flexibility exists in the selection of a strategy to meet all of the *functional requirements* of the *basement envelope system* identified in Part 1, provided that all functional requirements are successfully met to the level of expectation dictated by the class or intended use of the basement. There currently exists a wide variety of approaches to basement envelope construction – many with a proven track record.

The specification for a complete *basement envelope system* is actually the result of an extensive set of decisions (either explicit or by default) that lead to a final system specification – ‘the package.’ This section reviews the complete set of options involved by working through a ‘decision tree process,’ in which the implication of each decision on the next options are discussed. For each decision, a different set of requirements results for the materials being considered. (Those material requirements are reviewed in Part 3.)

Sections 2.1 to 2.7 identified the sets of options that are available to address the major functions of the envelope system. These are summarized in Table 2.8.

FUNCTION	OPTIONS				
STRUCTURE	CIP	CMU	PCP	PWF	SIP
INSULATION PLACEMENT	EXT	INT	STG	ITG	ICF
INSULATION COVERAGE	F	FG	P	N	
CONSTRUCTION MOISTURE	W	D			
DRAINAGE	EDR	IDR	NDR		
WATERPROOFING	FWP	PWP	NWP		
DAMPPROOFING	FDP	EDP	PDP	NDP	
AIR LEAKAGE AND SOIL GAS CONTROL	IAB	EAB	HAB	NAB	
MOISTURE CONTROL	VBMC	BMMC	NMC		

Table 2.8 Summary Available Options for Basement System Control Functions

Assuming that none of the combinations were exclusive of one another, the control function options represent a total of 5 x 5 x 4 x 2 x 3 x 3 x 4 x 4 x 3 = 86,400 potential combinations. It should be noted that options for slab-on-grade insulation and uninsulated walls have not been included above. Fortunately, after accounting for exclusive combinations and practical considerations, such as building physics and costs, the number of adequately performing options is reduced to a manageable set.

Theoretically, all of these options are possible to build – but all are not equal in terms of material requirements for proper function. We start with the assumption that all of the envelope functions required to meet the *intended use* can be satisfied with each combination. The key difference between combinations is the number of functions the materials involved are expected to fulfill, and how well such materials can be expected to perform over the service life of the basement envelope system. For some combinations, the materials may not exist to deliver all of the properties required by the system. Such systems should thus be considered impractical at the current time, based on the state of material availability. The key to rationalizing the selection of components for the basement system is to make appropriate selections, starting in the left column of Table 2.8 and systematically moving downward, taking each previous decision into account.

Implicit in this approach is the fact that the moisture control strategy is selected last, and must take into account all of the previous decisions. This moisture control factor makes successful basement envelope system specification difficult. It is possible for a proposed design to successfully satisfy all control functions up to the point that moisture control is taken into consideration. Sometimes, however, adequate moisture control can not be provided for all materials previously selected. Once a combination is found that potentially satisfies all criteria, it usually stands out. Some of the more common ‘packages’ with demonstrated successful past performance are presented below.

Exterior Insulation Basement System (EIBS) Option

The building science community has shown strong preference for exterior insulation configurations because, given proper selection of the structural and exterior insulation materials, all of the other options fall into place without need for additional materials:

Control Function	Option	Description
Structure	CIP or CMU	Cast-in-place concrete or concrete masonry units
Insulation Placement	EXT	Exterior insulation placement
Insulation Coverage	F	Full coverage of foundation walls
Construction Moisture	W or D	Wet or dry construction
Drainage	EDR	Explicit drainage provided by exterior insulation
Waterproofing	NWP	None
Dampproofing	NDP	None (PDP is an alternative: bottom 300 mm)
Air Leakage & Soil Gas Control	HAB	Hybrid system of structure, caulking, membranes
Moisture Control	NMC	No explicit moisture barrier membrane

Table 2.9 Description of exterior basement insulation system control function options.

In terms of the system performance, this approach has clear advantages. It is flexible – whether built wet or dry. In most circumstances it will dry out and stay dry. However, depending on the footing drainage system used and surrounding soil conditions, some dampproofing of the lower portion of the wall may be needed.

This system puts extra demands on the insulation layer because it is exposed directly to the soil environment, and accordingly must play the drainage role as well as the thermal role. As with all designs, the element of the envelope that is exposed to the surroundings takes the brunt of the environmental loads, and in the case of the exterior insulation option below grade, the exposed element is the insulation. Recent field tests indicate that a wide variety of insulation materials can provide acceptable performance in external insulation basement systems (EIBS). This technique also loads some additional requirements on the structural material. If the structural material is to satisfy the continuity requirements of the air barrier system, e.g., if it is part of the air barrier/soil gas barrier system, then a continuous crack-free structure must be joined to the rest of the air barrier elements.

Once the materials are selected to address these requirements, the *system* itself addresses the remaining control requirements, including moisture control. Because so many functions are addressed without the use of additional materials such as impermeable membranes, the system allows for the moisture control criteria to be satisfied whether moisture is flowing inward, outward, up or down through the envelope. This ensures that, at any time of the year, there are no major discontinuities in permeability through the system to trap the moisture.

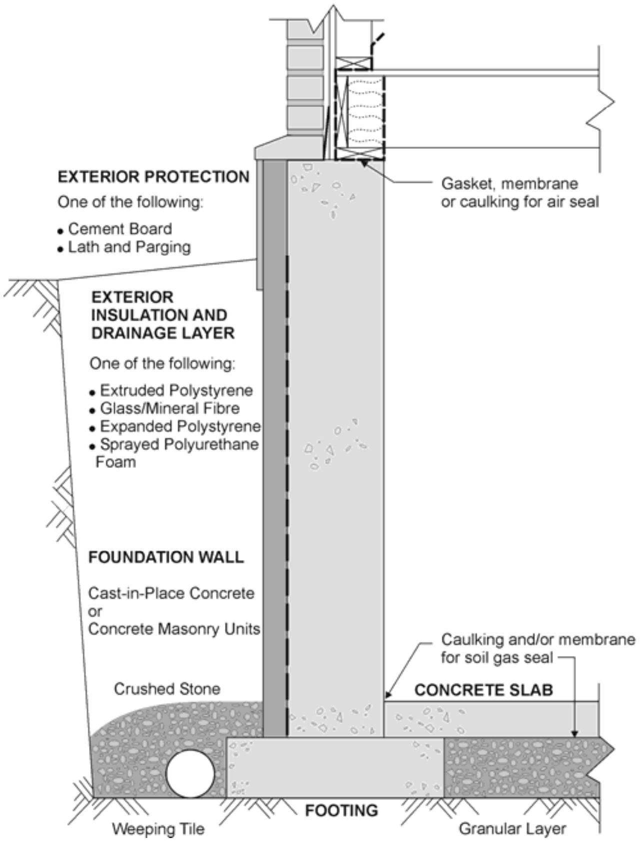


Figure 2.9 Typical configuration of exterior insulation basement system.

When combined with insulation beneath the floor slab, EIBS have the advantage of delivering a Class A basement which is more resistant to damage by flooding and sewer backup. While affording these advantages, exterior insulation strategies do not provide a recognizable ‘finished’ basement appearance to prospective homebuyers.

Interior Insulation Between Framing Option for a Class ‘A’ Basement

When housing markets demand either a finished basement (Class A-2), or one that can be readily finished (Class A-3), interior insulation strategies are often preferred. This option, as depicted in Figure 2.10, is perhaps the most widely used combination, has a relatively good performance track record, but features several impermeable control surfaces.

Control Function	Option	Description
Structure	CIP or CMU	Cast-in-place concrete or concrete masonry units
Insulation Placement	INT	Interior insulation placement between strapping
Insulation Coverage	F	Full coverage of foundation walls
Construction Moisture	W or D	Wet or dry construction
Drainage	EDR	Explicit drainage provided by membrane
Waterproofing	NWP	None
Dampproofing	FDP	Full below-ground wall, exterior and interior coverage
Air Leakage & Soil Gas Control	HAB	Hybrid system of structure, caulking, membranes
Moisture Control	VBMC	Vapour barrier, Type I, inboard of the thermal barrier

Table 2.10 Description of interior insulation between framing option.

This combination has been used widely in Ontario since 1993, especially for finished basements. Its success is attributed to the fact that it addresses almost all of the control functions explicitly, and has apparent additional market value due to its reputation as a performer – a Class “A” basement.

It does have one weakness – dealing with embodied (construction) moisture is made difficult by the presence of the vapour barrier on the inside. Section 2.7 discusses this problem in depth and offers several suggestions for avoiding this problem. In addition to these measures, the use of sprayed polyurethane foam between the strapping has provided relief from construction moisture problems.

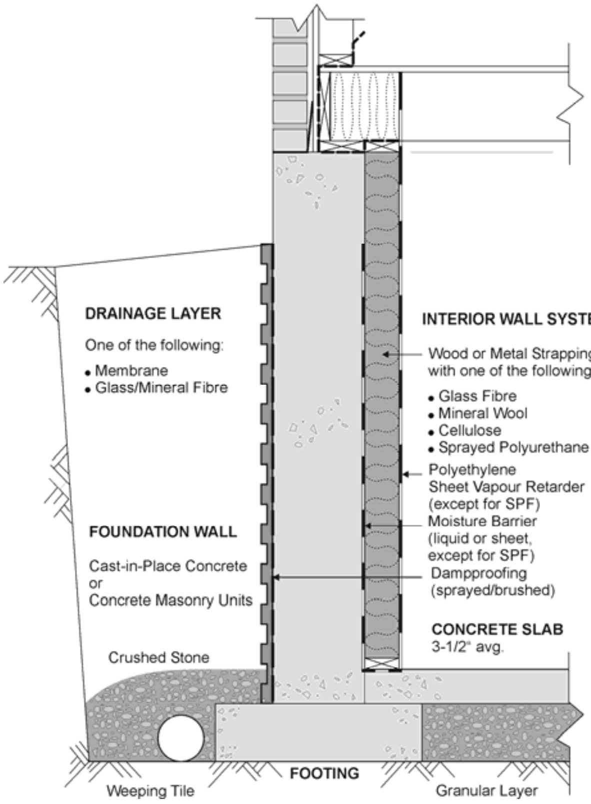


Figure 2.10 Typical Configuration of Interior Insulation Between Framing Option

Interior Board-Type Insulation Option for a Class ‘A’ Basement

Where a finished, Class A basement is desirable in a given housing market, another approach to interior insulation and finish is depicted in Figure 2.11. This approach to a fully insulated and finished basement avoids the use of vapour permeable insulation, and also isolates integral framing members from direct contact with wet, curing concrete.

Control Function	Option	Description
Structure	CIP or CMU	Cast-in-place concrete or concrete masonry units
Insulation Placement	INT	Interior insulation (board type, integral strapping)
Insulation Coverage	F	Full coverage of foundation walls
Construction Moisture	W or D	Wet or dry construction
Drainage	EDR	Explicit drainage provided by membrane
Waterproofing	NWP	None
Dampproofing	FDP	Full below-ground wall exterior coverage provided by insulation
Air Leakage & Soil Gas Control	HAB	Hybrid system of structure, caulking, membranes
Moisture Control	NMC	None, moisture control provided by insulation

Table 2.11 Description of interior board-type insulation option.

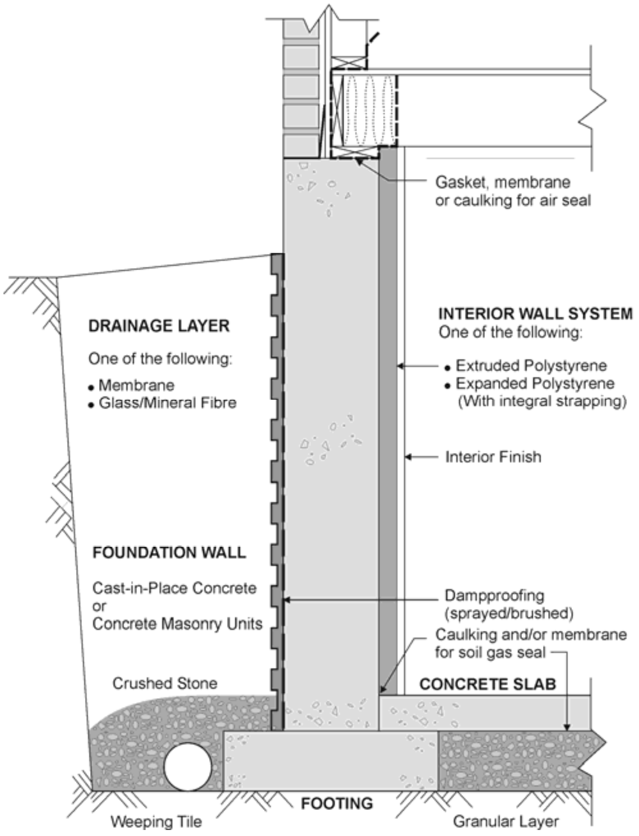


Figure 2.11 Typical configuration of interior board-type insulation option.

Insulating Concrete Forms (ICFs) Option for a Class ‘A’ Basement

Insulating concrete forms may be employed to construct foundation walls for basements, resulting in full-height insulation on both the interior and exterior faces of the basement wall as depicted in Figure 2.12. ICFs provide good management of embodied moisture, since the system usually requires pumping concrete with a carefully controlled water-to-cement ratio. ICFs combine the advantages of exterior insulation placement (Figure 2.9) and interior Rigid placement (Figure 2.11).

Control Function	Option	Description
Structure	CIP	Cast-in-place concrete
Insulation Placement	ICF	Interior and exterior insulation provided by forms
Insulation Coverage	F	Full coverage of foundation walls
Construction Moisture	W	Wet, but curing concrete normally encapsulated by forms (dry)
Drainage	IDR	Implicit drainage provided by exterior of polystyrene forms
Waterproofing	NWP	None
Dampproofing	FDP	Exterior and interior coverage provided by insulation
Air Leakage & Soil Gas Control	HAB	Hybrid system of structure, caulking, membranes
Moisture Control	NMC	None, moisture control provided by polystyrene forms

Table 2.12 Description of insulating concrete forms option.

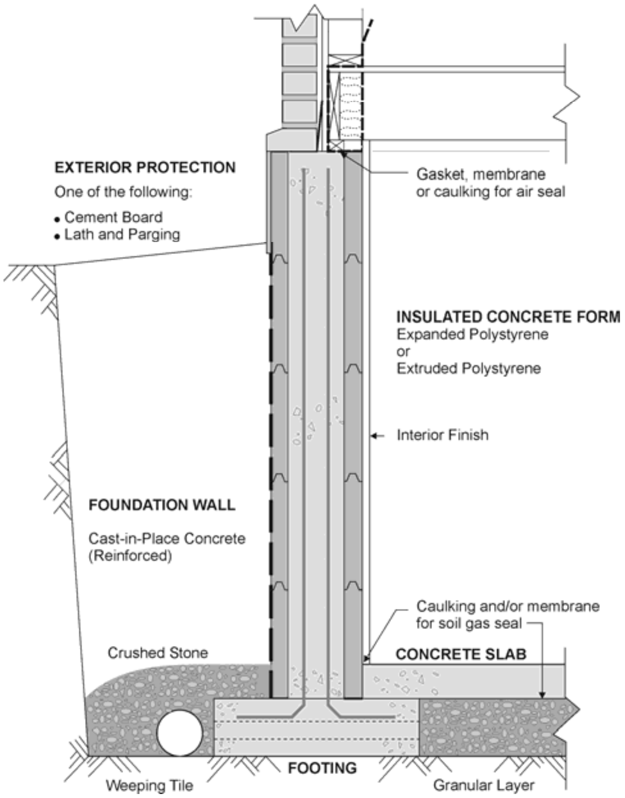


Figure 2.12 Typical configuration of ICF basements.

Permanent Wood Foundation Option for a Class A Basement

Permanent wood foundations represent dry construction with integral thermal insulation, as depicted in Figure 2.13.

Control Function	Option	Description
Structure	PWF	Preservative treated lumber and plywood
Insulation Placement	ICTG	Integral within wall and floor cavities
Insulation Coverage	F	Full coverage of foundation walls and floors
Construction Moisture	D	Normally dry, unless materials are improperly protected from wet weather exposure
Drainage	IDR/EDR	Implicit drainage provided by polyethylene on exterior walls – explicit drainage beneath foundation provided by granular layer
Waterproofing	NWP	None
Dampproofing	FDP	Exterior and interior coverage provided by polyethylene
Air Leakage & Soil Gas Control	HAB	Hybrid system of structure, caulking, membranes
Moisture Control	VBMC	Provided by polyethylene

Table 2.13 Description of permanent wood foundation.

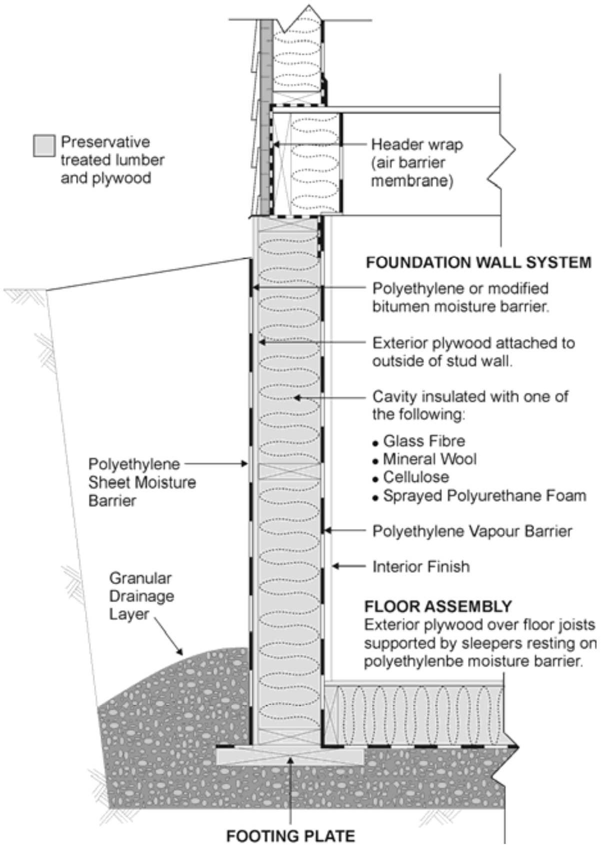


Figure 2.13 Common configuration for permanent wood foundation.

2.9 Strategies for Improved Resistance to Water Attack

Groundwater conditions may vary significantly within a locale, such that pockets of poorly draining soil and perched or fluctuating water tables occur unpredictably. First, these conditions must be identified, and then appropriate abatement measures must be taken.

Identifying Difficult Soil and Groundwater Conditions

Local experience may point to the known existence of difficult soil and groundwater conditions in an area, but only a proper investigation by a qualified person can accurately identify the nature and severity of difficult conditions for a particular site.

Improved Drainage Systems

Engineered foundation drainage systems may be required to deal with difficult soil conditions, where an unusual distribution of fine particles in the soil surrounding the basement may lead to plugging of conventional drainage pipe systems. Typically, engineered drainage systems differ from conventional drainage pipe systems as follows:

1. Engineered drainage systems are typically “active,” while most conventional drainage systems are “passive.”
2. The piping is smooth-walled, and protected by a specified geotextile filter selected to exclude fine soil particles, as determined by soil gradation testing.
3. Piping is installed with a positive grade to ensure flow away from the basement foundation.
4. Clean-outs are provided so that the system may be periodically flushed (back-washed) to provide a long service life and consistent performance.

Complete Waterproofing Systems

When site conditions result in periodic or chronic occurrences of ineffective foundation drainage, complete waterproofing systems may be required. Complete waterproofing systems wrap the entire envelope exposed to bulk water, including beneath floor slabs, between footings and walls, and the exterior of walls up the high groundwater level. Penetrations must also be properly sealed. When employing these systems, it is important to ensure that the structural design of the foundation takes hydrostatic pressures into account.

2.10 Strategies for Improved Resistance to Frost Heaving and Adfreezing

Frost heaving results when water in the soil beneath the foundation freezes and exerts an upward force on the structure. For this reason, the National Housing Code of Canada requires that the depth of foundations in cohesive, poorly draining soils is greater than the depth of frost penetration in a particular geographic location. These requirements are summarized in the *National Housing Code of Canada 1998 and Illustrated Guide*.

Adfreezing, a term describing adhesion freezing of below-grade elements, is known to occur in cohesive, poorly draining soils where the outer, below-grade surface of a building element attains sustained temperatures below the freezing point of water. Water vapour from the surrounding soil mass migrates towards the element which is at a lower vapour pressure, and subsequently freezes along with the adjacent soil. The expansion of the adhered soil can lift or crack the foundation structure. Frost heaving and adfreezing phenomena are summarized in the building note below, extracted from the *National Housing Code of Canada 1998 and Illustrated Guide*. Figure 2.14 identifies potential locations of adfreezing problems in typical houses.

In order to avoid these problems in basements, several key factors must be considered.

Identifying Special Climate and Soil Considerations

Considerations for special climate and soil conditions are based on the severity and duration of freezing temperatures coupled to the characteristics of the soil surrounding the basement. Normally, the depth of frost penetration is known locally by the building department based on past experience. However, this depth can vary significantly depending on the depth of snow cover, amount of water in the soil and the type of soil. In free-draining, sandy or granular soils, the depth of frost penetration is relatively shallow, typically less than 0.6 m (2 feet). In poor-draining, cohesive soils, the depth of frost penetration may attain depths as great as 3 m (10 feet) in extremely cold climates. In parts of Canada that experience permafrost, conventional basements are simply not feasible.

Identifying special conditions requires consultation with local authorities as well as design and construction professionals. This is especially true in areas where pockets of highly frost-susceptible soil are known to occur. Conditions are less obvious where the depth of snow cover is reduced over sustained periods of the winter. Driveways and walkways adjacent to the basement represent examples of conditions where the depth of frost penetration may exceed local norms.

Control of Surface Water

While the surface exposure of the soil surrounding the basement may be required for walkways and driveways, and the severity of climate remains uncontrollable, the amount of water in the soil surrounding the basement can be controlled to some degree. The primary control strategy involves the management of surface water to convey it away from the basement. This will reduce the potential for both frost heaving and adfreezing.

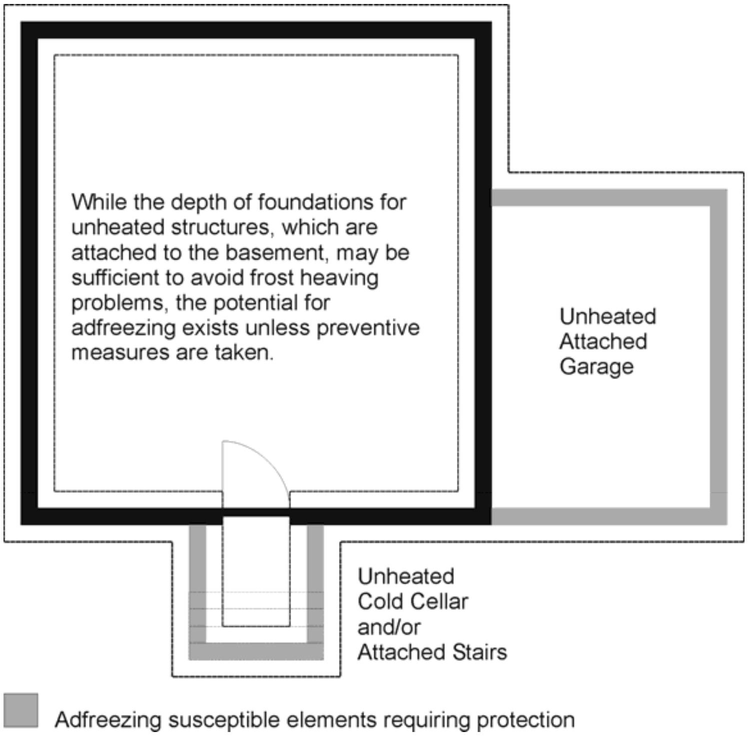


Figure 2.14 Potential locations for adfreezing problems.

Control of Heat Flow

Thermal isolation of unheated, below-grade structural elements is an effective means of preventing adfreezing problems. For high thermally conductive materials such as concrete and steel, the simplest approach is to encapsulate the below-grade portion of the element with thermal insulation. The water vapour in the soil no longer “sees” the lower vapour pressure surface of the element and the development of ice lenses is therefore arrested.

Providing a Slip Plane (Bond Break)

Where it is not practical to apply insulation, a slip plane may be applied to the structural element to prevent frost from adhering to the surface of the element. Materials such as polyethylene, asphalt-impregnated and waxed building papers may be employed. Insulation materials used to control heat flow also serve as slip planes.

Figures 2.15 and 2.16 depict approaches to adfreezing protection which rely on site grading, drainage, control of heat flow and a slip plane to minimize potential problems.

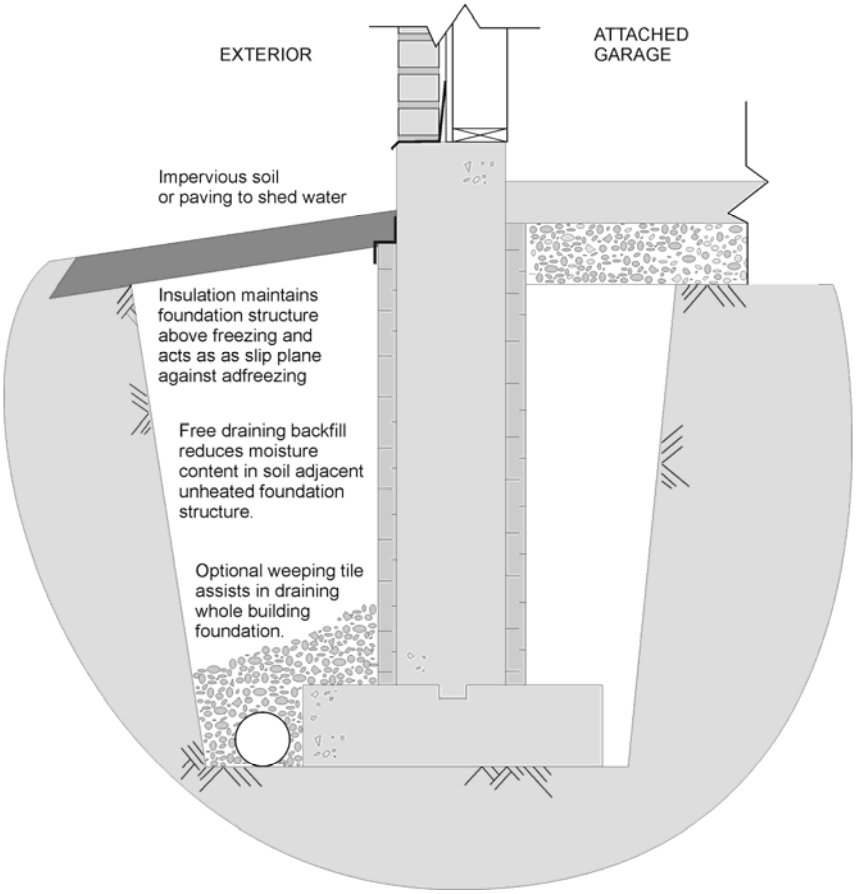


Figure 2.15 Complete approach to adfreezing protection of unheated, attached structures.

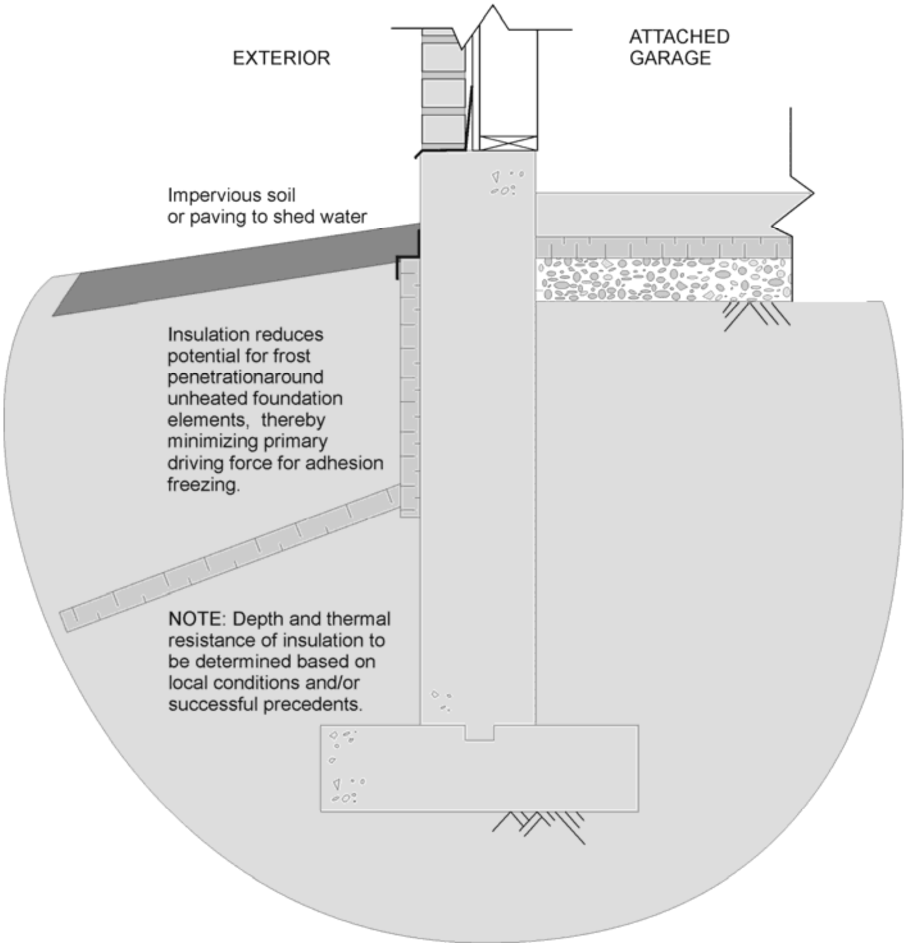


Figure 2.16 Modified approach to adfreezing protection of unheated, attached structures.

2.11 Strategies for Improved Resistance to Moisture Attack

When site and occupancy conditions prove challenging to the design of the moisture control functions of the basement envelope system, special strategies are required to provide improved levels of resistance beyond minimum levels prescribed in the code. First, difficult conditions must be accurately identified, and then appropriate measures taken for the selected basement envelope system.

Identifying Difficult Outdoor Climate and Soil Conditions

Difficult outdoor climates include sustained periods of extreme temperature, humidity or precipitation. This information is available from climate data. Difficult soil conditions are less obvious, such as pockets of poor-draining and/or low bearing capacity soils. These are usually familiar to local building departments and builders, but require special consideration when designing basements in unfamiliar locales. When uncertain about building soil conditions, it is advisable to seek the advice of a qualified soils engineer. From a design and construction perspective, it is helpful to compare successful, local approaches to basement construction under the same conditions.

Identifying Difficult Indoor Climate Conditions

Difficult indoor climates result from the intended use of the basement, occupant behaviour, and in some cases, construction-related moisture. Features such as saunas, whirlpools or swimming pools located in the basement require special attention. An example of difficult moisture conditions resulting from occupant behaviour is the use of the basement for growing of plants, as in the case of an indoor greenhouse space used to start seedlings. Another example involves the storage of wet firewood or lumber. Conventional approaches to moisture management may not be able to adequately control such sources of moisture generation. Wet construction, such as cast-in-place concrete, taking place at a time when full curing of the materials prior to enclosure is not possible, must also be identified.

Meeting the Requirements for All Seasons

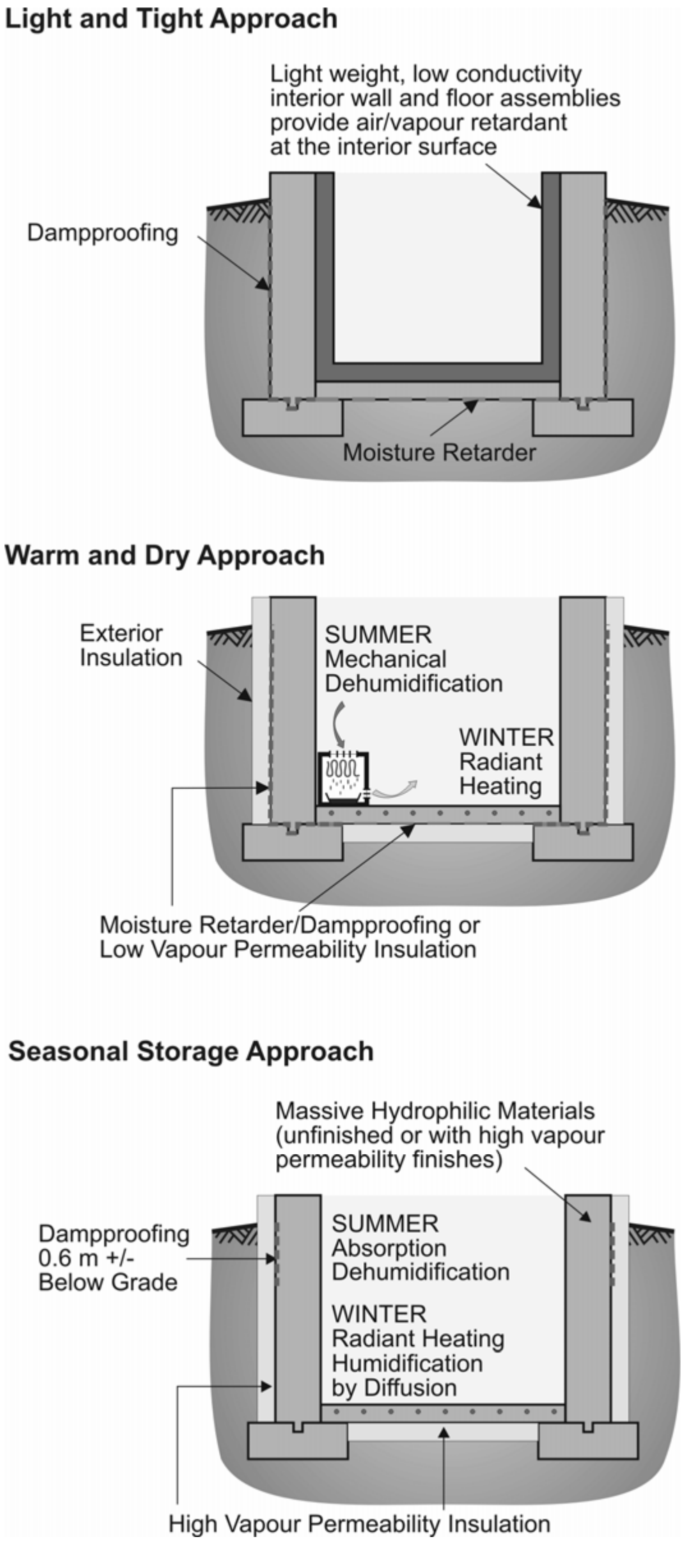
When moisture loads due to climate, soil and indoor conditions are combined, they must be considered within the context of the entire year, especially starting with the first year of occupancy. For example, a high water table in spring may saturate the basement assemblies without causing any leakage, and when this is followed by a hot, humid summer, there may be no significant opportunity for drying of the materials. Under these conditions, interior assemblies employing air permeable insulation and wood framing may sometimes experience mould growth. If only the winter condition is considered, this envelope system may provide entirely acceptable performance, but under extreme conditions and peak events, it may not prove as successful.

Use of Permeable and Impermeable Insulating Materials in a System

The most effective means of dealing with moisture management in basements involves the selection and arrangement of permeable and impermeable materials. In simple terms, this results in three basic strategies for basement thermal/moisture control design:

- Light and Tight Approach – This approach utilizes low thermal diffusivity surface finishes and an air and vapour tight assembly to completely isolate the basement thermal/moisture control elements (located on the interior) from both the interior and exterior environments.
- Warm and Dry – This approach keeps the structure warm and dry, and relies on an exterior insulation strategy.
- Seasonal Storage – This is an innovative approach that allows controlled exchanges of moisture between the basement and its surrounding soil environment.

These strategies are depicted schematically in Figure 2.17, and the use of mechanical means for augmenting temperature and humidity control should be noted.



Light and Tight Approach

Warm and Dry Approach

Seasonal Storage Approach

Figure 2.17 Basic arrangements of thermal and moisture control strategies for basements.

Synopsis

Basement envelope system selection requires a logical procedure where the required control functions are addressed explicitly at each step in the process. Designers and builders should recognize that unless such a process and parameters are employed, critical aspects of the basement envelope system may be under-designed, resulting in potential performance problems, or over-designed, causing unnecessary expenditures which could be more effectively assigned to other aspects of the house construction.

By following the process advocated in these Guidelines, it is possible to appropriately select a type of basement construction which delivers the required level of performance for a given class of basement.

Part 3, which follows, deals with the materials needed to achieve acceptable performance for selected measures corresponding to each of the critical control functions identified in Part 2.

PART 3 - SELECTION OF MATERIALS AND EQUIPMENT FOR THE BASEMENT SYSTEM

3.0 Overview

Having identified a suitable basement package which addresses site and market conditions, the next step in the basement system design process involves the selection of materials and equipment. From a practical perspective, the key considerations at this stage are:

Will the materials fulfill their intended role with respect to critical control functions? For example, the ability of a drainage membrane to effectively convey water to the foundation drainage system is very important where it serves as the first line of protection.

Are the materials compatible with one another? It is possible that one material, for example a coating or emulsion, may have an adverse chemical reaction with other building materials in an assembly, leading to degradation and a reduction in performance.

What equipment is required to carry out environmental control functions corresponding to the class of basement being constructed? Normally, mechanical systems are selected based on the requirements of the above-grade floors of a house. There may be cases where these are not well suited to providing comfort in basements intended to serve as livable spaces.

From a regulatory perspective, a critical issue to resolve is:

Are the selected materials and equipment permitted by the regulatory authority having jurisdiction?

In Canada, there are essentially four compliance paths available for basement construction, materials and equipment. These are depicted in Figure 3.1.

Building construction, materials and equipment permitted for use in house construction are regulated by a consensus codes and standards process. The National Building Code of Canada (NBC) lists the applicable codes and standards to which materials and equipment must comply. It is important to ensure that materials and equipment selected for the basement system conform to applicable codes and standards.

Many traditional materials and equipment are not covered by current codes and standards. For example, standards governing the physical composition of natural stone materials are not available. Under the National Building Code of Canada, these exceptions are addressed by:

> **2.5.1.3 Equivalence Demonstrated by Past Performance, Test or Evaluation**
>
> 1) Materials, appliances, systems, equipment, methods of design and construction procedures not specifically described herein, or which vary from the specific requirements of this Code, are permitted to be used if it can be shown that these alternatives are suitable on the basis of past performance, tests or evaluations.

Novel and innovative materials and systems that do not fall under existing codes and standards, or have demonstrated past performance, are evaluated by centres such as the Canadian Construction Materials Centre (CCMC). CCMC offers a national evaluation service for all types of innovative construction materials, products, systems and services, and provides an online listing of product evaluations http://www.nrc.ca/ccmc.

When considering materials and systems that have been evaluated, it is very important to review the Usage/Limitations section of the evaluation report. Most products and systems are evaluated with respect to code requirements establishing their intended usage. Check that the selected material or system conforms to the usage and limitations contained in the evaluation report. Also ensure that materials and systems are marked with an evaluation number. In some cases, manufacturers may produce a variety of similar products where only a subset have evaluations and markings. These markings permit regulatory authorities inspecting the construction to verify compliance. Failure to use appropriately marked materials and systems may cause problems and delays.

A fourth means of compliance with code requirements involves engineering design according to applicable codes and standards. This compliance path is usually necessary when basement construction falls outside the scope of Part 9 of the National Building Code. Part 9 applies to housing and small buildings and contains prescriptive requirements for conforming construction. Engineering design applies to situations where the construction does not fall within the scope and limitations of Part 9 prescriptive requirements.

For designers and builders, it is important to ensure that materials and equipment selected for use in the basement system fall under one of these four means of assuring compliance and acceptable performance.

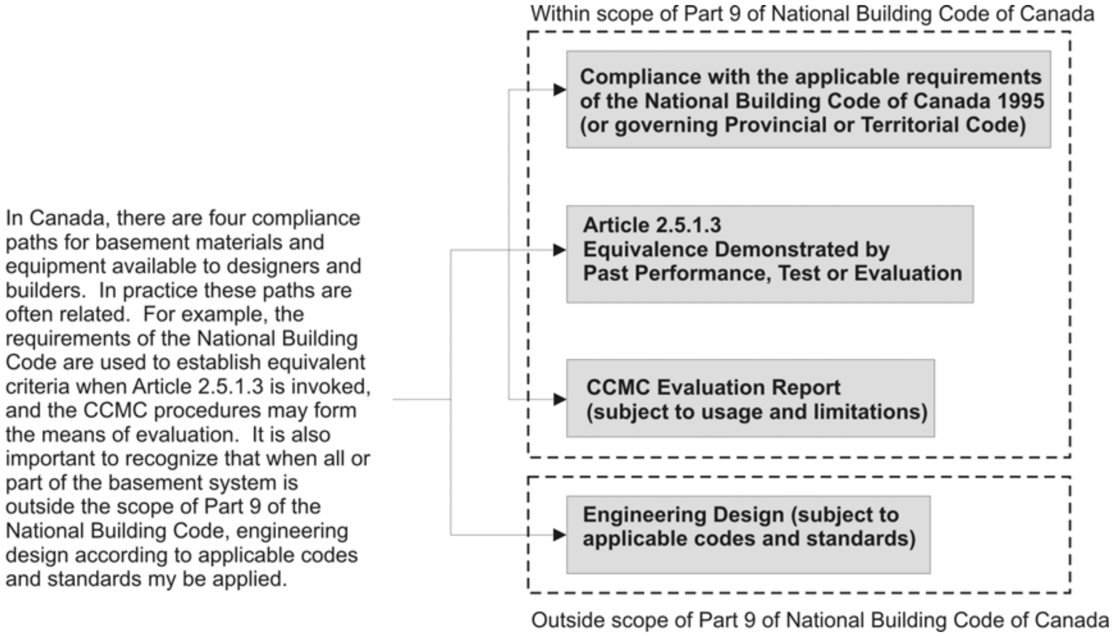


Figure 3.1 Compliance paths for basement construction, materials, and equipment.

3.1 Structural Materials

The selection of structural materials for the basement system should consider strength and durability. Several structural material options are currently available in Canada, the most prevalent being cast-in-place concrete and concrete masonry units (concrete block). In some parts of Canada, permanent wood foundations (PWFs) are employed. The use of prefabricated or pre-cast concrete panels is a relatively novel and innovative approach to achieving a concrete basement structure.

Cast-In-Place Concrete

The National Building Code of Canada provides minimum requirements for cast-in-place concrete used for footings, foundation walls and slabs-on-grade. Refer to *Subsection 9.3.1 Concrete* in the NBC for applicable requirements.

From a designer or builder perspective, the two most important considerations are the type of concrete mix specified, and the proper workmanship employed in its placement. Unlike prefabricated materials, improper batching, mixing and placement practices can significantly affect the physical properties of the concrete.

Concrete Mix

The concrete mixing proportions must be selected to provide necessary workability, consistency, strength, durability, density, and appearance for a particular application. The required characteristics are determined by: 1) the intended use of the concrete; and 2) the expected conditions at the time of placement.

The concrete mix must be specified according to the performance desired, and is based on the following items:

Strength – type and time

Air Content/durability

Maximum Aggregate Size

Degree of Workability [slump]

Set Type: normal, accelerated or delayed [retarded]

Specialty products (admixtures)

Practically speaking, it is advisable to order concrete from a ready mix supplier. However, it is permissible to mix concrete on site according to the proportions set out in *Table 9.3.1.7, Concrete Mixes*, of the National Building Code. When ready mixed concrete is used, it is strongly recommended to order concrete from a concrete company in:

the province of**Ontario** that has a current ***'Certificate of Ready Mixed (or Mobile Mix) Concrete Production Facilities'*** as issued by the Ready Mixed Concrete Association of Ontario.

Atlantic Provinces that is a member in good standing of the Atlantic Provinces Ready Mixed Concrete Association

the province of**Quebec** that is a member in good standing of the Association Béton Québec

the province of**Manitoba** that is a member in good standing of the Manitoba Ready Mixed Concrete Association

the province of**Saskatchewan** that is a member in good standing of the Saskatchewan Ready Mixed Concrete Association the province of**Alberta** that is a member in good standing of the Alberta Ready Mixed Concrete Association

the province of**British Columbia** that is a member in good standing of the British Columbia Ready Mixed Concrete Association

It is important to ensure that all products and materials for the specification or production of concrete shall be under the control and responsibility of the concrete supplier. This includes products such as admixtures, cementing materials, fibres, supplementary cementing materials, colour, aggregates, etc.

Cast-in-Place Concrete Workmanship
All cast-in-place concrete work for basement systems is governed by the requirements of CAN3-A438-M, *Concrete Construction for Housing and Small Buildings*.

Prefabricated Concrete Panels

Prefabricated or precast concrete panels are engineered products typically manufactured indoors under controlled conditions in a pre-cast plant. The design of pre-cast concrete structures must conform to CSA A23.3-94 *Design of Concrete Structures*. Within this standard, related standards pertaining to materials and methods are referenced. To avoid technical complexities and uncertainties associated with pre-cast concrete products, it is recommended to only use prefabricated concrete panel products produced by companies which are members in good standing of:

Canadian Precast/Prestressed Concrete Institute
196 Bronson Avenue
Ottawa ON, K1R 6H4
http://www.cpci.ca

It is important to recognize that the selection of pre-cast concrete panels for basement systems will often necessitate the involvement of the supplier in the design and installation of these structural components, as most builders will not possess the necessary equipment and expertise required to achieve a successful installation.

Concrete Masonry Units (Concrete Block)

Unit masonry construction must conform to the requirements of Section 9.20 of the National Building Code of Canada. Limitations on the depth of the foundation and the height of backfill are governed by Table 9.15.4.1, *Thickness of Foundation Walls*.

The concrete masonry units must comply with CAN/CSA-AI65.1, *Concrete Masonry Units*, and their compressive strength over the net area of the block must not be less than 15 MPa.

The mortar materials used in concrete block construction must comply with:

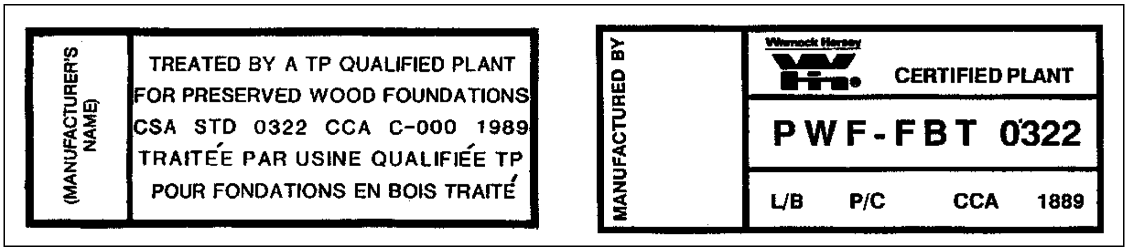
ASTM C 5, *Quicklime for Structural Purposes*;
ASTM C 207, *Hydrated Lime for Masonry Purposes*;
CAN/CSA-A5, *Portland Cement*;
CAN/CSA-A8, *Masonry Cement*; or
CSA A82.56-M, *Aggregate for Masonry Mortar*, as applicable.

Water and aggregate must be clean and free of significant amounts of deleterious materials. Where lime is used in mortar, it must be hydrated. Where lime putty is used in mortar, it shall be made by soaking quicklime in water for a minimum of 24 hours or soaking hydrated lime for a minimum of 12 hours.

Treated Wood for PWF's

Permanent wood foundations must be designed in accordance with CAN/CSA-S406 Construction of Preserved Wood Foundations. All plywood and lumber used in PWFs must be pressure treated with preservatives in accordance with CAN/CSA 080.15-M, *Preservative Treatment of Wood for Building Foundation Systems, Basements and Crawlspaces by Pressure Processes*.

Either of the two stamps shown in Figure 3.2 appearing on treated plywood and lumber assure that the materials are suitable for use in permanent wood foundations.



(MANUFACTURER'S NAME)

TREATED BY A TP QUALIFIED PLANT
FOR PRESERVED WOOD FOUNDATIONS
CSA STD 0322 CCA C-000 1989
TRAITÉE PAR USINE QUALIFIÉE TP
POUR FONDATIONS EN BOIS TRAITÉ

MANUFACTURED BY

CERTIFIED PLANT

PWF-FBT 0322

L/B P/C CCA 1889

Figure 3.2 Facsimiles of certification markings.

Additional information regarding permanent wood foundation systems may be found at: http://www.cwc.ca

3.2 Insulating & Framing Materials

Insulation materials vary in their thermal effectiveness, cost and physical characteristics. Insulation materials that may be acceptable for a particular application may not be well suited, or not permitted, for other applications. It is important to select appropriate materials that possess properties congruent with the environmental conditions to which they are exposed, and which lend themselves to proper and economical installations that perform as intended.

Framing materials are predominantly used on the interior of basement envelopes, typically in finished basements to provide space for insulation, plumbing and wiring, as well as a means of attaching interior finishes. Framing materials commonly used include wood and steel framing. It is important to specify materials that will provide compatibility with the basement system design strategy and long-term performance.

Plastic Insulation Materials

An insulating material slows the rate of heat flow from a warmer to a cooler area. Building envelopes are generally composed of several components that act in different ways to slow heat flow. Most insulation materials have a cellular structure of a solid material that blocks heat flow by radiation (i.e., it is "opaque" to radiation much as dark glass is opaque to light transfer). The material contains tiny pockets of air or other gas(es) that reduce the conduction of heat. The air or gas pockets should be small enough that the possibility of heat flow via convection is reduced.

The thermal resistance of insulation materials will vary, depending on:

cell structure – the smaller the cells, the moreeffective they are in reducing heat transfer

the gas contained in the insulation – somegases, such as refrigerant gases, have proven to be more effective than air at stopping heat transfer by conduction, and

moisture content – any water trapped in an insulating material will tend to fill the spaces that are normally occupied by air or gas, reducing the material's ability to block heat flow by conduction.

However, heat transfer through the building envelope is probably most affected by the way the insulation is used and installed. The insulated space must be completely filled with material, eliminating all gaps and voids, or the insulation material must be in full and continuous contact with the interior vapour barrier, finish or a low air permeance foundation wall. The material must be kept dry. Loose fill insulations in particular must be installed according to design specifications if they are to perform as expected.

Insulation materials available include: batt-type, loose fill, boardstock, and spray-type. Table 3.1 summarizes the relevant physical characteristics of these various types of insulation.

Fibrous Insulation Materials

Batt-Type

Batt-type insulation is made from glass or mineral fibres. These fibrous materials are suitable for interior use, specifically inside exterior walls and foundation walls. Insulation values of the various products are a function of the density of the materials. Increased density will generally improve the resistance of the materials and will at the same time reduce convective air movements within a framing cavity. The performance of batt-type insulation products is directly related to installation practices. Gaps around wiring and plumbing must be prevented (splitting batts with material on both sides of wires is the best practice), and batt materials should fill cavities completely and evenly.

The standard, CAN/ULC-S702-97, *Standard for Thermal Insulation, Mineral Fibre, for Buildings*, applies to glass and mineral wool insulation in the form of batts, blankets, boards, and sheets, with or without membranes. It does not apply to insulation less than 25 mm thick, or to preformed insulation used above a roof deck.

Loose Fill

Loose fill insulations may comprise glass fibre, mineral wool or cellulose products. Compressed bags of loose fill insulation material are generally broken up, mixed with air, and blown into place using special machinery. It can be used on the interior of basement walls to insulate framing cavities. It must be applied at the correct density to provide good performance, and is ideally applied by installers certified by the product or equipment's manufacturer.

Article 9.25.2.2 of the National Building Code of Canada and Section 5.3., requires that glass and mineral fibre loose-fill insulations conform to CAN/ULC-S702-97, *Standard for Thermal Insulation, Mineral Fibre, for Buildings*.

Cellulose fibre insulation is typically made from recycled newsprint. The raw material is shredded and treated with chemicals to control flammability, to prevent the growth of moulds and fungi, and to keep rodents from nesting in the material. The chemicals can be added to the paper either dry or in a fine spray. Article 9.25.2.2 of the National Building Code of Canada requires that this type of insulation conform to CAN/ULC-S703-2001, *Standard for Thermal Insulation, Cellulose Fibre Insulation (CFI) for Buildings.*

INSULATION MATERIAL	**Thermal Resistance** RSI/mm (R/inch)	**Density** kg/m^3 (lb/ft^3)	**Permeance** ng/Pa.m^2.s (grain/ft^2.h.in.Hg.)	**Flame Spread**	**Smoke Development**
Batt Type					
Glass Fibre	0.022 (3.2)	10-25 (0.6-1.6)	1666 (29)	15	0
Mineral Fibre	0.024 (3.5)	24-64 (1.5-4.0)	1666 (29)	15	0
Loose Fills					
Glass Fibre	0.020 (2.9)	9.6-40 (0.6-2.5)	1666 (29)	15	0
Mineral Fibre	0.023 (3.5)	24-64 (1.5-4.0)	1666 (29)	15	0
Cellulose Fibre	0.025 (3.6)	25-51 (1.5-3.2)	1666 (29)	60-100	15
Boardstock					
Expanded Polystyrene Type I and II	0.026-0.030 (3.8-4.4)	14.4-25.6 (0.9-1.6)	115-333 (2.0-5.8)	110	500
Extruded Polystyrene Type III and IV	0.034 (5.0)	25.6-32 (1.6-3.4)	23-92 (0.4-1.6)	200	500
High Density Glass or Mineral Fibre	0.029-0.031 (4.2-4.5)	48-144 (.3-9.0)	1725 (30)	15	0
Spray Type					
Cellulose Fibre	0.024 (3.5)	varies	varies	<25	<25
Mineral Fibre	0.025 (3.7)	varies	varies	15	0
Polyurethane	0.041 (6.0)	varies	varies	<500	Up to 500

Table 3.1 Physical characteristics of insulation materials.

Boardstock

There are various boardstock insulation products used in building construction. Only the predominant types used in residential basement construction are described below.

Moulded/expanded polystyrene (EPS) is made by expanding polystyrene beads in a mould. To make boardstock, large blocks of expanded polystyrene are cut into sheets of various thicknesses using hot wires. Low-density expanded polystyrene is referred to as Type I, and higher-density material is referred to as Type II or III. All three materials are suitable for interior and exterior basement applications. Because these materials are combustible, they must be covered with a fire-protective covering, such as 12.7 mm (1/2 in.) drywall, if used to insulate living spaces.

Extruded/expanded polystyrene (XPS) is manufactured by extruding a hot mass of polystyrene through a slit. At atmospheric or reduced pressure it expands, creating a closed-cell foam material. This product is available as Type II, III and Type IV insulation, based on its density, and exhibits a higher thermal resistance per unit thickness than expanded polystyrene boardstock. Extruded polystyrene is suitable for use in both interior and exterior basement applications. This material must also be covered with a fire-protective covering if used in living spaces.

Article 9.25.2.2 of the NBC requires that both EPS and XPS materials comply with the requirements of CAN/ULC-S701- 97*, Thermal Insulation Polystyrene, Boards and Pipe Covering*.

Glass and mineral fibre insulation can also be manufactured as a semi-rigid boardstock. It is compressed to a higher density than batt-type insulation (typically three to five times more than a batt-type product), and is generally held together using a combustible, organic binder. It can be used on the interior of basements, but is most commonly used as below-grade exterior wall insulation because its fibres efficiently carry away any water reaching its outer surface. Article 9.25.2.2 of the National Building Code of Canada and Section 5.3., require that this type of below-grade exterior insulation conform to CAN/ULC-S702-97, *Standard for Thermal Insulation, Mineral Fibre, for Buildings*.

Spray-Type

Spray-type insulations are a relatively recent innovation in the residential construction industry. There are predominantly three different types used in basement construction.

Spray cellulose insulation is available in a variety of formulations to suit specific applications. The material is applied using special applicators that mix water with the insulation material (which has been blended with adhesive(s) by its manufacturer), allowing it to hold together and adhere to the surface to which it is applied. Wet spray materials are gaining broader market acceptance because they offer thorough cavity coverage at reduced cost due to no need for installing netting, slightly reducing envelope air leakage characteristics. Several of the spray-applied materials require the installation of a mesh material over the face of the wall to contain the insulation material prior to the installation of the finished wallboard.

The National Building Code of Canada 1995, Article 9.25.2.2, requires that spray cellulose insulation comply with the requirements of CAN/ULC-S703-2001, *Standard for Thermal Insulation, Cellulose Fibre Insulation (CFI) for Buildings.*

Spray mineral fibre insulation is similar to spray cellulose insulation in terms of its variety of formulations and applications. This type of insulating product must comply with the requirements of CAN/ULC-S702-97, Type 5, *Standard for Thermal Insulation, Mineral Fibre, for Buildings*.

It is important to note that both cellulose and mineral fibre spray-type insulations can only be used on the interior of the building envelope.

Spray polyurethane foam (SPF) formulations are available for use in a variety of spray applications. For large applications, the material is mixed on site using special foaming equipment. For smaller applications, single-component polyurethane foam is available in cans with "gun type dispensers" or in 4.5 kg (10 lb) canisters for sealing spaces around windows, doors and other penetrations. Article 9.25.2.2 of the National Building Code of Canada 1995 requires that all SPF formulations comply with the requirements of CAN/ULC-S705.1-98, *Thermal Insulation – Spray Applied Rigid Polyurethane Foam, Medium Density, Material Specification*. In addition, the quality of workmanship must be assured by a third-party organization recognized for its training program and follow-up inspection of installers trained to spray urethane foam insulation in accordance with CAN/ULC-S705.2-98, *Thermal Insulation – Spray-Applied Rigid Polyurethane Foam, Medium Density, Installer's Responsibilities - Specification*.

SPF insulation may be used both on the interior and exterior below-grade areas of the building envelope. Due to its combustibility, SPF installed on the interior of living spaces must be covered with a fire-protective covering, such as 12.7 mm (1/2 in.) drywall.

Insulated Concrete Forms

Basement foundation construction employing insulated concrete form (ICF) technology represents a recent innovation where thermal insulation, either EPS or XPS, is moulded to create formwork for cast-in-place concrete. After placement and curing of the concrete, the formwork remains in place to provide interior and exterior insulation of the typically reinforced concrete foundation structure. ICF systems permitted for use in Canada generally require CCMC evaluations containing usage and limitations criteria but may be based on Part 4 engineering specifications. Insulated concrete form types break down into three categories:

Block Systems – a typical block unit is 200 mm (8") to 400 mm (16") tall, and 1200 mm (48") to 2400 mm (96") long. They have interlocking edges that stack together similar to Lego® blocks.

Panel Systems – are the largest ICF system. These units are 300 mm (12") to 1200 mm (48") tall and 2.4 m (8') to 3.6 m (12') long.

Plank Systems – are 200 mm (8") to 300 mm (12") tall, and 1.2 m (4') to 2.4 m (8') long. The main difference between the panel and the plank system is the assembly method.

Code requirements for ICF systems apply to each of the constituent materials, plastic foam insulation and concrete, respectively.

Permitted Placement of Thermal Insulation Materials

As noted previously, the performance of thermal insulation can be significantly affected by its moisture content and excessive compression. For these reasons, the placement of certain insulation materials is not permitted in exterior, below-grade environments. Table 3.2 summarizes the permitted placement of thermal insulation materials by product type, and also indicates additional requirements for fire protective coverings when certain product types are installed on the interior of livable spaces.

	Permitted Placement	
Insulation Type	***Interior***	***Exterior, Below-Grade***
Glass or Mineral Fibre Batt	YES	NO
Glass or Mineral Fibre Loose Fill	YES	NO
Cellulose Loose Fill	YES	NO
Glass or Mineral Fibre Boardstock (Semi-Rigid)	YES	YES
Expanded Polystyrene Boardstock (Types I, II and III)	YES*	YES
Extruded Polystyrene Boardstock (Types II - manufacturer may still restrict to interior and exterior above grade applications, III and IV)	YES*	YES
Glass or Mineral Fibre Spray Type	YES	NO
Cellulose Spray Type	YES	NO
Polyurethane Spray Type	YES*	YES
Insulated Concrete Forms	YES*	YES
* Because these materials are combustible, they must be covered with a fire-protective covering, such as drywall, if used to insulate living spaces.		

Table 3.2 Permitted placement of thermal insulation.

Framing and Furring Materials

Framing and furring materials in basement systems are typically used on the interior of the foundation structure for the attachment of finishes and to provide a space for insulation, plumbing and wiring. It is important to distinguish between framing and furring as it is defined in the National Building Code of Canada.

Framing includes loadbearing and non-loadbearing walls, floors and roofs. In basements, framing normally involves only loadbearing and non-loadbearing walls.

Furring is attached to framing or other types of structures (e.g., concrete foundation wall) to provide a means of attaching finishes. The furring space may be insulated and serve as a chase for plumbing and wiring.

The most predominant materials for framing and furring are wood and sheet steel members. Code requirements for each of these materials are different, as are the requirements for framing and furring.

Framing
Framing in wood must comply with the requirements of Section 9.23, Wood-Frame Construction, of the National Building Code of Canada. Lumber and wood products must conform to the requirements of Subsection 9.3.2, Lumber and Wood Products. It is important to observe the code limitation on the maximum moisture content of lumber – 19% at the time of installation.

Steel framing of non-loadbearing walls must conform to the requirements of Section 9.24, Sheet Steel Stud Wall Framing. Steel studs and runners must conform with the requirements of CAN/CGSB-7.1-M, Cold Formed Steel Framing Components. Loadbearing steel stud applications must be designed in conformance with Part 4.

Furring
Wood furring must comply with the requirements of Subsection 9.29.3, Wood Furring, of the National Building Code of Canada. In practice, lumber sizes used for furring in basement construction exceed the size requirements in Table 9.29.3.1, Size and Spacing of Furring, due to thermal insulation and building services considerations.

Requirements for steel furring are the same as for steel framing of non-loadbearing walls.

3.3 Materials For Drainage, Dampproofing & Waterproofing Systems

Part 2 of these Guidelines presents the various options for drainage, dampproofing and waterproofing. Typically, drainage and dampproofing are employed in situations where the foundation drainage system is continuously effective, either passively or actively (see Figure 2.2), and the local groundwater does not rise above the footings. In areas with periodically ineffective foundation drainage, waterproofing is applied to resist hydrostatic pressures. Foundation drainage is also provided to control groundwater pressures by draining away accumulated water. Requirements for materials used in each of the above cases are presented below along with key considerations.

Granular Drainage Layer and Backfill Materials

Granular drainage layers represent an alternative to drainage pipes for the purpose of foundation drainage. Typically, granular drainage layers are used when active foundation drainage (sump pit and pump) is required. When gravity drainage to a storm sewer, ditch or dry well is possible, drainage pipes are typically installed. Article 9.14.2.1, Foundation Wall Drainage of the National Building Code of Canada, requires that:

1) Unless it can be shown to be unnecessary, the bottom of every exterior foundation wall shall be drained by drainage tile or pipe laid around the exterior of the foundation in conformance with Subsection 9.14.3, or by a layer of gravel or crushed rock in conformance with Subsection 9.14.4.
2) Where mineral fibre insulation or crushed rock backfill is provided adjacent to the exterior surface of a foundation wall, it shall extend to the footing level to facilitate drainage of groundwater to the foundation drainage system. (See Appendix A of the NBC)

Granular Drainage Layer
Requirements for granular drainage layers are found under Subsection 9.14.4 of the National Building Code of Canada. Granular material used to drain the bottom of a foundation must consist of a continuous layer of crushed stone or other coarse clean granular material containing not more than 10% of material that will pass a 4-mm sieve. Proper gradation of the drainage material ensures sufficient voids to transport water effectively. Granular material must be laid on undisturbed or compacted soil to a minimum depth of not less than 125 mm (5 inches) beneath the building, and extend not less than 300 mm (12 inches) beyond the outside edge of the footings.

Backfill Materials

Requirements for backfill materials in the National Building Code of Canada simply restrict the inclusion of deleterious materials and boulders larger than 250 mm (10 inches) diameter within 600 mm (2 feet) of the foundation. In some cases, native soils are poor draining and may impair the proper performance of the foundation drainage system. Either free-draining granular backfill or a drainage medium applied full-depth, below grade to the exterior of the foundation wall is advisable. (Note: In Ontario, all Class A basements require an explicit wall drainage system to be installed.)

Foundation Wall Drainage

Code requirements for drainage tile and pipe may be found under Subsection 9.14.3, Drainage Tile and Pipe, of the National Building Code of Canada. Article 9.14.3.1, Material Standards, requires that drain tile and drain pipe for foundation drainage shall conform to:

ASTM C 4, *Clay Drain Tile*;

ASTM C 412M, *Concrete Drain Tile (Metric)*;

ASTM C 444M, *Perforated Concrete Pipe (Metric)*;

ASTM C 700, *Vitrified Clay Pipe, Extra Strength, Standard Strength and Perforated*;

CAN/CGSB-34.22-M, *Pipe, Asbestos Cement, Drain*;

CAN/CSA B182.1-M, *Plastic Drain and Sewer Pipe and Pipe Fittings*;

CSA G401, *Corrugated Steel Pipe Products*; or

NQ 3624-115, *Thermo-Plastic Pipe - Flexible Corrugated Tubing and Fittings for Soil Drainage*.

In Canada, the most commonly employed foundation drainage pipe is corrugated plastic drainage tubing and fittings, made from thermoplastic materials, designed for use in the drainage of land, foundations, and under floors. This type of piping and fittings is governed by the NQ 3624-115 standard, which distinguishes between three types of tubing:

Type 1 – for non-perforated tubing

Type 2 – for perforated tubing (perforation width varying from 0.5 mm to 2.0 mm); and

Type 3 – for perforated tubing (perforation width > 2.0 mm)

Important Note: Type 3 tubing must be used with appropriate geotextile filters to prevent clogging.

Relevant requirements for all types of foundation drainage piping cited in the National Building Code of Canada include:

9.14.3.2. Minimum Size

1) Drain tile or pipe used for foundation drainage shall be not less than 100 mm in diameter.

9.14.3.3. Installation

1) Drain tile or pipe shall be laid on undisturbed or well-compacted soil so that the top of the tile or pipe is below the bottom of the floor slab or crawl space.
2) Drain tile or pipe with butt joints shall be laid with 6 mm to 10 mm open joints.
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% of material that will pass a 4-mm sieve.

Additional means of providing foundation wall drainage are currently available in Canada. These typically rely on either a plastic membrane or thermal insulation system to effectively convey water adjacent to the basement walls downwards to the drainage tile or granular drainage layer.

Note on Engineered Drainage Products
Wall drainage products for use in basement construction are normally of Type 2, Class A or B, as evaluated by CCMC. The difference between Class A and Class B products is based on the rate of water drainage through various types of soils, ranging from pervious (sand/gravel) to impervious (clay). Class A products perform effectively in impervious soils (the drainage medium performs the entire drainage function) where Class B products are limited for use in pervious and semi-pervious soil conditions that allow for some drainage through the soil. It is extremely important to properly identify native soil composition if it is to be used as backfill against these drainage products. Pervious and semi-pervious soils comprise very fine sand, organic and inorganic silts, mixtures of sand, silt and clay, glacial till, and stratified clay deposits that have a soil grain size defined by $D_{10} > 0.002$ mm where D_{10} is the sieve size that permits 10% by weight of the soil to pass through in a sieve analysis test. It is not to be used in practically impervious soil conditions (homogeneous clays below zone of weathering) where the soil grain size $D_{10} < 0.002$ mm. All Type 2 drainage products are limited for use in depths up to 3.7 m (12 feet) below grade. For all other usage and limitations information, check the CCMC evaluation report corresponding to the selected wall drainage product.

Plastic Membranes
Currently evaluated plastic membrane products available in Canada typically consist of carbon-compounded high-density polyethylene sheet roll, manufactured in such a way that the material has a dimpled surface on one side to provide an air gap between the concrete wall and the adjacent soil. When properly installed, these products provide a level of dampproofing performance equivalent to that required in the NBC 1995, Subsection 9.13.2.

The use of these products has been evaluated for applications falling under the provisions of Part 9 of the NBC 1995, in depths up to 3.7 m. Applications below such depths could be appropriate; nevertheless, they are not covered by the present CCMC evaluations. It is also important to note that these products are not intended to resist flood conditions. Where there is a risk of flooding or drainage backup, appropriate waterproofing measures should be considered.

High-Density Mineral Fibre Insulation (in dual role)
Semi-rigid glass or mineral wool insulation products may play a dual role, as thermal insulation, and for foundation wall drainage. These systems are designed to be used as a protective layer or

a capillary breaking layer against the foundation wall to protect the wall against transient or intermittent water that may come in contact with the wall surface.

The material, size and installation requirements for drainage tile and pipe shall conform to Subsection 9.14.3 of the OBC. The finished grade is to be within 75 mm (3 inches) of the top of these products. The placement and grading of backfill shall conform to the requirements of Subsection 9.12.3 of the OBC.

The insulating board must be installed to the top surface of the footing to facilitate evacuation of water from the drainage layer to the weeping tile. It is recommended that an impervious “topping off” layer of clay/silt material be placed on top of the backfill with a positive slope leading surface water away from the building.

Foam Plastic Insulations (in dual role)
Foam plastic insulations, both boardstock and spray-type, have been evaluated by CCMC for use as foundation wall drainage. Currently, Type I and II polystyrene boardstock systems have been evaluated. These Type 2 drainage products are either Class A or Class B rated (see above note on Engineered Drainage Products). Class A products should be selected to deliver transient water, including heavy rainfall, to the weeping tiles when installed against the foundation wall, in either pervious, semi-pervious or practically impervious soils.

Spray polyurethane foam on the exterior of basement walls has also been demonstrated to be an effective foundation wall drainage option.

For further information on exterior insulation basement system (EIBS) performance, refer to the following publications:

Journals and Conference Proceedings

Swinton, M.C., Karagiozis, A.N., "Investigation of warm weather condensation in new and insulated basement walls," Thermal Performance of the Exterior Envelopes of Buildings VI (Clearwater, Florida, USA, December 05, 1995), pp. 101-107, December 01, 1995. (NRCC-38754) (IRC-P-4035)

Swinton, M.C., Bomberg, M.T., Kumaran, M.K., Maref, W., "In-situ performance of expanded molded polystyrene in the exterior insulation systems (EIBS)" *Journal of Thermal Envelope and Building Science,* 23, (2), pp. 173-198, October 01, 1999. (NRCC-43679)

Bomberg, M.T., Kumaran, M.K., Swinton, M.C.,, "On variability in physical properties of molded, expanded polystyrene," *Journal of Thermal Envelope & Building Science,* 23, (3), January, pp. 244-262, January 01, 2000. (NRCC-43987)

Bomberg, M.T., Kumaran, M.K., Swinton, M.C., Maref, W., "Performance of exterior basement insulations over two-year exposure period," International Building Physics Conference (IBPC) (Eindhoven, 2000-09-01), pp. 81-90, September 01, 2000. (NRCC-44221)

Swinton, M.C., Maref, W., Bomberg, M.T., Kumaran, M.K., Normandin, N., "Thermal analysis of heat flows in basement walls with exterior insulation," 1, International Conference on Building Envelope Systems and Technologies ICBEST 2001 (Ottawa, ON, June 26, 2001), pp. 347-351, July 01, 2001. (NRCC-44769)

Swinton, M.C., Maref, W., Bomberg, M.T., Kumaran, M.K., Normandin, N., "Assessing heat flow patterns in basement walls with exterior insulation," Performance of Exterior Envelopes of Whole Building VIII: Integration of Building Envelopes (Clearwater Beach, FL, December 02, 2001), pp. 1-9, December 12, 2001. (NRCC-45204)

Available on the Web

Swinton, M. C.; Bomberg, M. T.; Kumaran, M. K.; Maref, W.; Normandin, N.; Marchand, R. G. *In-Situ Performance Evaluation of Exterior Insulation Basement Systems (EIBS) - Spray Polyurethane Foam: Summary Report*.
http://irc.nrc-cnrc.gc.ca/fulltext/ir820/IR-820.pdf

Maref, W.; Swinton, M.C.; Kumaran, M.K.; Bomberg, M.T.
Three-dimensional analysis of thermal resistance of exterior basement insulation systems (EIBS). Building and Environment, 36, (4), May, pp. 407-419, May 01, 2001.
http://irc.nrc-cnrc.gc.ca/fulltext/nrcc43090/

Kesik, T. J.; Swinton, M. C.; Bomberg, M. T.; Kumaran, M. K.; Maref, W.; Normandin, N. *Cost effective basement wall drainage alternatives employing exterior insulation basement systems (EIBS).* Eighth Conference on Building Science & Technology (Toronto, Ontario, 2/22/2001), pp. 377-392, March 01, 2001.
http://irc.nrc-cnrc.gc.ca/fulltext/nrcc44756/

Swinton, M.C.; Kumaran, M.K.; Bomberg, M.T.; Normandin, N.; Maref, W.
Performance of Thermal Insulation on the Exterior of Basement Walls. Construction Technology Update.
http://irc.nrc-cnrc.gc.ca/pubs/ctus/36_e.html

Dampproofing and Waterproofing: Coatings, Sheets & Membranes

Moisture protection from external moisture sources for building elements in contact with the ground is generally categorized as either waterproofing or dampproofing. Waterproofing provides a continuous protection against water ingress and is intended to resist hydrostatic load. Dampproofing, on the other hand, does not provide a seal against bulk water ingress and cannot withstand hydrostatic pressure – it only serves as a barrier to the ingress of capillary water and water vapour (diffusion).

It should be recognized that manufacturers of moisture protection products often produce materials that can fulfill more than one control function. As noted earlier, plastic membranes and certain plastic foam insulation materials can satisfy requirements for dampproofing below-grade elements of the basement system.

Article 9.13.2.1 of the National Building Code of Canada identifies materials standards applicable to exterior dampproofing and waterproofing materials:

CAN/CGSB-37.1-M, *Chemical Emulsified Type, Emulsified Asphalt for Dampproofing*;

CAN/CGSB-37.2-M, *Emulsified Asphalt, Mineral Colloid Type, Unfilled, for Dampproofing and Waterproofing and for Roof Coatings*;

CGSB 37-GP-6Ma, *Asphalt, Cutback, Unfilled for Dampproofing*;

CAN/CGSB-37.16-M, *Filled, Cutback Asphalt for Dampproofing and Waterproofing*;

CGSB 37-GP-18Ma, *Tar, Cutback, Unfilled for Dampproofing*;

CAN/CGSB-51.34-M, *Vapour Barrier, Polyethylene Sheet for Use in Building Construction*; and

CSA A123.4-M, *Bitumen for Use in Construction of Built-Up Roof Coverings and Dampproofing and Waterproofing Systems*.

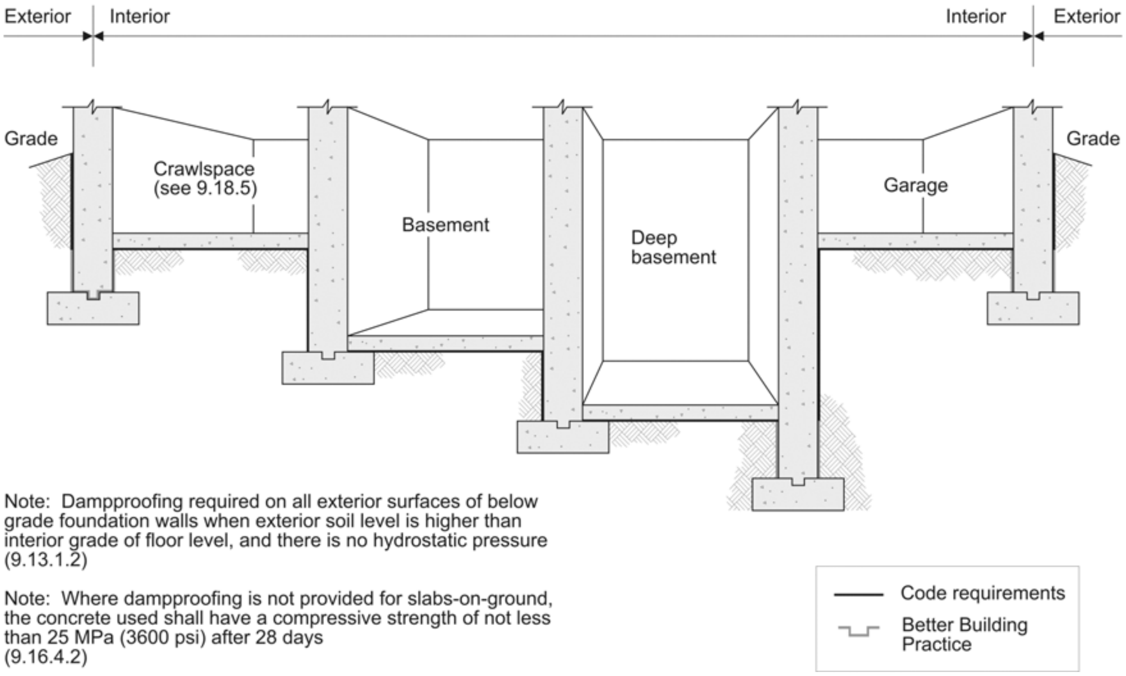
Standards for application of all bituminous waterproofing and dampproofing materials are prescribed as:

CAN/CGSB-37.3-M, *Application of Emulsified Asphalts for Dampproofing or Waterproofing*;

CGSB 37-GP-12Ma, *Application of Unfilled Cutback Asphalt for Dampproofing*; or

CAN/CGSB-37.22-M, *Application of Unfilled Cutback Tar Foundation Coating for Dampproofing*.

Requirements for the dampproofing of basements are depicted in Figure 3.3.



Note: Dampproofing required on all exterior surfaces of below grade foundation walls when exterior soil level is higher than interior grade of floor level, and there is no hydrostatic pressure (9.13.1.2)

Note: Where dampproofing is not provided for slabs-on-ground, the concrete used shall have a compressive strength of not less than 25 MPa (3600 psi) after 28 days (9.16.4.2)

Figure 3.3 Requirements for basement dampproofing.
[Adapted from National Housing Code of Canada 1998 and Illustrated Guide]

The following section deals with materials for air and moisture control, with an emphasis on the control of interior sources of moisture migration into the building envelope.

3.4 Materials for Moisture and Air Control

Materials used for control of moisture and air movement may be selected to deal with each control function separately or, as is often the case, to deal with both control functions simultaneously. This section examines the use of materials that are normally applied on the interior of the basement envelope.

Interior Dampproofing

Interior dampproofing is required when a separate interior finish is applied to a concrete or unit masonry wall, or concrete slab, that is in direct contact with the soil. It is also required where wood members are applied over below-grade concrete or unit masonry elements for the installation of insulation and/or finish.

In the case of walls, the dampproofing must extend from the basement floor up to ground level. Permissible dampproofing materials include 0.05 mm or thicker polyethylene film, Type S roll roofing, or any membrane or coating. This implies than a variety of plastic foam and specially faced insulation materials also satisfy requirements for interior dampproofing. However, it is important to ensure that such materials with a permeability of less than 170 ng/(Pa.s.m^2) are not applied to the interior surface of the above-grade portions of the foundation wall.

For floors-on-ground, the dampproofing must be installed beneath the floor, except when a separate floor is provided over a slab, in which case the dampproofing may be applied over the slab. Dampproofing membranes installed below the slab must consist of either 0.15 mm, or thicker, polyethylene film, or Type S roll roofing, lapped not less than 100 mm (4 inches). Where dampproofing is applied above the floor slab, it must consist of two mopped-on coats of bitumen, 0.05-mm polyethylene film, or any other material providing equivalent performance.

Vapour Diffusion Control

The control of vapour diffusion is essential for all insulated assembles inboard of the foundation wall and floor slab. There are several materials options available:

1) the use of polyethylene sheets or film;
2) the use of a membrane-type vapour barrier material other than polyethylene;
3) the use of a coating over the interior finish; or
4) the use of a material satisfying the permeability requirements for vapour barriers (e.g., plastic foam insulation, plastic or rubber finishes, etc.).

Specifically, Article 9.25.4.2, Vapour Barrier Materials, of the National Building Code of Canada cites the following requirements:

1) Except as required in Sentence (2), *vapour barriers* shall have an initial permeance not greater than 45 ng/(Pa.s.m^2).
2) When used where a high resistance to vapour movement is required, such as in wall constructions that incorporate exterior cladding or sheathing having a low water vapour permeance, *vapour barriers* shall have a permeance not greater than 15 ng/(Pa.s.m^2). (See Appendix A.)
3) Where polyethylene is installed as the *vapour barrier* required in Sentence (2), it shall conform to CAN/CGSB-51.34-M, "Vapour Barrier, Polyethylene Sheet for Use in Building Construction."
4) Membrane-type *vapour barriers* other than polyethylene shall conform to the requirements of CAN /CGSB-51.33-M, 'Vapour Barrier Sheet, Excluding Polyethylene, for Use in Building Construction."
5) Where a coating is applied to gypsum board to function as the *vapour barrier*, the permeance of the coating shall be determined in accordance with CAN/CGSB-1.501-M, "Method for Permeance of Coated Wallboard."

Air Leakage Control

Materials for air leakage control must satisfy requirements for resistance to air pressures, and more importantly, should be selected keeping in mind the continuity of the air barrier system. In basements, air leakage control is required at key interfaces between building assemblies. Air leakage control where the superstructure attaches to the foundation walls, typically the floor header assembly, is critical. The proper air sealing of penetrations around windows, doors, ducts, piping and wiring must also be addressed. Finally, adequate control of soil gas at the perimeter and penetrations of the basement floor slab must be provided, including the isolation of sumps and sewage ejectors (see below).

Requirements for air leakage control may be found under Subsection 9.23.3, Air Barrier Systems, of the National Building Code of Canada. The materials for air leakage control should be considered in the context of the air barrier system provided.

Polyethylene with Sealants

Where polyethylene sheets or film serves as an air barrier material, it must conform with CAN/CGSB-51.34-M, *Vapour Barrier, Polyethylene Sheet for Use in Building Construction*. Typically, joints in the polyethylene are lapped and clamped. Penetrations of the polyethylene and junctions with other materials are typically addressed with sealants or special tapes that should be selected on the basis of compatibility and durability with the adjoining materials.

Sheet/Panel and Gaskets/Sealants

When sheet or panel materials are selected for the air barrier system, penetrations and joints are typically sealed with gaskets and/or sealants. Specific materials are not prescribed in the code, but any material must provide an effective barrier to air movement under differential pressure due to stack effect, mechanical systems or wind.

Sprayed-in-Place Air Barrier
Extensive evidence now supports the use of spray polyurethane foam as an air barrier system. All SPF formulations comply with the requirements of CAN/ULC-S705.1-01, *Thermal Insulation - Spray Applied Rigid Polyurethane Foam, Medium Density, Material Specification*, and the installation must comply with CAN/ULC-S705.2-1998, *Thermal Insulation - Spray Applied Rigid Polyurethane Foam, Medium Density, Installer's Responsibilities - Specification.*

Soil Gas Control

Floors-on-ground, other than garages, must be constructed to reduce the potential for entry of radon or other soil gases. In most cases, this will be accomplished by placing 0.15 mm polyethylene under the floor, and sealing the perimeter and penetrations with a flexible sealant. Where polyethylene is used beneath the slab, it must conform with CAN/CGSB-51.34-M, *Vapour Barrier, Polyethylene Sheet for Use in Building Construction*. Other sheet or membrane materials may be used provided they conform to the requirements for air leakage control under Subsection 9.23.3, Air Barrier Systems, of the National Building Code of Canada. Refer to Section 2.6 of these guidelines for further information on soil gas control measures.

3.5 Finishing Materials

Finishing materials account for the final stages of construction for the exterior and interior of basements. While these are largely selected on the basis of appearance in the marketplace, due consideration for durable, moisture-resistant and washable finishes is warranted. For the vast majority of basements constructed in Canada, exterior finishes consist of the foundation material itself, either cast-in-place concrete or concrete masonry units. As these options do not involve material selection, this section focuses on the exterior treatment of external insulation basement systems (EIBS). Interior finish materials for basements are also examined with respect to the class of basement being constructed.

Exterior Above-Grade Finishing Materials for EIBS

External insulation basement systems involve a variety of boardstock and spray-type insulation materials, and from the perspective of above-grade finishes, also include insulating concrete form systems. There are several options available for achieving an acceptable exterior finish: 1) metal lath and stucco; 2) cement board and stucco; and 3) proprietary finish systems.

Metal Lath and Stucco
This approach represents the most traditional use of materials. A metal lath is mechanically fastened to the foundation over the exterior insulation, and a cementitious parging is applied. Normally, two coats of parging are applied, extending from the bottom of the exterior wall finish to approximately 150 mm (6 inches) below grade. The relevant requirements of Section 9.28, Stucco, of the National Building Code of Canada apply to this approach for exterior above-grade finishing of EIBS.

[See Figure 4.3 Lathe and parging protection option.]

Cement Board
A more recent approach to above-grade finishes utilizes cement board. These product types consist of aggregated Portland cement boards with glass-fibre mesh embedded in their back and front surfaces. The cement board is mechanically fastened to corrosion-resistant metal furring which has been attached to the foundation and/or building structure. In some cases, the joints in the cement board are covered with battens, but increasingly a fibre-reinforced tape is applied over the joints, followed by a polymer-modified pre-mixed stucco finish. Cement board used in such applications must conform with National Building Code of Canada 1995, Article 9.23.16.2, Thickness, Rating and Material Standards.

[See Figure 4.4 Cement board protection option.]

Proprietary Finish Systems

There are many innovative finishing products and systems available for the above-grade areas of exterior insulation basement systems. These range from fibre-reinforced stucco materials, through thin brick, tile or masonry units, to metal and plastic panels. While appropriately selected finishes can provide acceptable performance, many of the available options have yet to find acceptance in Canadian housing markets. Important considerations in the selection of these products are conformity with applicable material standards and code requirements, and where these are not applicable, CCMC or equivalent third-party evaluations.

Interior Finish Materials for Basements

Interior finishes for use in basements are governed by the requirements of Part 29*, Interior Wall and Ceiling Finishes,* and Part 30, *Flooring,* of the 1995 National Building Code of Canada. At present, there are no limitations placed on material usage depending on the class of basement system being constructed (see Table 1.2). The basement classification system is implicitly related to the level of thermal and moisture protection provided by the envelope system and the degree of environmental control in relation to that normally provided in livable, above-grade areas of the building. It is strongly recommended to base interior finishing materials selection on the class of basement being constructed, as described in Table 3.3.

Basement Classification	Interior Finish Recommendations
Class A	Same limitations on floor, wall and ceiling finishes as per Section 9.29 of the National Building Code of Canada.
Class B	Use of moisture-resistant materials with low susceptibility to mould growth recommended, unless basement is situated in free draining soils with effective site and foundation drainage.
Class C	Interior finishing not recommended unless proper measures are later provided to provide comparable performance to Class B basements.
Class D	Only interior finishes capable of withstanding periodic wetting, drying, cleaning and disinfecting are recommended.
Class E	Not applicable.

Table 3.3 Recommended limitations on interior finishes based on class of basement.

3.6 Mechanical Equipment

Requirements for mechanical equipment will vary according to the class of basement and its intended use. Livable basements will require mechanical equipment capable of providing controlled heating, ventilation and dehumidification. In some instances, cooling may be required where large glazed areas attracting heat gains in summer are provided. When the living space is a separate dwelling unit (Class A-1), a separate mechanical system is mandatory to prevent the spread of fire and smoke.

Heating

Detailed requirements for space heating may be found under Section 9.33, Heating and Air-Conditioning, of the National Building Code of Canada. For Class A basements, the quality of heating provided should be equivalent to that provided in other livable areas of the dwelling. The choice of heating system used in basements is often dictated by the type of system selected for the above-grade areas of the building. Options include forced air systems, hydronic (hot water) systems, and unitary systems, such as electric heaters or fuel-fired appliances, serving individual rooms and areas. Where forced-air systems are used to heat Class A-1 basements (separate dwelling units), either a separate heating system which does not communicate with other dwelling units must be installed, or appropriate measures for controlling the movement of fire and smoke must be provided, typically consisting of fire dampers in the ductwork at points of fire separation.

Ventilation

Requirements for ventilation of basements may be found under 9.32, Ventilation, of the National Building Code of Canada. Ventilation requirements are essentially distinguished as natural ventilation and mechanical ventilation.

Requirements for natural ventilation, typically provided as operable windows serving rooms and areas, are differentiated between livable areas and unfinished basements. For Class A basements, the provision of natural ventilation should conform to requirements for livable areas.

Mechanical ventilation requirements are dictated by the usage of a room or space, and whether or not the mechanical ventilation system is connected to a forced-air system. In Class A-1 basements, issues related to the control of fire and smoke in common forced-air heating systems also apply to common central ventilation systems.

Key considerations in mechanical ventilation of basements include depressurization and effective zone control. Excessive depressurization of the basement may cause soil and sewer gases to infiltrate the basement space, and cause the products of combustion from atmospheric, fuel-fired appliances to contaminate the indoor air. This is of particular concern for Class A basements intended to be livable. Provisions of the National Building Code of Canada must be strictly observed with regard to depressurization caused by the mechanical ventilation system. The responsiveness of the ventilation system to occupant demands, however, is not completely prescribed, hence the need for informed judgement. In Class A basements, an effective means of controlling mechanical ventilation is strongly recommended, and for Class A-1 basements, it may prove most practical to provide a separate mechanical ventilation system.

For other than Class A basements, observing requirements for natural ventilation, and the provision of mechanical ventilation for specific room types (e.g., bathrooms) is often sufficient.

Dehumidification

The control of the moisture content (relative humidity) of the air is a critical consideration for practically all classes of basements, and especially for Class A basements. Basements, particularly those constructed from cast-in-place concrete or concrete masonry units, are highly susceptible to condensation which causes problems such as deterioration of materials and finishes, odours and the growth of moulds.

In most Canadian climates, the ventilation of basements during periods of high outdoor humidity (summer) is not effective because the outside air supplied to, or drawn into, the basement is very near to its dew point. Typically cooler basement temperatures render many vapour-accessible envelope surfaces and basement contents susceptible to condensation problems.

Mechanical dehumidification of basement air is not explicitly prescribed by the National Building Code of Canada; however, it is highly recommended to satisfy the intent of code provisions for condensation control. In basements served by forced-air systems, air-conditioning equipment is often more than sufficient in capacity to effectively control basement humidity levels. In buildings without central air-conditioning, a stand-alone, portable dehumidifier properly sized for the basement area is an effective alternative. When using this approach, it is advisable to convey the condensate to a plumbing drain to avoid mould problems associated with condensate pans.

Another alternative to dehumidification is the use of interior finishes with low thermal diffusivities. These types of materials are characterized by low density, specific heat and thermal conductivity properties (e.g., insulation materials, both natural and synthetic). They are capable of rapidly changing temperature in response to contact with air/vapour mixtures, such that their surfaces remain above the dew point of outside air entering the basement. This strategy assumes that such finishes are continuous (full coverage of floors, walls and ceilings) and adequate air leakage control measures are provided.

Provisions for Controlling Temperature and Humidity

The building envelope plays a passive role in modification of the environment, and in some cases, this role must be supplemented with active mechanical systems. Some examples are the provision of space heating to maintain acceptable temperatures in the basement, and dehumidification to control water vapour levels in the basement.

Experience has shown that basements heated by central, single-zone systems (e.g., forced-air furnace with single thermostat located in above-grade living area) experience periods of insufficient heating during the spring and fall when solar gains satisfy above-grade heating demand for most of the day. Effective basement heating requires separate zone control or its own heating system. Similarly, dehumidification of the basement by ventilation may prove adequate during the fall, winter and spring months, but actually serve to increase moisture levels during hot, humid summer periods. This occurs in many climate zones of Canada when the moist outdoor air replaces basement air exhausted by the ventilation system. Under these conditions, dehumidification is required using either a stand-alone dehumidifier, or the air-conditioning in a forced-air system.

In Class A basements, it is assumed that temperature and humidity control will be comparable to that delivered in the above-grade areas of the house. Again, consideration of difficult conditions is necessary to select and properly install appropriate active systems.

Sump Pumps

In basements where gravity drainage of the foundation is not possible, sumps and sump pumps are required. These should conform to Article 9.14.5.2, Sump Pits, of the National Building Code of Canada. Several issues not explicitly addressed by code requirements should be carefully considered in practice. The first deals with the area and configuration of the basement. For very large basements, or basements with unusual shapes (e.g., L-shape, J-shape or U-shape), more than one sump may be required for effective drainage. Second, in low-permeability soils, the minimum required depth of the sump (750 mm or 30 inches) may not result in sufficient drawdown to maintain water levels at the extremities of the basement below the basement slab or floor assembly. Third, for Class A basements, it is advisable to provide an emergency back-up power supply to the sump pump as the correlation between extreme weather phenomena and power failures is quite high. A pump alarm is also recommended to indicate when a pump has failed and/or requires maintenance. As a guideline, review local practices for sump pumps.

Sub-Slab Depressurization Equipment

Where sub-slab depressurization is employed for the control of soil gas entry, the appropriate selection of materials and equipment is critical to safety and reliable performance.

Installation of the sub-slab depressurization system requires that piping cast through the slab 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. Material standards for exhaust pipes are not explicitly cited in the National Building Code of Canada, however, in practice piping should conform with applicable requirements cited in the National Plumbing Code of Canada 1995.

The exhaust fan serving the sub-slab depressurization system should be located outside the occupied space where noise will not be a nuisance. 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. Equipment standards for exhaust fans and sizing criteria are not explicitly cited in the National Building Code of Canada. However, the fan should be of a type suitable for the application and capable of continuous operation. Access for convenient inspection and maintenance is prudent. It is also advisable to connect a sensor that indicates failure of the exhaust fan that, if installed as recommended, is neither visible nor audible.

Synopsis

The selection of materials and equipment for basement systems is largely governed by the intended use, or class, of the basement. Within the spectrum of site conditions encountered by builders across the country, there can be large lot sizes and natural slopes that allow surface drainage away from the house in all directions, local soils can be free draining and stable, the water table can be well below the footings, and the local climate can be relatively dry most of the time. As a result, the code minimum requirements have to reflect the possibility that a very basic basement configuration can perform adequately in such conditions. Nevertheless, it is improbable that all of those favourable conditions all exist together most of the time. As a result, when the builder is dealing with one, some or many challenging conditions in a given location, consideration has to be given to additional measures that may be needed beyond the code minimum to compensate for those challenging site conditions.

These guidelines advocate that designers and builders must carefully consider material and equipment selection within the context of the actual site and environmental exposure conditions where the basement will be constructed, and in conjunction with its intended use and occupancy. In most cases, exceeding minimum code requirements will be necessary to achieve acceptable levels of performance corresponding to modern consumer expectations, especially for Class A basement systems.

The next part of this guidelines publication deals with critical design details corresponding to the selected basement systems and materials.

References

National Building Code of Canada, 1995, including all Revisions and Errata.

National Plumbing Code of Canada 1995.

National Housing Code of Canada 1998 and Illustrated Guide.

PART 4 - CRITICAL DESIGN DETAILS

4.0 Overview

In addition to the proper selection of an appropriate basement system and materials, it is also necessary for designers and builders to address critical construction details. This part of the guidelines presents a number of design details intended to address a large number of commonly encountered and easily avoidable performance problems.

Detailing Tips

Designers:

Work at an appropriate scale (1:10 or larger). Building materials have real dimensions, and most importantly, tolerances.

Draw details in the order of construction. Drawing on paper, or using computer-aided-design software, is not the same as actually building something. Footings must be constructed before foundation walls. By observing the proper sequence it is possible to discover potential problems, conflicts and cost-effective improvements. Additionally, with suitable design details, planning of construction sequences, materials procurement, and actual timing erection, the best use of mortgage draws and hence improved profitability can be maintained. Remember, basement erection includes site drainage, basement area drainage, backfilling and rough landscaping.

Review designs for consistency with related details so that the work may be performed using similar materials, equipment and techniques. Going beyond the skill level of locally available trades and labour invites on-site modifications and substitutions that lack the benefit of forethought.

Builders:

Focus on non-typical areas, especially intersections between different assemblies. The weak links in a design are usually where one material or assembly is connected to another.

Review details with trades and sub-contractors. Drawing on the knowledge and experience of those performing the work has many advantages that translate into better performance and less inflated costs.

Note field modifications to details on drawings for future projects.

For further information on typical construction practices and details, refer to Part 2 of the *National Housing Code of Canada 1998 and Illustrated Guide.*

4.1 Site Grading and Drainage

Proper site grading and drainage represent a primary line of protection against basement moisture problems. In many municipalities, a site grading and drainage plan is required, ensuring that the control of runoff from rainfall and snowmelt is planned ahead of construction. Regulations normally require that runoff is directed overland to the roadway or ditch, and away from adjacent properties.

Assuming that the site grading and drainage satisfies local regulations, a common problem around the perimeter of the basement is the settlement of the backfill resulting in a loss of positive slope away from the building.

Figures 4.1 and 4.2 indicate simple measures for avoiding situations where water is directed toward the foundation walls, causing a greater risk of dampness and/or leakage.

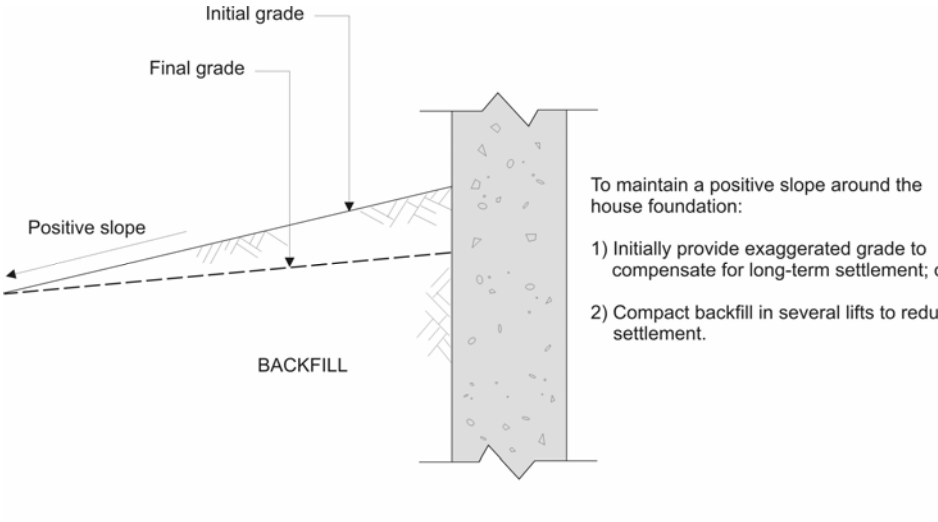


Figure 4.1 Compensating for backfill settlement.

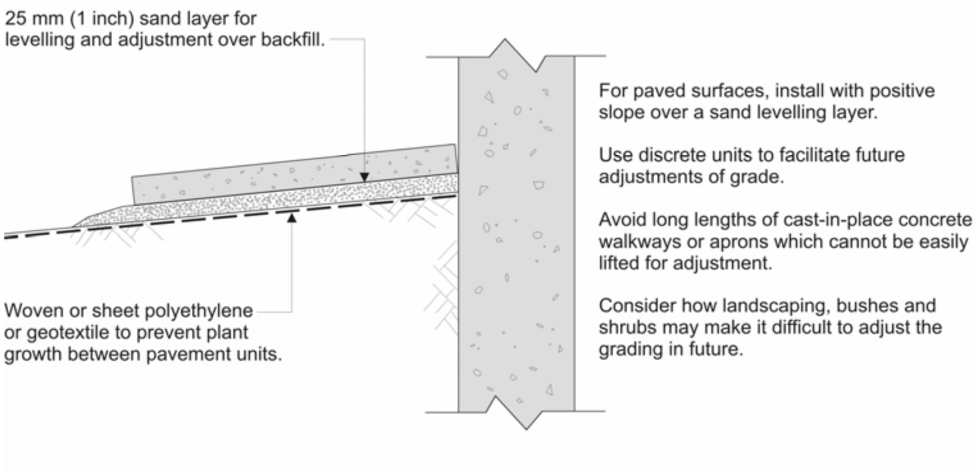


Figure 4.2 Installation of paved surfaces adjacent to the basement walls.

4.2 Above-Grade Portion of the Basement Wall and Windows

It is normally the case that greater attention is spent dealing with below-grade than above-grade elements of the basement system. At times, sufficient attention to detail in parts of the basement extending above-grade is lacking. This section deals with two key aspects of above-grade detailing critical to basement system performance: the protection of exterior insulation above grade, and the installation of basement windows.

Protection of Above-Grade Exterior Insulation

Figures 4.3 and 4.4 depict the two most common options for protection of the above-grade portions of the basement insulation, when full-height, exterior basement insulation is employed.

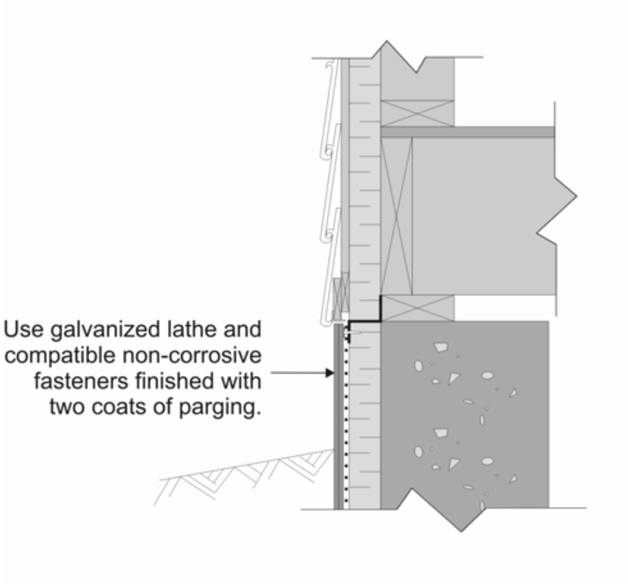


Figure 4.3 Lathe and parging protection option.

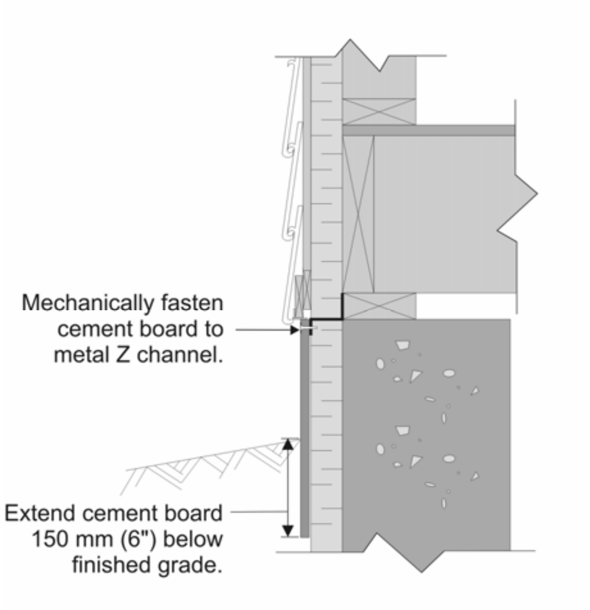


Figure 4.4 Cement board protection option.

Installation of Above-Grade Windows

The proper installation of basement windows requires careful attention to the sealing of the breaching, or gap between the window and rough opening. The seal should be air and water tight, and planned to consider the continuity of the air leakage and moisture protection system used inboard of the foundation wall. Figure 4.5 depicts typical details for conventional window installations in above-grade basement walls.

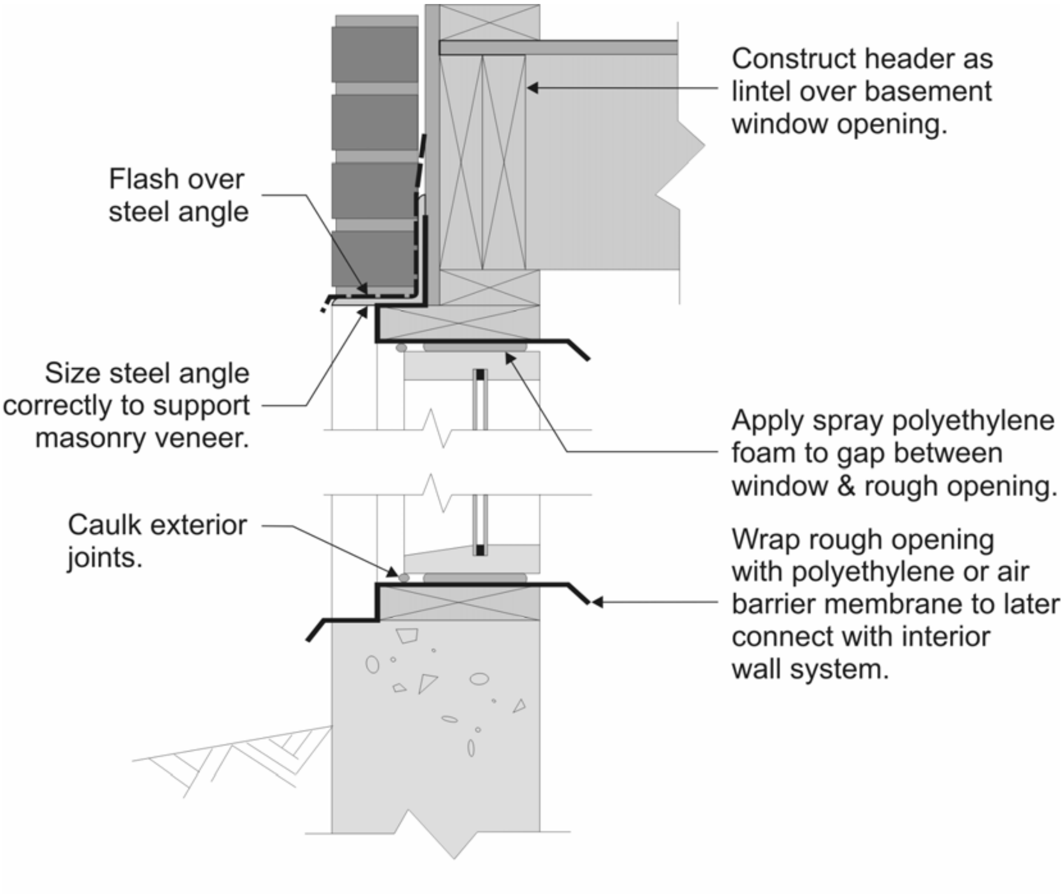


Figure 4.5 Above-grade window installation.

A similar approach may be adapted to the installation of exterior doors in basement walls. Another material gaining in popularity for security reasons is the use of glass block. The proper installation of these products is explained in manufacturer's instructions. Ensure that only those methods and compatible joint and sealing materials recommended by the manufacturer are used in these assemblies.

4.3 Window Well Detailing

Window wells are not a preferred basement construction practice and should be avoided at all cost, as they are lower than grade, they attract snow and surface water, and the good drainage needed to make them work can quickly overload the drain-pipe system below. That being said, if window wells are being used, these are some useful tips.

Window wells rely on positive drainage to avoid moisture problems at the foundation wall in the vicinity of the well, and wetting of the window itself. Figures 4.6 and 4.7 depict suitable details for proper window well performance.

When the foundation drainage system is being installed, T-fitting connections must be provided beneath the center of window wells. A vertical length of drainage piping must then be installed extending up to just below the top of the granular layer in the window well. Two options are available for the vertical piping:

1) the entire length of piping may be perforated provided it is wrapped with a filter cloth sock to prevent clogging by fine soil particles; or
2) only the portion of piping residing within the granular layer is perforated, and the remainder is solid.

In both cases, the top should be capped or protected to prevent granular material from falling into and plugging the drainage piping.

Two critical parameters affect the performance of the window well. The first is the distance from the top of the granular layer to the bottom of the window opening. This distance should be sufficient to avoid accumulations of water and melting snow to rise above the bottom of the window opening. The second is the distance from the finished grade to the top of the window well enclosure, which should be sufficient to minimize accumulations of blowing snow in the window well. Factors to consider include local weather conditions and the exposure of the window wells to wind, rain and snow.

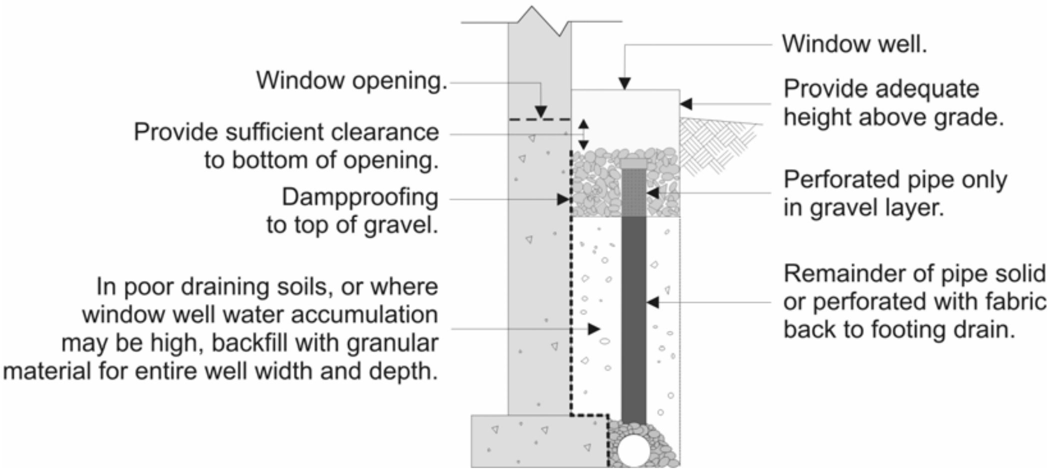


Figure 4.6 Section of critical window well details.

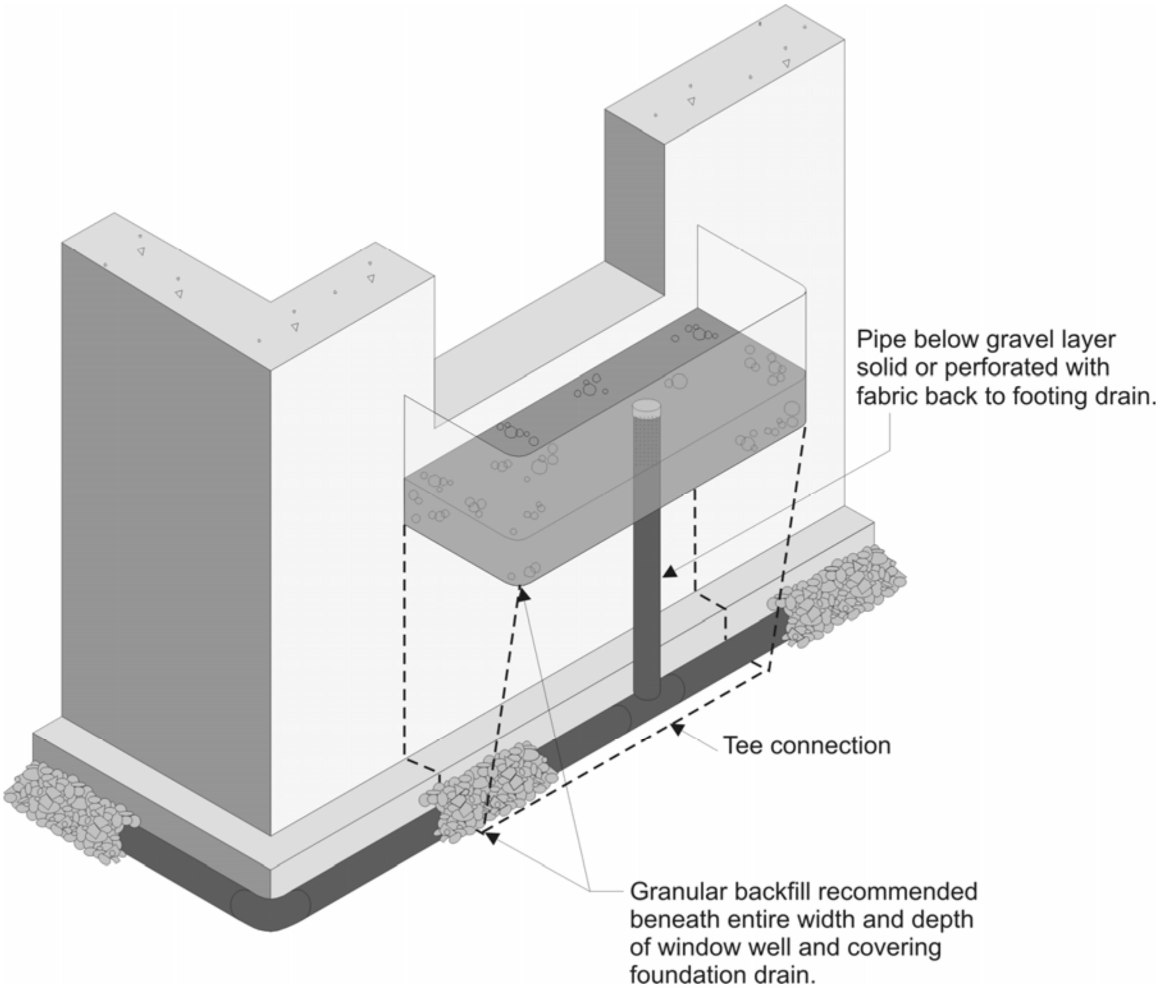


Figure 4.7 Isometric view of window well installation.

4.4 The Wall-Soil Interface

Foundation wall-soil interfaces account for most of the soil drainage opportunities around the perimeter of the basement. This section deals with wall-soil interfaces that employ either granular drainage layers or a drainage medium, such as a membrane or exterior insulation. First, and very importantly, proper backfill practices are essential and bad practices such as those depicted in Figure 4.8 must be avoided.

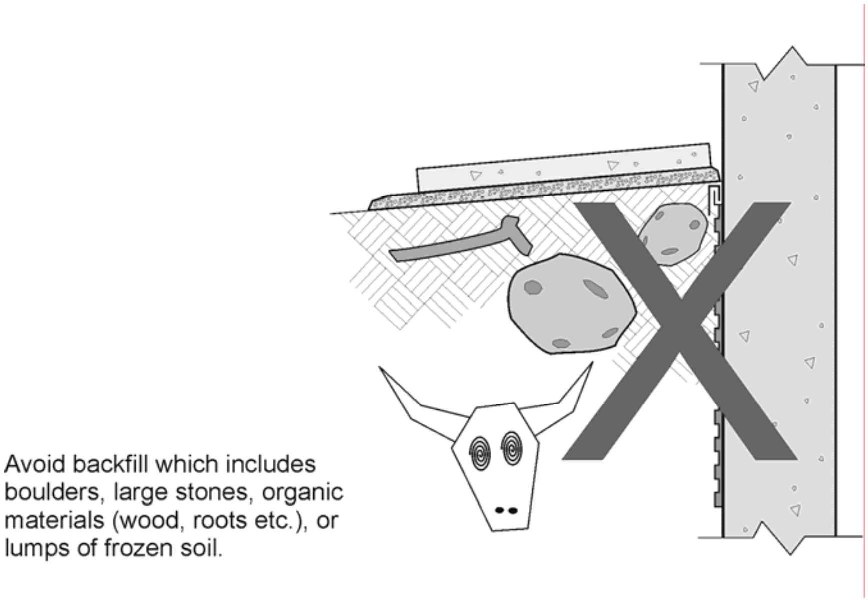


Figure 4.8 Bad backfilling practices to avoid.

Granular Drainage Layers

When granular drainage layers are provided around foundation walls, these should extend from just below grade to the top of granular material covering the foundation drainage system. In soils with loose, fine particles, such as silts, the risk of gradual and eventual plugging of the granular drainage layer is greater than in granular or clay soil types. The provision of top soil and plant materials may also reduce the drainage effectiveness of the granular drainage layer. For these reasons, it is advisable to protect the top surface of the granular drainage layer prior to the application of top soil and landscape elements such as grass, flowers or shrubs. Figure 4.9 depicts a practical approach to protecting granular drainage layers from plugging by fine soil particles.

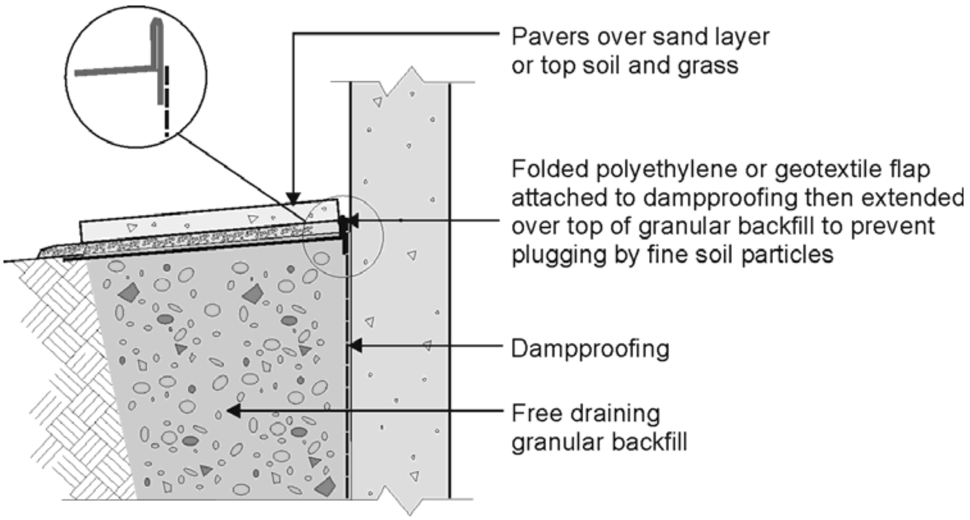


Figure 4.9 Protection of granular drainage layers from plugging by soil particles.

Drainage Media

Drainage media must be installed according to manufacturer's instructions. Most, but not all, systems require the installation of a moulding, channel or flashing to prevent the migration of soil behind the membrane or insulation material. This application is depicted in Figure 4.10 and is recommended for all approved drainage media. Note that the protective moulding, channel or flashing is installed just below grade. As importantly, it is generally not required when exterior insulation is installed continuously over the foundation and above-grade walls, provided a tight fitting joint is maintained between insulation materials.

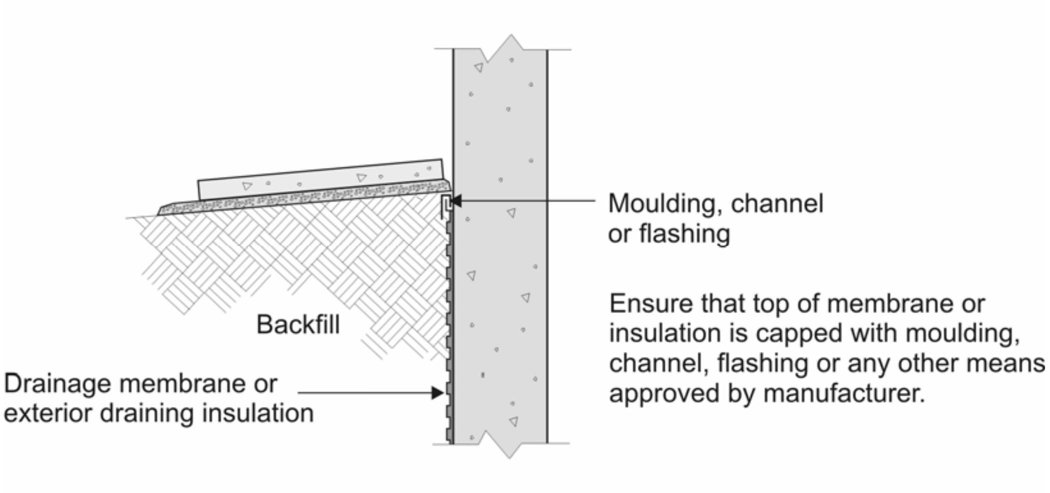


Figure 4.10 Protection of top edge of drainage media from soil migration.

4.5 Wall/Footing Intersection

The intersection at foundation walls and footings represents the potential for a number of problems, depending on the water table, soil conditions and intended use of the basement. Appropriate defensive measures are depicted in Figure 4.11. In areas with fluctuating water tables, the potential for footings to reside in groundwater is high, and as a result the capillary flow of water from the footing into the foundation wall may pose a moisture problem. When the local water table level cannot be maintained sufficiently below the footings (as a rule of thumb, at least the width of the footing below the bottom of the footing), dampproofing the top of the footing prior to construction of the foundation wall is advisable. It may also be prudent to improve communication between the sub-slab granular material and the foundation drainage piping. This may be accomplished with small diameter piping cast into the footings, or by arranging perforated piping within the granular material beneath the slab which is then connected to the perimeter drain pipe at several points around the basement footings.

To avoid the gradual accumulation of fine soil particles in the drain pipe, a layer of granular material, glass or mineral fibre wool placed beneath the drain pipe may be provided in addition to a fabric sock. This approach is recommended where rising water levels in silty soils can transport soil particles from underneath and into the drain pipe perforations.

Another area of potential concern is at the slab/footing/wall intersection. Heat transfer modelling of basement floor slabs indicates that heat flow from the interior, through the perimeter of the slab and down through the footing accounts for a significant thermal bridge effect in conventional construction. This type of thermal bridging can significantly reduce the effectiveness of sub-slab insulation, especially when in-floor heating is provided. This problem may be avoided by the installation of insulation between the edge of the slab and the foundation wall, and also between the bottom of the slab and the top of the footing. The granular layer must be fully compacted to prevent settlement and possible cracking of the slab in this area.

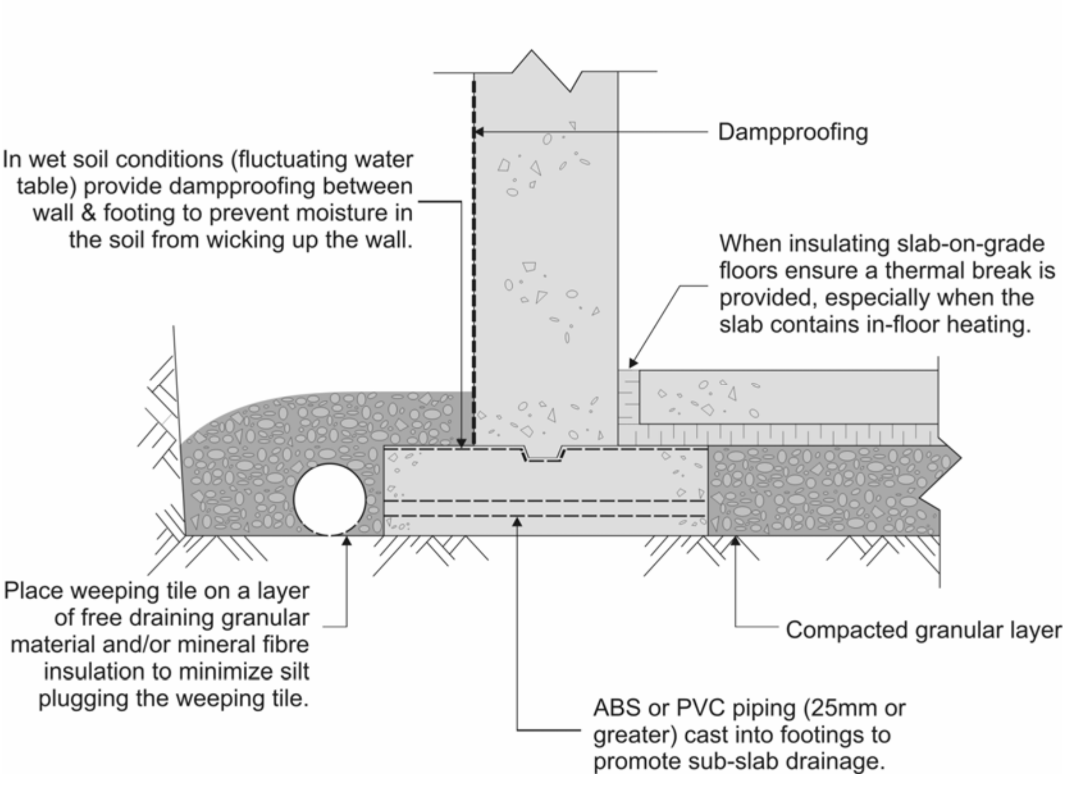
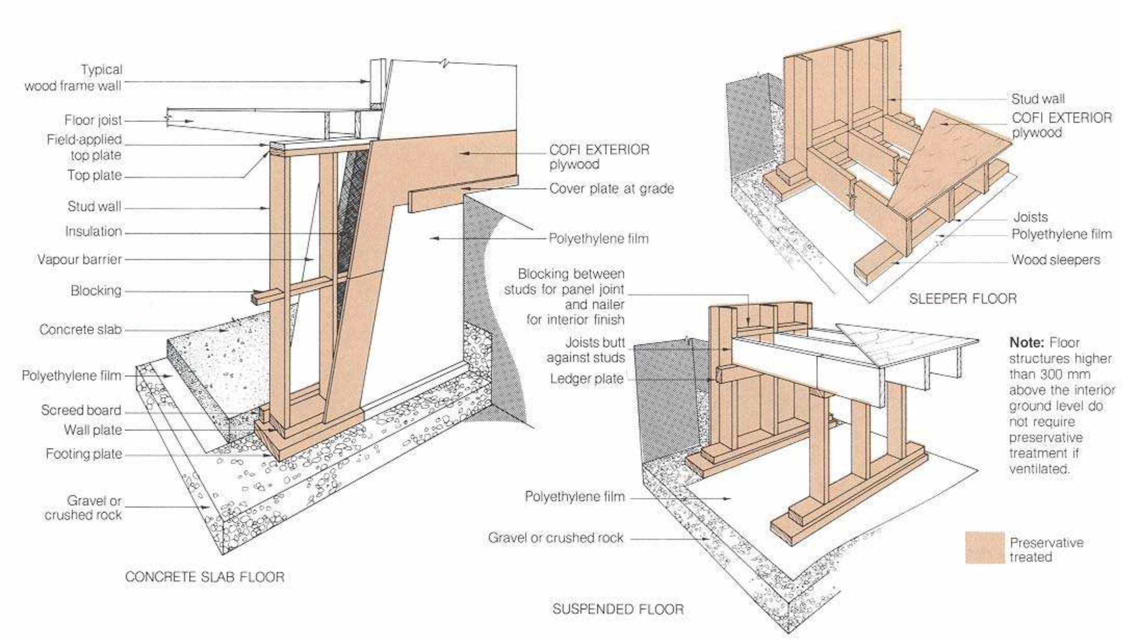


Figure 4.11 Detailing considerations for wall/footing intersection

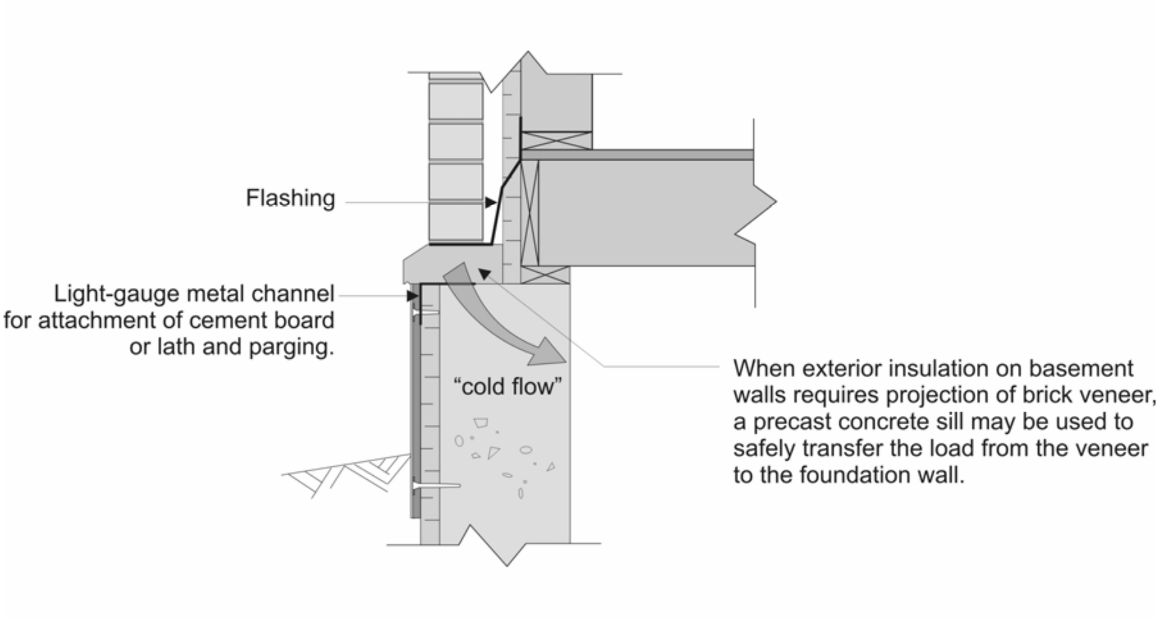


Note: Floor structures higher than 300 mm above the interior ground level do not require preservative treatment if ventilated.

Figure 4.12 Recommended wall/footing intersection details for permanent wood foundations. [Figure courtesy of Canadian Wood Council.]

4.6 Special Detailing for Support of Brick Veneer

When external insulation basement systems (EIBS) are employed in houses with brick veneer exterior finishes, it is important to properly detail the support of the brick. Figure 4.13 depicts an approach that provides both structural and aesthetic benefits. The structural basis of the detail is explained in Figure 4.14.



When exterior insulation on basement walls requires projection of brick veneer, a precast concrete sill may be used to safely transfer the load from the veneer to the foundation wall.

Figure 4.13 Support of brick veneer for EIBS.

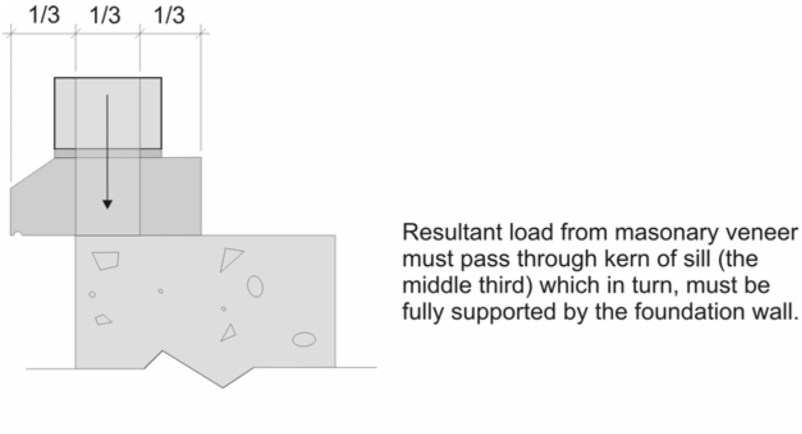


Figure 4.14 Structural basis for detailing of masonry sill or curb.

4.7 Moisture and Thermal Control in the Header Area

A major problem observed in the field and confirmed by hygrothermal modelling involves the header area and above-grade walls of cast-in-place concrete foundations (refer to *Special Conditions During Concrete Curing* in Section 2.7). The details that follow address issues of thermal bridging, air leakage and condensation control in the header area. These are not comprehensive, but instead illustrate basic strategies that may be modified to suit different types of basement and above-grade wall constructions.

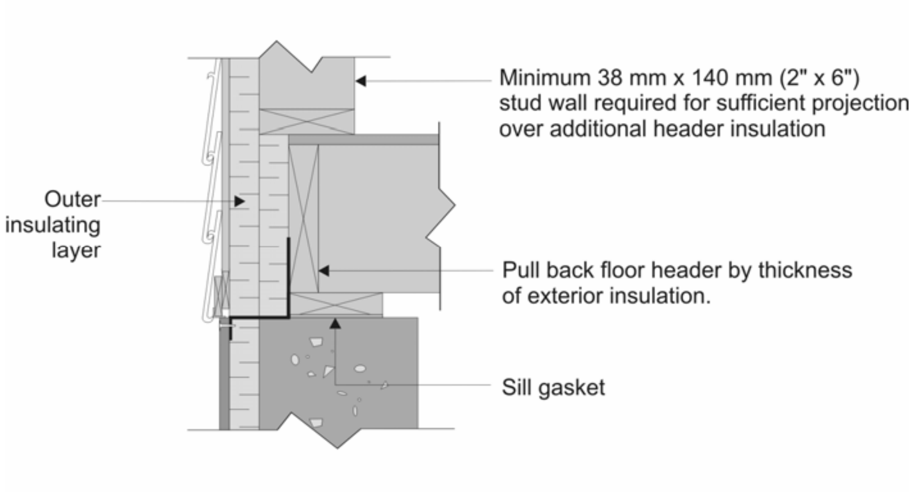


Figure 4.15 Extending exterior insulation in the header area.

Figure 4.15 illustrates a technique for providing additional exterior insulation in header areas such that higher levels of effective thermal resistance may be achieved. Additional insulation may be placed between floor joists on the interior (refer to **A-9.25.1.2. *Location of Low Permeance Materials*** in the Appendix to the *National Building Code of Canada 1995*).

In Figure 4.15, airtightness is addressed using a sill gasket in combination with a structural air barrier system provided by the exterior insulation system. Where this approach to the air barrier system is not selected, it is necessary to consider an alternative such as the header wrap depicted in Figure 4.16.

A special Z-channel is shown for attachment of the cement board or lath and plaster protection of the exposed above-grade exterior basement insulation. It is important that a suitable gauge and corrosion resistance of the metal channel are specified.

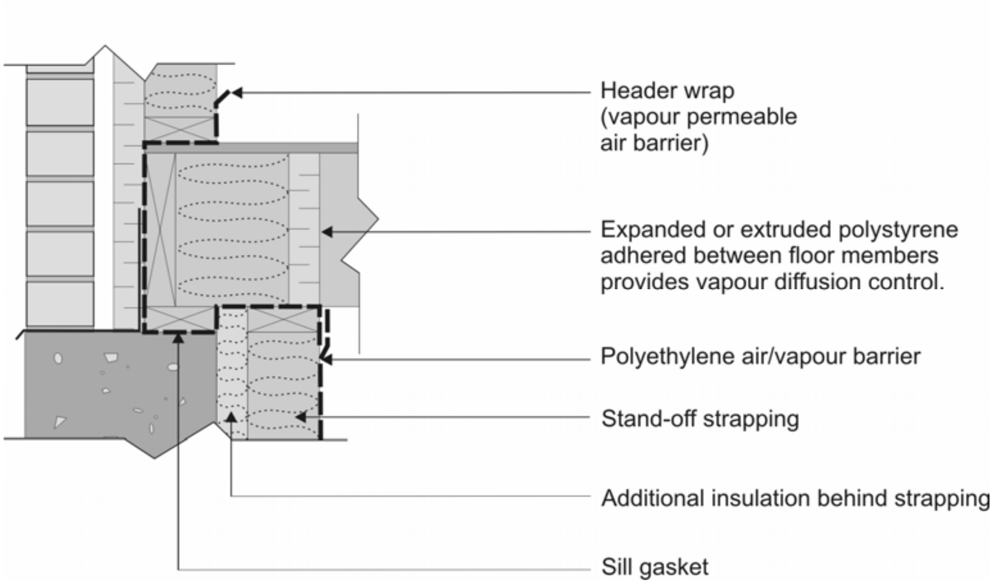


Figure 4.16 Thermal and air barrier continuity for interior basement insulation systems.

The detail in Figure 4.17 illustrates a proven approach to maintaining the continuity of thermal insulation and the air barrier in the header area. The framing stand-off compensates for foundation wall irregularities and permits additional insulation to be placed between the framing and the foundation wall to reduce thermal bridging. Where extruded polystyrene or faced isocyanurate boards are used as an exterior insulating sheathing, waste may be cut to size and cost effectively used for vapour diffusion control as shown. Note that the header wrap is included at the time the sill gasket and sill plate are installed.

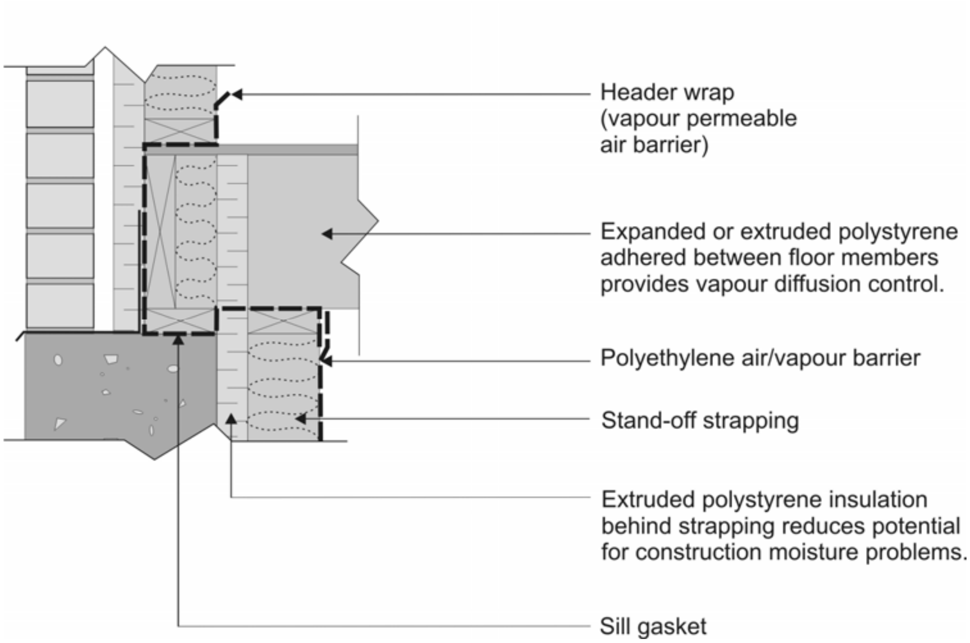


Figure 4.17 Alternative method for addressing construction moisture problems.

Figure 4.18 demonstrates an alternative to the detail in Figure 4.17. The use of extruded polystyrene between the stand-off strapping and foundation wall can deal effectively with construction moisture problems associated with concrete curing.

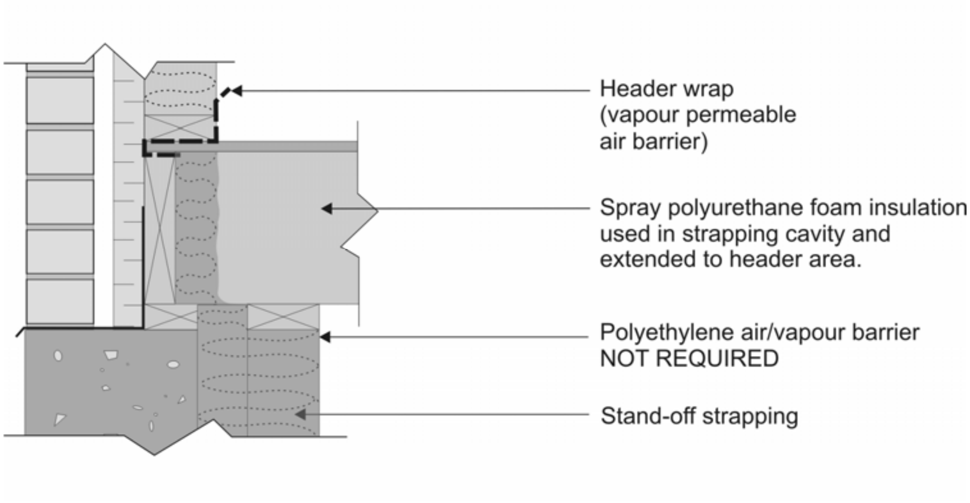


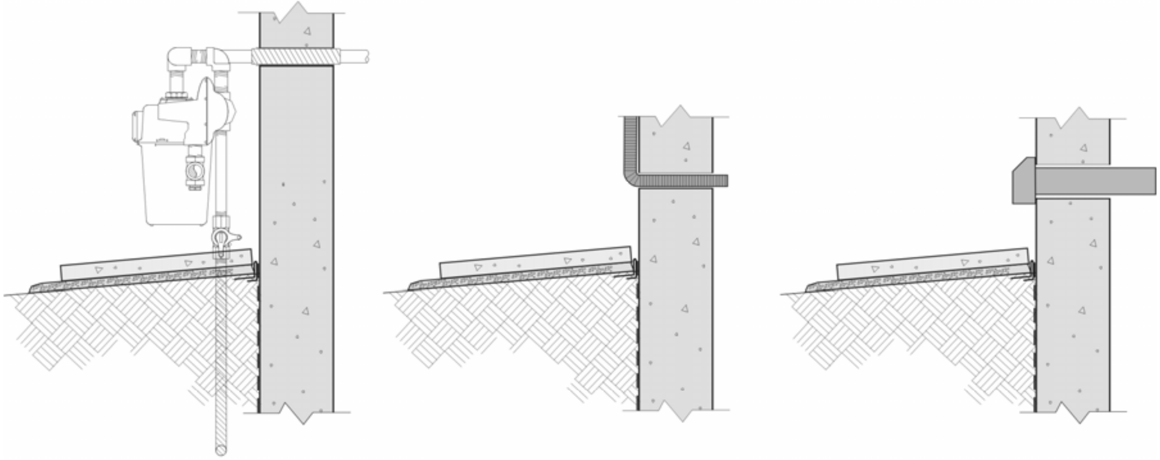
Figure 4.18 Use of spray foam insulation to address thermal and air barrier continuity.

The use of spray polyurethane foam insulation represents an effective alternative that addresses both thermal and air barrier continuity, and construction moisture problems associated with concrete curing. Requirements for the fire protection of the spray foam insulation are not shown in Figure 4.18; however it should be noted that a thermal barrier material meeting the requirements of NBC 9.29 is required to cover any spray foam surfaces exposed to the interior.

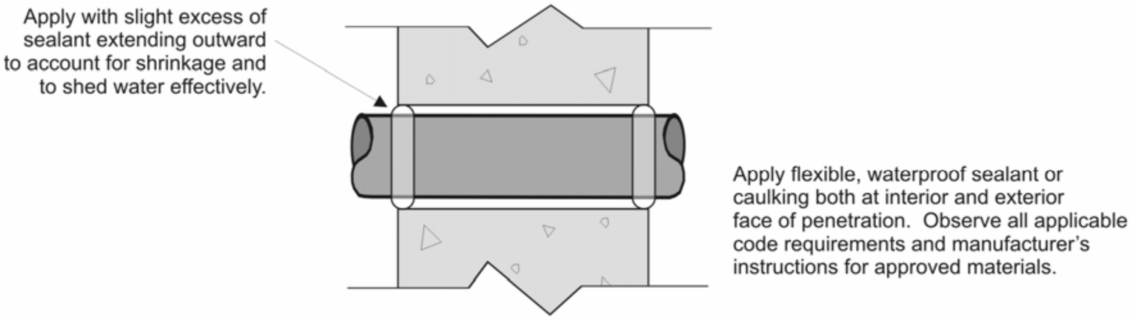
4.8 Penetrations

Penetrations of the foundation walls for the passage of wiring, piping and ductwork represent potentially weak links in the basement envelope system. When these are improperly detailed, moisture problems, air leakage, insect and possibly rodent invasion may result.

Above-grade penetrations are generally less problematic than below-grade penetrations because they are usually accessible in the event the seal around the opening deteriorates or fails.



Piping Above Grade **Wiring Above Grade** **Ductwork Above Grade**



Apply with slight excess of sealant extending outward to account for shrinkage and to shed water effectively.

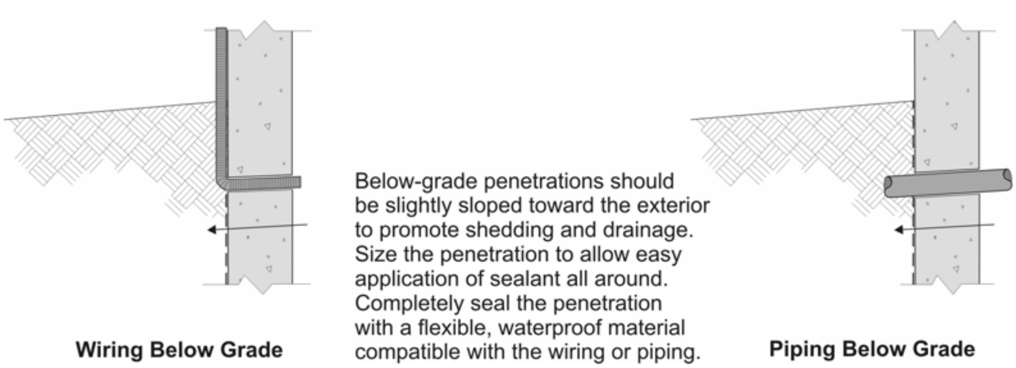
Apply flexible, waterproof sealant or caulking both at interior and exterior face of penetration. Observe all applicable code requirements and manufacturer's instructions for approved materials.

Figure 4.19 Above-grade penetrations.

The treatment of above-grade penetrations can vary depending on what passes through the penetration. For example, piping for natural gas is covered under specific code requirements applied by the authority having jurisdiction (check with the local utility). Requirements for wiring penetrations are addressed in electrical codes, often with additional local utility requirements based on past experience. Ductwork penetrations are typically covered by standards referenced in the building code.

In all cases, sealing of these penetrations is required. The most effective method involves sealing both the interior and exterior faces of the penetration. Figure 4.19 depicts the fundamental considerations for proper sealing of penetrations.

Below-grade penetrations should be detailed assuming they will not be easily accessible, and for all practical purposes, inaccessible without major work and disruption to either the exterior pavement and landscaping on the outside, or the finished interior of most basements.



Below-grade penetrations should be slightly sloped toward the exterior to promote shedding and drainage. Size the penetration to allow easy application of sealant all around. Completely seal the penetration with a flexible, waterproof material compatible with the wiring or piping.

Figure 4.20 Below-grade penetrations.

Unlike above-grade penetrations, it is recommended to completely seal around below-grade penetrations. By properly sizing the diameter of the penetration, and providing a slight outward slope, it is possible to apply the sealant from the interior to fill the entire void around the wiring or piping. The sloped penetration will also drain any potential water accumulation.

For both above and below-grade penetrations, proper planning will allow the placement of sleeves for penetrations at the time of foundation wall construction, thereby avoiding costly drilling of penetrations.

4.9 Additional Sources of Information

It is not possible to deal with the numerous construction details, both typical and proprietary, which apply to the many available approaches to basement system construction. Refer to manufacturer's installation instructions and trade literature for special products. Note that in general, CCMC approved products and systems require that manufacturers provide appropriate documentation on proper installation and detailing.

PART 5 - QUALITY ASSURANCE

5.0 Overview

Quality assurance in construction, sometimes referred to as quality control, is key to delivering well-performing basement systems. Quality control and quality assurance have the following formal definitions:

> **Quality Control (QC)**: A management function whereby control of the quality of (a) raw materials, assemblies, produced materiel, and components; (b) services related to production, and (c) management, production, and inspection processes is exercised for the purpose of preventing undetected production of defective material or the rendering of faulty services.
>
> **Quality Assurance (QA)**: 1. All actions taken to ensure that standards and procedures are adhered to and that delivered products or services meet performance requirements; 2. The planned systematic activities necessary to ensure that a component, module, or system conforms to established technical requirements.

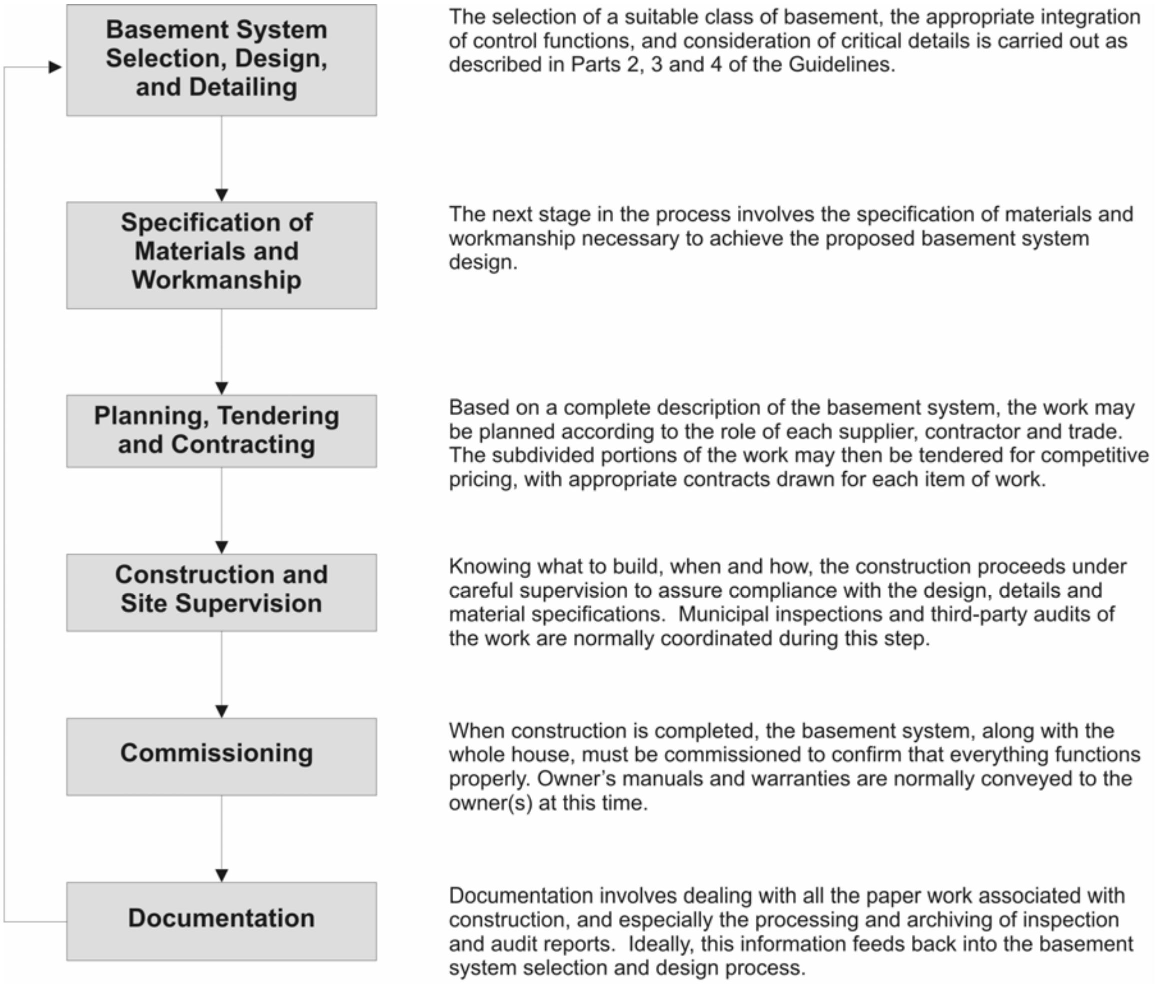
In residential construction, there is little distinction between these two terms because the builder is often responsible for both. Hence in this part of the Guidelines, the term quality assurance is used to describe both quality control and quality assurance activities.

Defects or failures in below-grade construction can have large impacts. Even with minor defects, significant de-construction may be required to access the defect, as in the case of water leakage in finished basements. Loss of profits and reputation are the common results. In severe cases, failures may cause property damage or injuries.

Similar to the control of costs, the most important decisions regarding the control of quality in a completed basement are made during the design and planning stages rather than during construction. It is during these preliminary stages, as laid out in these Guidelines, that basement system selection, component configurations, material specifications and functional performance are decided. Quality assurance during construction consists largely of ensuring conformance to these original design and planning decisions.

The effective communication and documentation of quality and performance requirements cannot be overemphasized. Unless all members of the builder's team clearly understand what is required and expected, achieving acceptable quality and performance remains at risk. Quality assurance is intended to reduce the risk of defects and failures, thereby maximizing quality and performance for the homebuyer, and profitability for the builder.

Quality assurance in basement system construction is vital to ensure proper performance and durability. QA extends beyond design, specifications, materials and workmanship. Previous parts of these Guidelines outlined appropriate selection of basement systems and materials, and also highlighted critical design details. These along with corresponding specifications for the materials and work are necessary but insufficient conditions to achieving acceptable performance. The builder must ensure that the materials correspond to those specified in the design documents, and also that they are properly assembled observing relevant standards and the manufacturer's installation instructions. During construction, the work must be carefully supervised and any required inspections or audits must be clearly documented. When the house is complete, the basement along with all other components must be commissioned to confirm that they function properly as intended. Finally, the documentation must be suitably archived so that it is available for input to future projects, call-backs or insurance claims. This basic process is summarized in Figure 5.1 below.



The selection of a suitable class of basement, the appropriate integration of control functions, and consideration of critical details is carried out as described in Parts 2, 3 and 4 of the Guidelines.

The next stage in the process involves the specification of materials and workmanship necessary to achieve the proposed basement system design.

Based on a complete description of the basement system, the work may be planned according to the role of each supplier, contractor and trade. The subdivided portions of the work may then be tendered for competitive pricing, with appropriate contracts drawn for each item of work.

Knowing what to build, when and how, the construction proceeds under careful supervision to assure compliance with the design, details and material specifications. Municipal inspections and third-party audits of the work are normally coordinated during this step.

When construction is completed, the basement system, along with the whole house, must be commissioned to confirm that everything functions properly. Owner's manuals and warranties are normally conveyed to the owner(s) at this time.

Documentation involves dealing with all the paper work associated with construction, and especially the processing and archiving of inspection and audit reports. Ideally, this information feeds back into the basement system selection and design process.

Figure 5.1 Basic stages of basement system quality assurance process.

5.1 Builder Specific Quality Assurance Activities

Each party involved in the life cycle of the basement, from initial concept to commissioning and documentation, can deploy a number of quality assurance procedures and tools. Procedures include checklists, site supervision, measurements and inspections. Tools include codes, materials performance and application standards, and specifications. Because systems inherently involve a number of different elements performing a variety of functions, the potential for failure of a system is greater than the potential for failure of a single simple element. Deploying a range of procedures and different tools is key to a successful basement system.

Basement System Selection, Design and Detailing

At the earliest stage, structural and environmental loads are identified to define the service environment of the proposed building envelope system. The owner must define the quality of the basement that is to be designed and constructed (see Classification of Basements by Intended Use, Table 1.1). From this information, the designer/builder/owner makes preliminary decisions with respect to the design of the basement, including all materials, components and assemblies to be used. Details are prepared to deal with critical or unusual aspects of the construction so that the materials and methods of construction are clearly conveyed to those involved.

Specification of Materials and Workmanship

In this second stage, information is gathered and assessed to aid in the proper selection of building materials, components and assemblies. In all cases, it is essential to determine if these are appropriate for the application. Criteria must be selected which will establish whether a material, component or assembly will meet the required level of performance as determined in the previous stage. It is generally the responsibility of the designer to compile the necessary information and the responsibility of the builder/owner to accept or reject the proposed material, component and assembly selections. Having decided on the materials, components and assemblies, the workmanship must be clearly defined to fulfill the intended quality and level of performance. Together, this information forms the specifications accompanying the design drawings for use in the next stage.

Planning, Tendering and Contracting

Planning involves the sequencing of work to be performed and the provision of permits, materials, labour and equipment needed to carry out the work. Usually, a chart is developed which identifies each activity according to a schedule. Planning forms the basis of tendering and contracting, along with specifications for materials and workmanship. It is vital that each party understands the scope of work, how and when it will be executed, the terms of payment, holdback and insurance requirements. The tendering process should also be used to identify qualified suppliers and contractors so that a fair comparison of bids is made possible. This tendering stage also provides an opportunity either for the manufacturers or suppliers to confirm that the materials, components and installation methods specified will meet the performance requirements, or for the parties involved to revise the specifications and/or design details. The builder is ultimately responsible for ensuring that each supplier and sub-contractor fully understands the terms of the contracts as originally drafted, or as revised after discussion with the designer and builder/owner.

Construction and Site Supervision

Quality control mechanisms during construction include acceptance of the materials delivered, review of the work in progress and after completion, sampling and testing of materials components and assemblies, correction of deficiencies, and certification of accepted work. Where assemblies involve a number of components, and especially where construction involves a number of trades, mockups have proven quite valuable. Coordination and communication with the trades affects not only the efficiency of the work but also its quality. Abuse of acceptable materials after delivery and before, during or after installation can seriously jeopardize the end product.

Commissioning

Test driving basements is harder than test driving cars. The function of many below-grade components cannot be witnessed until after the house is complete. In the case of basements it is essential to check that water drains away from the footings, foundation and final landscaping. Penetrations, joints and intersections between materials must be inspected for proper workmanship. Plumbing, electrical, heating and ventilation systems must be tested for proper operation. Owner's manuals and warranties should be assembled and conveyed to the owner at this time. There will always remain items that cannot be tested when the house is commissioned and therefore deserve the greatest attention during construction.

Documentation

The final stage in quality assurance is documenting the project so that it informs future projects. This requires a systematic approach to gathering and storing information for convenient retrieval. Table 5.1 summarize critical items corresponding to various stages of the QAP.

STAGE OF QAP	CRITICAL ITEMS
Basement System Selection, Design and Detailing	☐ intended use of basement ☐ site conditions (soil, water) ☐ site services ☐ climate ☐ permit drawings and details
Specification of Materials and Workmanship	☐ material standards ☐ equivalent products ☐ material characteristics (e.g., grade, strength, thickness, etc.) ☐ installation practices and procedures ☐ tolerances
Planning, Tendering and Contracting	☐ complete drawings and specifications ☐ construction schedule indicating sequence of work ☐ tendering only to qualified suppliers/installers/trades ☐ contracts (scope, value, schedule, termination) ☐ insurance and holdbacks
Construction and Site Supervision	☐ permits ☐ survey, excavation grades and setbacks ☐ services (sewer and water, gas, electricity) ☐ critical details (identified during detailed design) ☐ inspections (see Figure 5.2) ☐ footings and column pads ☐ basement structure ☐ foundation drainage ☐ exterior moisture protection/insulation ☐ backfilling/grading ☐ plumbing and electrical ☐ heating and ventilation ☐ interior moisture protection/insulation ☐ equipment, fixtures and finishes ☐ windows and doors ☐ access/egress and security
Commissioning	☐ grading and site drainage ☐ penetrations and joints between material intersections ☐ plumbing, electrical and HVAC
Documentation	☐ payments/holdbacks ☐ update costing data ☐ archive documentation

Table 5.1 Basic checklist for builder QAP.

5.2 On-Site Quality Assurance Program

Basements, be they of permanent wood, block, or poured in place concrete on insulated concrete forms, are constructed on-site. Hence, their quality is dependent on an effective on-site quality assurance (QA) program. An on-site quality assurance program can be a variety of initiatives that work together to ensure a specific product is installed correctly, or a specific service is being provided to the building owner to ensure industry standards.

A QA program deals with the installation of a product, or a number of products or systems, to ensure they are installed correctly in a building. An on-site quality assurance programs deals with methods and procedures to ensure the correct installation of the end product. The program usually ties together the manufacturer, contractor and actual installer of the product or system.

Some QA programs consist of initiatives such as training, site audits and inspections, or an industry standard or specification. Cast-in-place concrete is one example, among an increasing number of products, which is supported by this type of program.

An effective QA program ties in a number of initiatives to work together, for the end result of a correct installation. Today, most QA programs are based upon the principles of the ISO 9000 series of standards and incorporate modules, or initiatives, which a builder can deploy to ensure the correct installation of a product or system.

5.3 Matching QA Program to Business Needs

The complexity or sophistication of the QA program needed to achieve acceptable basement system performance will vary according to several factors:

- the size and experience of the builder's organization;
- the volume, scale and technical complexity of construction; and
- the availability of skilled labour and specialty materials and sub-systems.

Established builders with a good reputation tend to be those that have some form of QA program in place. Their quality assurance practices and procedures have successfully adapted to the marketplace. Inexperienced builders are most likely in need of a QA program, but also least likely to afford the type of system serving larger organizations. Small builders are advised to focus on essential QA procedures for critical items in order to avoid major and costly defects and failures.

Where a builder conducts a high-volume business, with many large projects underway at one time, and the work is complicated due to site conditions or the layout of the basement, a comprehensive quality assurance program is essential. Builders working on only a few houses at a time can use a simplified quality assurance program that is tailored to their particular type of basement construction. Where a builder has locked into a reliable basement system, and does not explore innovation, the QA program can be refined to be compact, yet effective.

In some housing markets, such as those found in or near large urban centres, skilled labour and suppliers of specialty materials and sub-systems are readily available (at a price). Local construction practices may be of high quality and require less supervision than in areas where a highly seasonal work force with low worker retention rates is prevalent. In areas where suppliers of specialty materials and sub-systems are affiliated with qualified installers, materials and workmanship are often covered by a single warranty, avoiding the risk associated with builders installing these under their own direct supervision. For builders who cannot rely on a network of suppliers with qualified installers, the need for both quality control/assurance and appropriate technical training is higher.

5.4 ISO 9000 Series of Standards for Quality Management Systems

ISO 9000 is a set of standards for quality management systems that is accepted around the world. Currently more than 90 countries have adopted ISO 9000 as national standards. When a product or service is purchased from an organization that is registered to the appropriate ISO 9000 standard, the client has important assurances that the quality of what is received will be as expected.

The ISO 9000 series of standards is the internationally accepted means of achieving consistent and predictable quality of products and services, including construction. Released in December 2000, the International Organization for Standardization (ISO) has introduced a revised set of standards. The standard intended for quality management system assessment and registration is ISO 9001. The standards apply uniformly to organizations of any size or description. Registered companies have had dramatic reductions in customer complaints, significant reductions in operating costs, and increased demand for their products and services. Other benefits can include better working conditions, increased market share, and increased profits.

There is now a single standard for quality management system (QMS) requirements. All requirements for the quality of the product or service will be covered in ISO 9001:2000. ISO 9004 will go beyond ISO 9001:2000 to cover performance improvement. This creates a consistent pair, more compatible with the ISO 14000 environmental management system standards. The structure and sequence of ISO 9001:2000 and ISO 9004 are based on eight quality management principles, the goal being "to benefit all interested parties through sustained customer satisfaction." These quality management principles are:

Eight Quality Management Principles

- Customer-focused organization
- Leadership
- Involvement of people
- Process approach
- System approach to management
- Continual improvement
- Factual approach to decision-making
- Mutually beneficial supplier relationships

The five ISO 9000:2000 Core Standards are:

- ISO 9000 Quality Management Systems - Fundamentals and Vocabulary
- ISO 9001 Quality Management Systems - Requirements
- ISO 9004 Quality Management Systems - Guidelines for Performance Improvement
- ISO 19011 Guidelines for Quality and Environmental Auditing
- ISO 10012 Quality Assurance for Measuring Equipment - Part 2: Guidelines for Control of Measurement Processes

For many builders, ISO 9000 registration may not be feasible. However, the key principles of quality management systems can be applied to any builder organization's quality assurance program to consistently achieve improved product quality and performance.

5.5 QA Program Components

Irrespective of the type of builder organization involved in basement system construction, the following 11 steps should be considered, where appropriate, for integration within day-to-day construction activities.[1] In many cases, these aspects of QA procedures apply to products and installers, rather than the activities of the builder. The builder should remain aware of these installation and development steps, as construction relies heavily on these activities.

1. ***Research and Development of Products*** – Installation practices, installed product performance, design considerations, and compatibility are an important part of the QA system. This component is on-going as products and installation practices change.
2. ***Development of Standards and Specifications*** – National and international standards for products and installation.
3. ***Licensing/Accreditation of Manufacturers*** – Criteria, methodology, and requirements for the licensing/accrediting of manufacturers.
4. ***Licensing/Accreditation of Contractors*** – Criteria, methodology, and requirements for the licensing/accrediting of contractors.
5. ***Certification of Installers*** – Certification criteria and processes for the verifiable training of installers.
6. ***Training of Installers*** – Design, develop and deliver industry training programs for installers.
7. ***Documentation and Reporting Procedures*** – Documentation forms, reporting requirements and processes, installer and contractor checklists, daily worksheets, and inspection forms.
8. ***Third-Party Field Compliance Audits*** – audit program to verify the manufacturers', contractors' and installers' compliance to the QA Program requirements.
9. ***Database Tracking System*** – Systematically tracks and reports on contractors, installers, field audits, and demerit points.
10. ***Appeal Process*** – Appeal process for the loss of licence, certification, or assessment of demerit points.
11. ***Third-Party Warranty Program*** – a program to back up the entire QA system.

There are numerous benefits associated with this step-by-step approach to a QA program. Consumers may purchase the builder's product with confidence in its quality. The builder can control costs and callbacks by planning and controlling the construction process from design through to final documentation. Suppliers, installers and sub-contractors are encouraged to become more professional and in so doing, should realize higher profits along with the builder.

It has been documented for a broad range of products, from cars to houses, that consumers are willing to spend more for quality assurance rather than defect insurance. They prefer to know a problem is less likely to happen rather than know the problem will be fixed after it occurs. Fixing something below-grade can be difficult and expensive, especially once landscaping is in place. Consistent quality and dependable performance are more marketable than after sales service.

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[1] The 11 components of the QAP have been derived from initiatives developed by Building Professional Consortium, Winnipeg, Manitoba. Their contribution of knowledge and experience towards these Guidelines is gratefully acknowledged.

5.6 Builder Role in QA Program

For most builder organizations, QA programs are far less costly and time consuming than may first be estimated. This is because manufacturers, suppliers and installers of building materials and components are increasingly becoming involved in quality assurance. The builder's role in quality assurance is better appreciated by reviewing an example.

	QUALITY ASSURANCE ACTIVITIES			
	By Builder		**By Others**	
QUALITY ASSURANCE COMPONENTS	On-Site	Off-Site	On-Site	Off-Site
Research and Development of Products	○		●	■
Development of Standards & Specifications	○			■
Licensing/Accreditation of Manufacturers				■
Licensing/Accreditation of Contractors			●	■
Certification of Installers				■
Training of Installers	○		■	●
Documentation & Reporting Procedures	■		●	
Third-Party Field Compliance Audits	○		■	
Database Tracking System				■
Appeal Process				■
Third-Party Warranty Program	○			■
Extent of Activity - Primary ■ Secondary ● Contributing ○				

Table 5.2 Role of builder versus others in quality assurance program.

With reference to Table 5.2, consider the case of a builder who is interested in using a supplier-installed product. The research and development of the product are carried out by the manufacturer, primarily off-site in a laboratory, and subsequently on-site during field trials. Standards and specifications governing the products are developed off-site by others, usually with industry, government and consumer participation. Builders in general play a contributing role through their associations, and by responding to manufacturers' surveys or requests for field trials. From a QA perspective, the builder needs to understand the product standard to the extent that an appropriate product may be correctly selected for a particular application.

Practically all matters pertaining to licensing, accreditation and certification remain the responsibility of the product industry sector, with the exception of the builder's participation in the training of installers. This occurs indirectly when either novice personnel work in the field on actual projects, or experienced installers encounter innovative applications.

The major emphasis in quality assurance on the part of the builder involves documentation and reporting procedures. This occurs throughout the construction process, and in the case of the supplier/contractor, deals with the contract, recording of the time and progress of work, invoices/payments, receipt of warranty and related municipal inspection report(s). Third-party field compliance audits may be conducted during the project by the industry sector certification organization. This may involve the builder to the extent of being present and permitting access to the site. The remaining components of the QA Program fall outside of the builder's involvement, with the exception of the third-party warranty, which may apply to product deficiencies.

An important aspect of this example pertains to the builder's own work forces, and possibly, sub-contractors. As much of the labour associated with construction does not fall under any existing industry quality assurance program, the builder must deal with components normally handled by others internally. The next section deals with some specific aspects of basement system construction the builder can address under these circumstances.

5.7 Role of Codes and Standards in QA Program

Requirements described in codes and standards represent a level of performance that has been accepted by the construction community as the minimum to which construction should be regulated. In many instances, one will have to go beyond the code to achieve performance that is at the minimum level acceptable to the market. As a result, codes and standards have several limitations for use within quality assurance programs:

1. Building codes are intended to describe constructions that meet some minimum acceptable level for health and safety purposes – aesthetics and quality of workmanship are not explicitly addressed;
2. The National Building Code of Canada and its referenced standards are written by the building community as a whole and, unless the industry sees fit to include requirements for particular situations, some issues may not be fully addressed.
3. The National Building Code of Canada specifies the characteristics of the end product and not the process by which it is attained, hence other references must be relied upon to provide information on quality assurance.

However, despite these limitations, codes and standards represent an important minimum threshold for any quality assurance program. As a minimum, basement construction should be able to pass the critical inspections depicted in Figure 5.2.

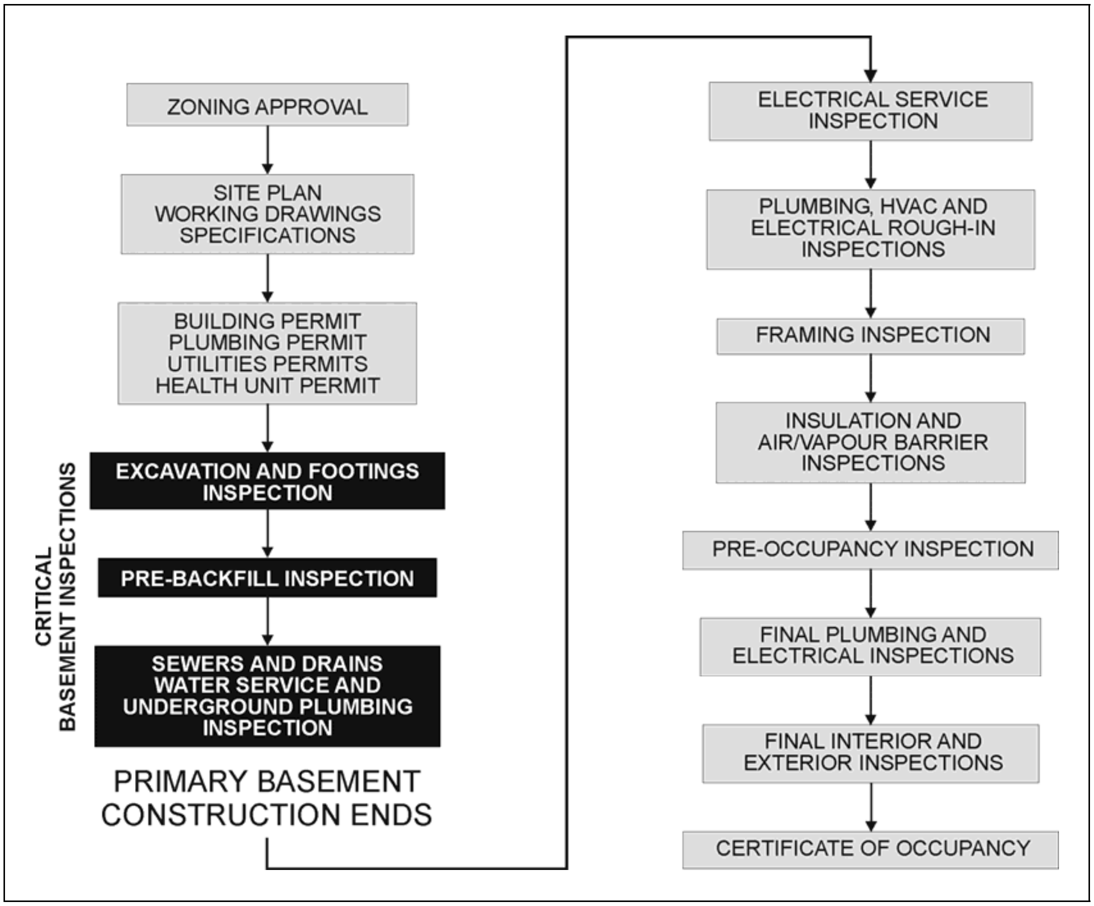


Figure 5.2 Relationship of primary basement-related inspections to typical building permits and inspections process.

Most municipalities in Canada make available a description of the building permit and inspections process, and also provide builders with sample inspection checklists to facilitate the construction and inspection processes. Two basic checklists are depicted in Table 5.3 below.

Excavation Inspection	Foundation Inspection
Identify soil type: ☐ Rock ☐ Coarse grain soils ☐ Silt ☐ Clay/undefined Is mechanically compacted fill material used? ☐ Yes ☐ No Is a soils engineering report available? ☐ Yes ☐ No ☐ Site condition and material storage (workmanship) ☐ Excavation free from organic material (NBC 9.12.1.1) ☐ Excavation free from standing water (NBC 9.12.1.2) ☐ Frost protection provided (NBC 9.12.1.3) ☐ Excavation to undisturbed soil (NBC 9.12.2.1) ☐ Trenches beneath footing formwork (NBC 9.12.4.1) ☐ Construction of step footings (NBC 9.15.3.8) ☐ Suitable footing formwork (workmanship)	Identify foundation type ☐ Poured ☐ Block ☐ Preserved wood ☐ Other Identify number of storeys: _____ ☐ Site condition and material storage (workmanship) ☐ Minimum thickness of foundation (NBC 9.15.4.1) ☐ Interior footings/pads in place (NBC 9.15.3) ☐ Anchor bolts at top of foundation(NBC 9.23.6.1) ☐ Placement of drain pipe (NBC 9.14.3) ☐ Sufficient stone cover over tile (NBC 9.14.3.3(4)) ☐ Below-grade form ties sealed (NBC 9.13.5.1(2)) (for cast-in-place concrete foundations) ☐ Excessive honeycombing/cold joints sealed (workmanship) (cast-in-place foundations) ☐ Below-grade parging/coved over footing (NBC 9.13.5.1(1)) (masonry block foundations) ☐ Below-grade water/dampproofing (NBC 9.13.3, 9.13.4, 9.13.5) ☐ Granular fill under basement slab (NBC 9.16.2.1(1)) ☐ Adequate footing depth/insulation (NBC 9.12.2.2) ☐ Adequate lateral support of foundation walls and suitable backfill material (NBC 9.12.3)

Table 5.3 Typical checklist for basement inspections (not including plumbing).

As mentioned previously, requirements found in codes and standards are not a substitute for quality assurance. Hence, the same may be said for building inspections conducted by the authority having jurisdiction. Permits and inspections may be useful to establish basic competency across the builder's team, from the designer through to the suppliers, installers and trades. In cases where compliance problems become consistently evident, inspection provides useful feedback to either encourage suitable training, or find another player for the team.

5.8 Role of CCMC In Product Evaluations

The construction industry relies on the Canadian Construction Materials Centre (CCMC) to evaluate new materials, products, systems and services for all types of construction. Operating within the National Research Council's Institute for Research in Construction (IRC), CCMC ensures that its evaluations are based on the latest technical research and expertise.

CCMC helps manufacturers by eliminating the need for separate product evaluations in each individual jurisdiction. CCMC Evaluation Reports and Listings are used throughout the country by regulatory officials and other decision-makers as a basis for determining the acceptability of products.

What Are Evaluations?

An evaluation is an impartial, technical opinion on the suitability of a product for its intended use. On the building side, that opinion often relates the equivalency of a product to the requirements of the National Building Code of Canada and of provincial codes.

Where a product is so novel that no appropriate standard exists, CCMC develops a set of technical criteria in consultation with experts from NRC and other organizations. CCMC then directs the client to appropriate testing laboratories. CCMC Evaluation Officers review the test results and if they are favorable, issue a positive opinion on the product's suitability in an Evaluation Report, together with necessary installation conditions.

For products for which specific standards exist, industry often relies on CCMC's evaluations to demonstrate conformity. Opinions on these products are published in Evaluation Listings. Depending on the nature of the product, an evaluation may take from four months to one year.

Registry of Product Evaluations

Evaluation Reports and Listings are contained in CCMC's Registry of Product Evaluations, indexed to the Masterformat system used throughout North America. With this useful publication, thousands of subscribers have quick access to up-to-date technical and regulatory information on hundreds of evaluated construction materials, products and systems.

Updated regularly, CCMC's Registry (available on the web) is especially valuable for building professionals and practitioners, who use it at every stage of design and construction to check plans, the acceptability of specified products and their installation.

National Recognition

Provinces and territories support the use of CCMC evaluations in determining the acceptability of products in the context of building code requirements. CCMC is specifically designated in the Ontario Building Code as a materials evaluation body for the purpose of supporting Minister's rulings on innovative products. Canada Mortgage and Housing Corp. (CMHC) and Public Works and Government Services Canada (PWGSC) accept CCMC-evaluated products on projects which they finance or sponsor.

Networking

The Centre's clients benefit directly from the technical support and the most up-to-date information on construction technology offered by NRC's Institute for Research in Construction. Benefits also accrue from CCMC's direct liaison with IRC staff who participate in the development of the National Building Code.

CCMC is actively linked with NRC's Industrial Research Assistance Program (IRAP) and the Industrial Technology Advisory field service network. This industrial network helps CCMC establish contacts with leading-edge manufacturers and with research and testing agencies throughout the nation.

Involvement in Canada's national standards system ensures mutual co-ordination in the development of standards and the possible transfer of new products from CCMC's evaluation service to standardization and certification programs as these products become more widely used by the construction industry. Centre staff also serve on numerous technical committees of standards-development bodies.

Use of CCMC Evaluated Products

For CCMC evaluated products, it is critical that builders review the Usage/Limitations section of each evaluation report so they may determine if the product is being properly installed. They should also verify that the selected material or system conforms to the usage and limitations contained in the CCMC evaluation report, and that materials and systems are marked with the appropriate CCMC evaluation number. These markings permit regulatory authorities inspecting the construction to verify compliance, and failure to use appropriately marked materials and systems may cause problems and delays.

For more information, contact:
Canadian Construction Materials Centre
Institute for Research in Construction
National Research Council of Canada
Ottawa, Ontario K1A 0R6
1-613-993-6189

Synopsis

Quality assurance is critical to running a successful business, especially a building business, because houses typically represent the largest single purchase the average person makes in his or her lifetime. Consumer expectations of product quality are increasing as the proportion of manufactured goods eclipses the proportion of goods fashioned on site. Basement systems are significantly different from computers and automobiles for reasons other than where they are assembled. The suppliers and labour force may vary from project to project, as may site conditions and the design of the home above the basement. With few exceptions, each basement is a "once off" item that bears little resemblance to goods produced on assembly lines.

The uncertainty associated with these factors may lead to an unacceptable level of risk to the builder and jeopardize the sustainability of his or her business. Quality assurance represents an effective means of reducing this risk and uncertainty within an acceptable margin. It is important to recognize that quality assurance is cost effective when compared to the deterioration of builder reputation, or worse, bankruptcy due to excessive defects and potentially, failures.

Builders are urged to develop an appropriate quality assurance program tailored to their organizations to ensure the quality and performance of basements and the whole house system. The potential to develop quality assurance networks with manufacturers, suppliers and installers of materials, components and assemblies continues to improve, and is increasingly important to become connected to these networks so that a majority of resources can be focused on building better basements.

References

Quality by Design, available through the Canadian Housing Information Centre, Canada Mortgage and Housing Corporation, 700 Montreal Road, Ottawa, ON K1A 0P7, Telephone: 1 800 668-2642
FAX: 1 800 245-9274, WEB: http://www.cmhc-schl.gc.ca

Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects and Builders, by Chris Hendrickson, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA l52l3 June 28, 1999. Available free of charge at: http://www.ce.cmu.edu/pmbook/

Fox, A.J. and Cornell, H.A., (eds). *Quality in the Constructed Project*. American Society of Civil Engineers, New York, 1984.

PART 6 - BASEMENT SYSTEM COST/BENEFIT ANALYSIS

6.0 Overview of Cost/Benefit Analysis

Questions asked about basement systems are often of a technical nature. How well does one alternative perform over another? What are the critical design details? Which material types better tolerate winter construction and wet soils? But there are also many other questions related to the costs of various basement system alternatives. How much more does one design alternative cost versus others? Which design is more cost effective in the long run? Does it make sense to insulate basements full-height and is there a reasonable payback on this investment? In the previous parts of these Guidelines, the focus has been on technology and the quality assurance needed to achieve well-performing basements; now the economic aspects of basement systems are presented.

This part of the Guidelines looks at the assessment of costs and benefits associated with various basement system options identified to be viable for the Canadian house construction market. The background behind this part of the Guidelines is based on several earlier studies. In recognition of the importance of an economic assessment of viable basement technology alternatives, a preliminary study was commissioned in 1997 by IRC/NRCC, entitled *Economic Assessment Issues Relating to Residential Basement System Performance.*[1] This was followed by a more detailed study entitled *Economic Assessment of Basement Systems*[2] completed in March 2000. To a great extent, these form the basis of the cost/benefit analysis presented in this part of the Guidelines.

The primary objectives of this part of the Guidelines are as follows:

1. To comparatively assess conventional basement system alternatives and the marginal cost of improved construction, in the form of packaged systems, from three economic perspectives: the builder, the consumer, and society;
2. To assess the cost effectiveness of various technological developments in materials, components and sub-systems aimed at improving the performance of the basement system; and
3. To assess the cost effectiveness of various better construction practices aimed at improving the quality and performance of the basement system.

It is important to recognize that many questions regarding the cost effectiveness of various basement systems could not be answered. In some cases, differences in performance were difficult to quantify, such as the health costs associated with moulds. In other cases, costs limited the scope of the work that was possible to undertake. The cost/benefit analysis presented in these Guidelines represents the questions and issues deemed essential for a broad range of stakeholders. The following section outlines the methodology employed to satisfy the fundamental objectives of the basement systems cost/benefit analysis.

6.1 Cost/Benefit Study Methodology

The major tasks involved in the completion of the cost/benefit study are outlined below in Figure 6.1. There are essentially 7 steps associated with the study, not including review and comment at key stages, and roundtable meetings with various stakeholders.

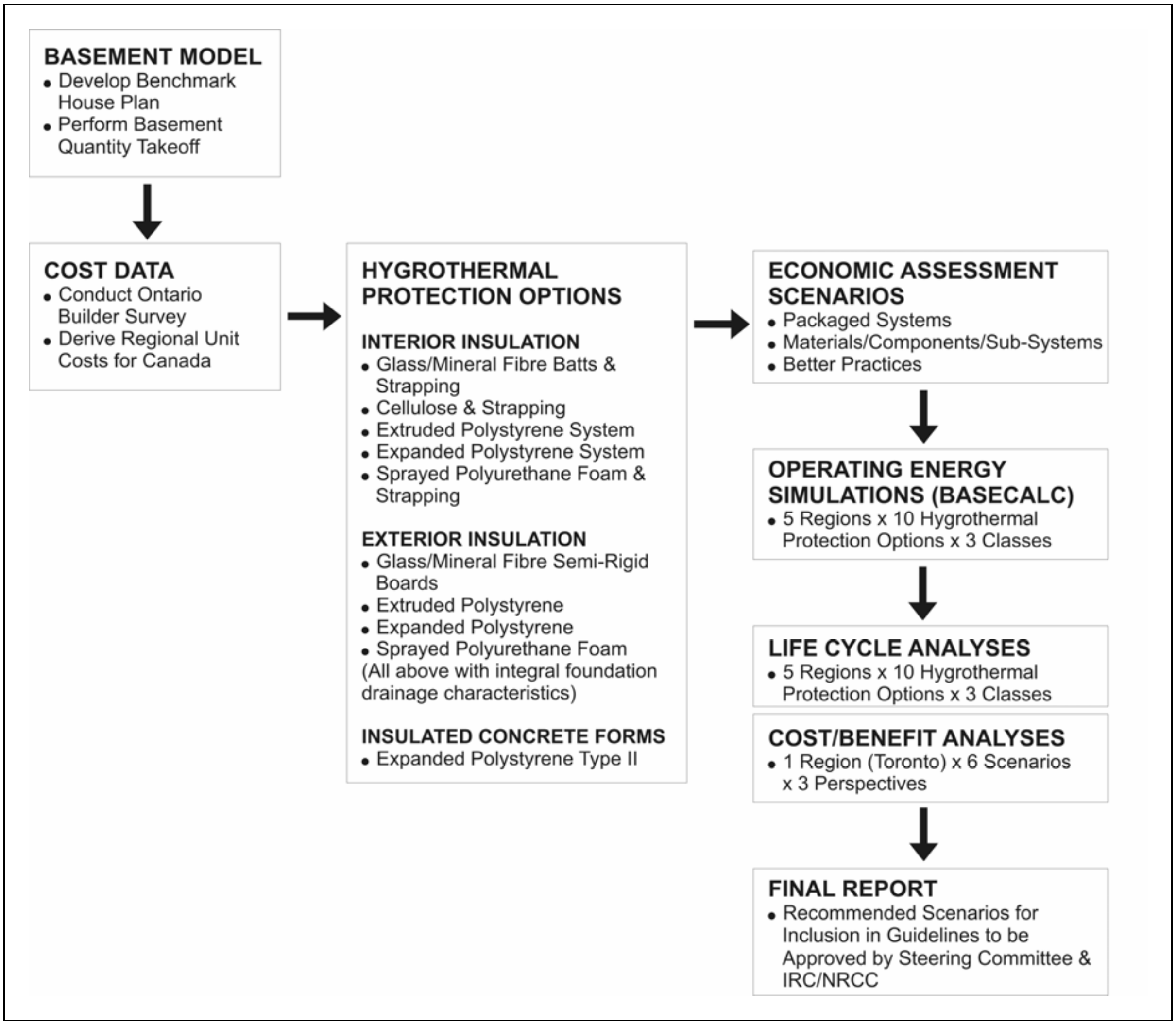


Figure 6.1 Outline of major tasks associated with the *Economic Assessment of Basement Systems* study.

Scope, Assumptions and Limitations

This cost/benefit study was guided by several key assumptions and limitations. The scope of the study was limited to a single, simple model of a residential basement system, which is assessed according to a limited number of scenarios that are later described. The rationale supporting the scope of this study is as follows:

1. The most common types of basement system alternatives are of greatest interest to the vast majority of stakeholders.
2. A case study approach to the alternatives, using real builders and localities, provides a more realistic and credible perspective than a “quantity survey” approach.
3. A comprehensive and exhaustive economic assessment of basement system alternatives is neither affordable nor useful to stakeholders.

It was assumed that the results of the study would be comparatively extensible to most typical basement systems, recognizing they may not necessarily apply to unusual cases. More importantly, this study was intended to assess typical examples – users of these Guidelines are cautioned to exercise judgement and to use local cost data when applying the assessment methodologies presented herein.

The study was also limited in the assessment of factors affecting basement performance. Table 6.1 indicates the types of factors that are readily quantifiable, somewhat quantifiable or not practically quantifiable. Ill-defined factors, such as adaptability, are not addressed in this study.

MONETARY	INTANGIBLE*	ILL-DEFINED**
Construction	Comfort	Moulds (Health Impact)
Operating	Compatibility	Adaptability
Maintenance	Buildability	Sustainability
Repair	Marketability	
Warranty Fees		
Insurance Premiums		
Externalities		
Opportunity Costs		
* Factors which may be monetized and/or qualitatively expressed.		
** Factors which are difficult to monetize and/or qualitatively express.		

Table 6.1 Limitations of quantitative economic assessments of basement system alternatives.

Due to the regional variations in basement construction practices across Canada, it has not been possible to address every type of basement system in this study. However, the developed methodologies may be applied by interested parties to yield specialized/localized answers to questions that commonly interest builders, consumers and society. Recognizing these diverse stakeholders’ interests, the study attempted to reconcile their respective economic perspectives vis-à-vis costs and benefits associated with basement system alternatives.

Economic Perspectives: Builders, Consumers and Society

The various perspectives, brought to bear on investments in building technology, require careful consideration if the results obtained from analyses are to prove useful to stakeholders. For buildings in general, including residential basements, there exist three major perspectives to be considered: builders; consumers (owners and tenants); and society.[3]

Builders and/or developers, are primarily concerned with first costs and how these costs affect their business operations. The tendency of builders not to exceed minimum code requirements is most evident when the benefit is not visible to occupants (e.g., thermal insulation, drainage layers, etc.) as opposed to highly visible amenities (e.g., upgrades to fixtures and finishes, etc.). The carrying costs and opportunity costs associated with higher first costs must result in substantial benefits, both short term (marketability) and long term (reduced callbacks and complaints), before builders select better practices.[4]

Consumers of housing are generally more interested in affordability and accessibility.[5] Accessibility, as it relates to the financial capacity of potential homebuyers, primarily relates to mortgage policies employed by financial institutions that finance housing purchases. Affordability relates the cost of securing adequate housing at a cost that does not place an unreasonable financial burden on a household. It involves the down payment and monthly expenditures on principal, interest, taxes and energy (PITE). Insurance premiums may also prove significant depending on the risk of damages associated with a particular dwelling (e.g., flooding, etc.). Generally, consumers are averse to improvements in housing which negatively impact affordability, unless these arise in response to matters of health and safety.

The societal perspective on investments in building technology is generally long term, taken over the useful life of the dwelling. The primary concern is the viability of the housing over its life cycle and how to maximize this benefit across all of society. The construction of new housing commits society to supply many forms of energy and services, on demand, for the useful life of the building (50 years, plus). Where housing development exceeds the capacity of existing infrastructure, an escalation in the cost of energy and municipal servicing normally results. The societal commitment to servicing new housing and dealing with all forms of effluents (storm water, sewage, products of combustion, etc.) must be partly attributed to basements. Economic repercussions, environmental impacts and quality of life are some of the issues that take on a societal importance with respect to building technology, including basements.

Table 6.2 summarizes the criteria associated with the selection of appropriate study periods and economic measures used in the assessment of basement systems, based on the economic perspective of key stakeholders.

Perspective	Investment or Improvement	Study Period	Economic Measure
Builder	Technology exceeding minimum health and safety requirements	Commencement of construction to time of sale (< 1 year, typically)	Internal Rate of Return (IRR)
Consumer	Discretionary, depreciable and non-depreciable improvements	Expected period for benefits to exceed costs (5 to 10 years)	Simple Payback (SPB) or IRR
	Non-discretionary, depreciable investments	Useful service life of investment	Life Cycle Cost (LCC) using Uniform Present Worth (UPW)
	Non-discretionary, non-depreciable investments	Duration of tenure or mortgage (25 to 40 years)	Life Cycle Cost (LCC) using Uniform Present Worth (UPW)
Societal	All investments	Service life of system, including components, equipment, fixtures and finishes (50 to 100 years)	Life Cycle Cost (LCC) using Modified Uniform Present Worth (MUPW)
The term *discretionary improvements* refer to any measures that exceed minimum requirements for health and safety, whereas *non-discretionary investments* refer to any available measures needed to comply with minimum requirements for health and safety. From a consumer perspective, a *depreciable* item is one with a service life that is less than the duration of tenure or mortgage, whereas a *non-depreciable* item does not significantly depreciate during this period.			

Table 6.2 Study periods and measures for economic assessment of housing technology.

Measures of Cost Effectiveness

The mathematical formulae for the calculation of costs and benefits associated with each of the economic measures listed in Table 6.2 are summarized on the following page. These conform to practices regularly used for economic assessment within the building industry.

Internal Rate of Return (IRR)

$$PVNB = \sum_{t=0}^{N} \frac{(B_t - \bar{C}_t)}{(1 + i^*)^t} = 0$$

where:

$PVNB$ = present value of net benefits (or, if applied to a cost-reducing investment, present value of net savings).

N = number of discounting periods in the study period.

B_t = dollar value of benefits in period *t* for the alternative evaluated less the counterpart benefits in period *t* for the mutually exclusive alternative against which it is compared.

$\bar{C}_t$ = dollar costs, excluding investment costs, in period *t* for the alternative evaluated less the counterpart costs in period *t* for the mutually exclusive alternative against which it is compared.

i^* = interest rate for which PVNB = 0, that is, the IRR measure expressed as a decimal.

Simple Payback

$$SPB = C_o/(B - \tilde{C})$$

where:

SPB = period of time, expressed in years, over which investments are recovered to the breakeven point.

C_o = dollar value of initial investment costs, as of the base time.

B = dollar value of annual benefits (or savings).

$\tilde{C}$ = dollar value of annual costs.

Life Cycle Cost

Modified Uniform Present Worth

$$P = A_o \cdot \left(\frac{1 + e}{i - e}\right) \cdot \left[1 - \left(\frac{1 + e}{1 + i}\right)^N\right]$$

Uniform Present Worth

$$P = A \cdot \left(\frac{(1 + i)^N - 1}{i\,(1 + i)^N}\right)$$

where:

P = present sum of money.

A = end-of-period payment (or receipt) in a uniform series of payments (or receipts) over N periods at i interest or discount rate.

A_o = initial value of a periodic payment (receipt) evaluated at the beginning of the study period.

N = number of interest or discount periods.

i = interest or discount rate.

e = price escalation rate per period.

Life Cycle Cost Approach to Cost/Benefit Analysis

An important aspect of the cost/benefit analysis presented in these Guidelines deals with life cycle costs. Life cycle cost assessments attempt to monetize various alternatives to compare their cost effectiveness. The most common method involves the use of the modified present worth measure described on the previous page. For a given life cycle period, all of the annual costs (or savings) are converted into a present worth using time-value of money economics.

For example, how much money would an individual have to set aside today to pay for all home energy bills until he/she sells the home at retirement? This will depend on how much interest the lump sum of money set aside earns, but also the rate at which the price of energy increases. If this exercise were performed for all of the costs associated with living, the present worth of an adult's life cycle could be estimated.

Investments in buildings may be treated in a similar fashion. By adding the capital cost of a building to the present worth of its predicted life cycle operating energy costs, meaningful comparisons among alternatives may be considered.

Parameters which strongly influence the life cycle assessments include the economic perspectives of the particular stakeholder, the associated study period, and in particular, the relationship between the interest rate versus the escalation rate.

Relationship Between Interest Rate and Escalation Rate

Figure 6.2 indicates the present worth of a $100 per year savings based on various study periods (up to 50 years), interest rates and escalation rates. It could also express the present worth of an annual expenditure of $100 to estimate the amount of money needed to be set aside today to cover these expenditures over the study period.

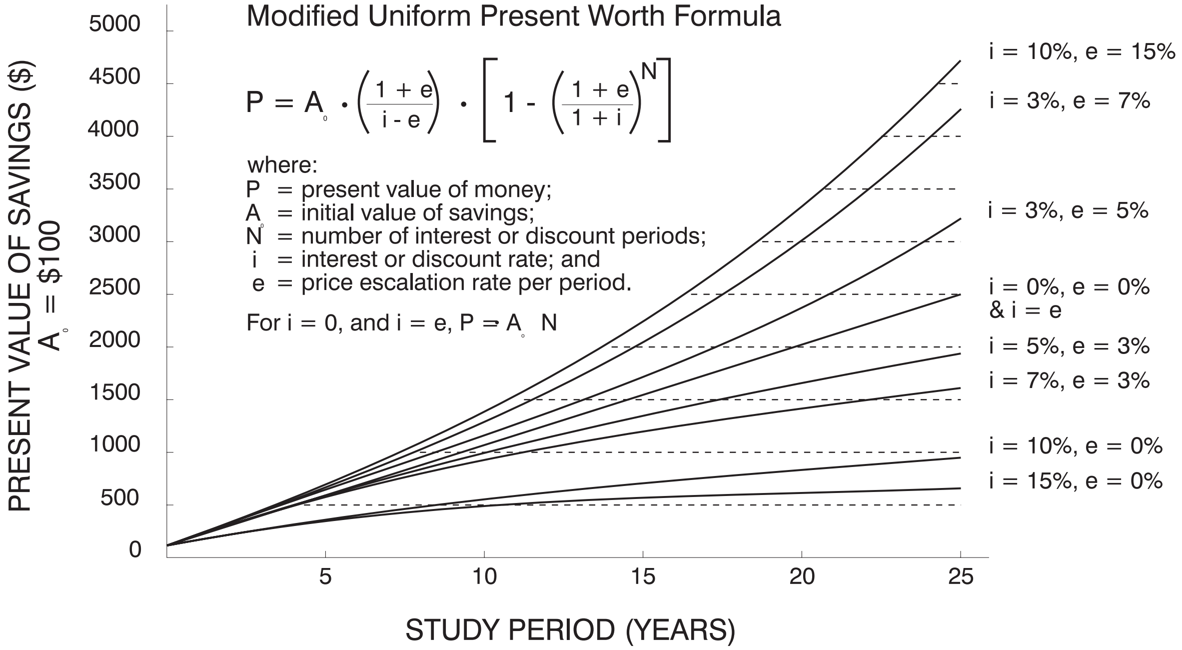


Figure 6.2 Sensitivity of present value savings to study period, discount rates and escalation rates *(adapted from Fig. 3, ASTM E917-93)*.

Based on Figure 6.2, and looking at investments that improve energy efficiency, the following observations may be noted:

1. When interest rates are high, and the escalation rate of energy is low, investments in energy efficiency are not encouraged. Put simply, it is better to invest the money and make more from interest than can be saved from energy-efficiency improvements.
2. When the interest rate and the escalation rate are the same, the relationship is purely linear and there is not a preferred alternative.
3. When the escalation rate of energy exceeds the interest rate, investments in energy efficiency are very attractive - especially over long time periods. An investment that saves $100 in annual energy costs has a present worth of over $4,500 when the interest rate and escalation rate differ by 5% over a 25-year study period. In other words, it is cost effective to invest $4,500 today to save $100 annually over the next 25 years under these economic conditions.

Life Cycle Costing Example

The use of the modified present worth measure of life cycle cost effectiveness is best illustrated through a comparative example – in this case involving automobiles. In order to objectively compare between the life cycle cost of two vehicle options, the purchase price and cost of fuel over 7 years of ownership are assessed. Auto A is a conventional vehicle, and Auto B is a fuel-efficient vehicle. It is assumed each vehicle is driven for 20,000 kilometers annually.

Life Cycle Parameters

Three interest rate and fuel escalation rate scenarios are considered in the analysis.

	Low	*Current*	*High*
Interest	3.5%	4.0%	6.0%
Escalation	2.0%	10.0%	16.0%
Period	7	7	7

	Purchase	**Annual**	**Present Cost of Fuel**			**Present Cost of Automobile**		
	Price	**Fuel**	*Low*	*Current*	*High*	*Low*	*Current*	*High*
Auto A	$26,500	$1,830	$12,089	$16,133	$18,672	$38,589	$42,633	$45,172
Auto B	$32,800	$1,120	$7,398	$9,874	$11,428	$40,198	$42,674	$44,228

Based on this present worth analysis, Auto A is more cost effective when fuel price escalation is low compared to interest rates. If fuel prices are rising faster than interest rates, as is currently happening in 2002, Autos A and B are comparable. Auto B is a better investment if fuel prices continue to escalate sharply, as is predicted by most energy economists.

There are some notable observations regarding the use of life cycle costing. First, it is a measure that is not favoured by sales and marketing forces because it has a discouraging effect on the consumer. Imagine if every automobile price tag listed the estimate life cycle cost of $45,172 versus $26,500. Second, there are many costs that may not appear in life cycle costing if they are equal among alternatives. In the example above, the cost of licences, insurance, maintenance and repairs has not been included because they are considered roughly equivalent. This same technique has been applied to the assessment of basement system alternatives in Section 6.3.

Description of Study Models

A number of models were developed and/or adopted for use in the study. Some were used to describe the basement system, and others to simulate operating energy performance and to perform economic assessments of alternative basement technologies. The modelling approach taken in this study was consistent with approaches taken in similar studies conducted in the past.[6]

Benchmark House and Basement System Model

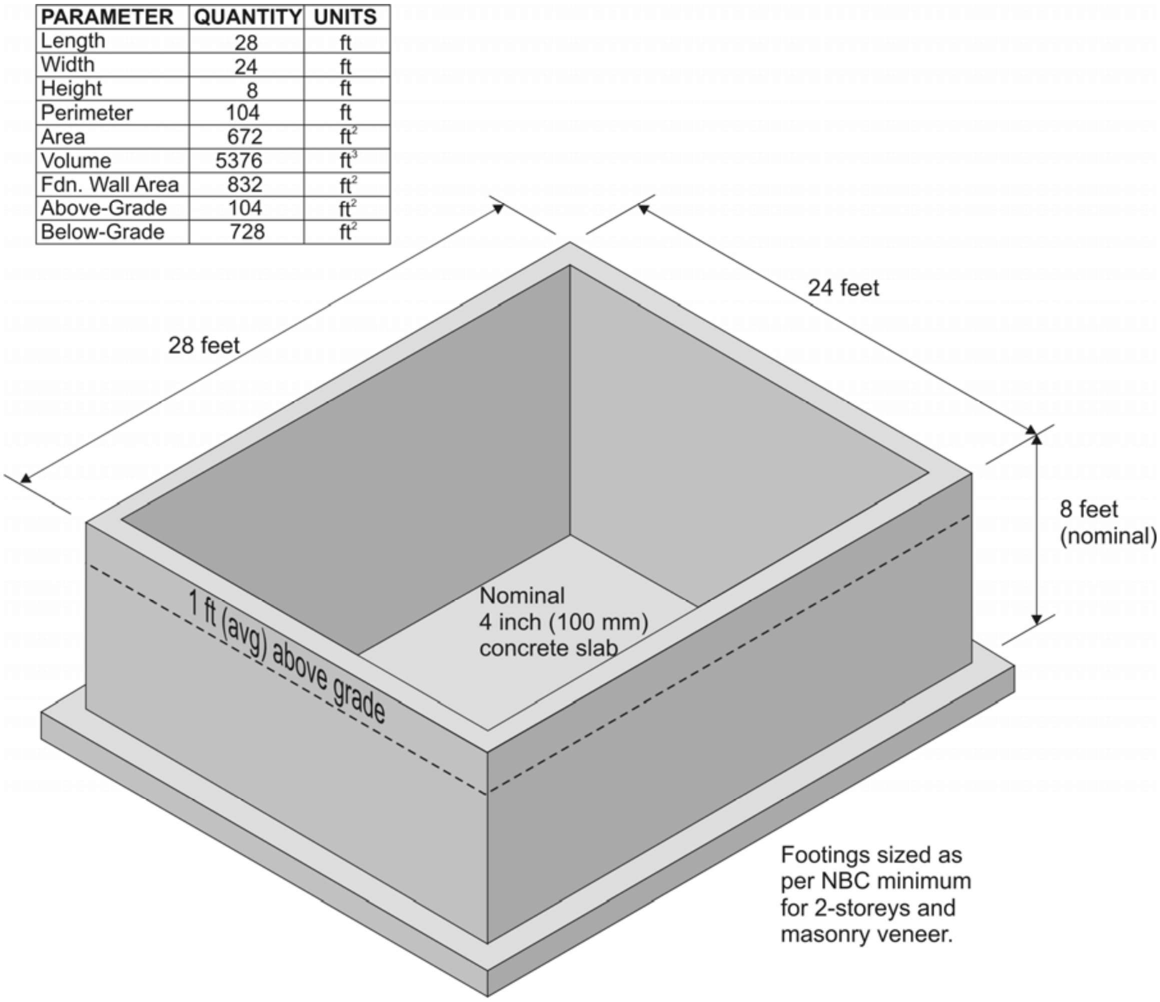
The benchmark house plan that was selected for use in the study is depicted in Figure 6.3. This modest design was selected for its simplicity of basement configuration, recognizing that analyses will not involve the ground and second floor elements of the dwelling.

Figure 6.3 Plans and elevations of benchmark house.

The basement model used for estimating costs and operating energy performance is depicted in Figure 6.4. Two critical features of the basement configuration are:

1. The average height of the basement walls above grade is set at 1 foot (300 mm) in keeping with conventional practices for typical new homes. This enables a more realistic modelling of the above-grade heat loss.

2. No windows are included in the basement, recognizing that these are usually provided. Using the windowless model provides for more efficient economic modeling and thermal analysis. The difficulty associated with the inclusion of windows is that the cost of the windows must be factored into the total basement system cost, and their orientation impacts solar gains. Window qualities and costs vary significantly, and the cost implications of window wells must also be considered.



PARAMETER	QUANTITY	UNITS
Length	28	ft
Width	24	ft
Height	8	ft
Perimeter	104	ft
Area	672	ft^2
Volume	5376	ft^3
Fdn. Wall Area	832	ft^2
Above-Grade	104	ft^2
Below-Grade	728	ft^2

Figure 6.4 Physical characteristics of benchmark basement model.

Moisture, Thermal and Air Leakage Protection Options

In Part 1 of the Guidelines, a basement system classification was proposed and presented in Table 1.1. For packaged basement system scenarios, the moisture, thermal and air leakage requirements associated with each classification are applied to the basic benchmark model of the basement depicted in Figure 6.3.

The combination of materials and assemblies needed to satisfy the requirements for moisture, thermal and air leakage protection in basements is often guided by the placement of insulation with respect to the foundation walls. Figure 6.5 delineates conventional basement system alternatives according to insulation placement and type of material.

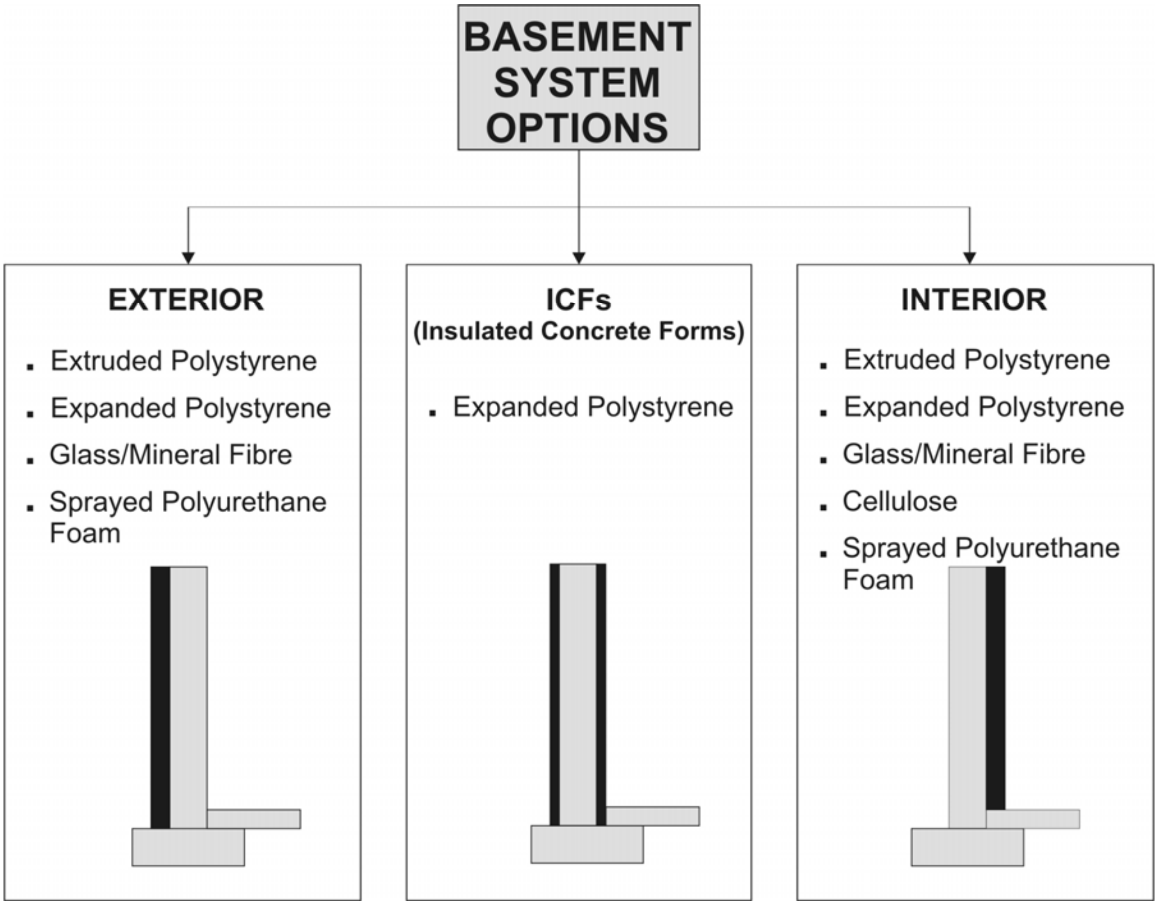


Figure 6.5 Basement system alternatives considered in the study based on thermal insulation placement.

These options were applied to actual basement assemblies to arrive at a number of basement system types depicted in Figures 6.6 to 6.9, inclusive. It is important to recognize that in each of these instances, only the full-height basement insulation scheme is illustrated. Partial-height insulation schemes, where practical, simply reduce the height of the insulation below grade with no changes to materials or construction. Insulated basement floors are also not shown in these figures, as these are beyond the scope of this study. (Refer to an analysis of insulation options for heated slabs in the *National Energy Code for Houses, 1995*.)

Figure 6.6 depicts the most common approach to the insulation of new residential basements. The provision of a drainage layer is shown in the instance of full-height basement insulation. It should be recognized that while a foundation drainage layer is not explicitly required in the National Building Code, in some jurisdictions, such as Ontario, it is required for basements that are to be lived in, insulated to a depth of 3 feet (900 mm) or more below grade. A variety of approved insulation materials are available to fill the cavity between and/or behind the wall framing.

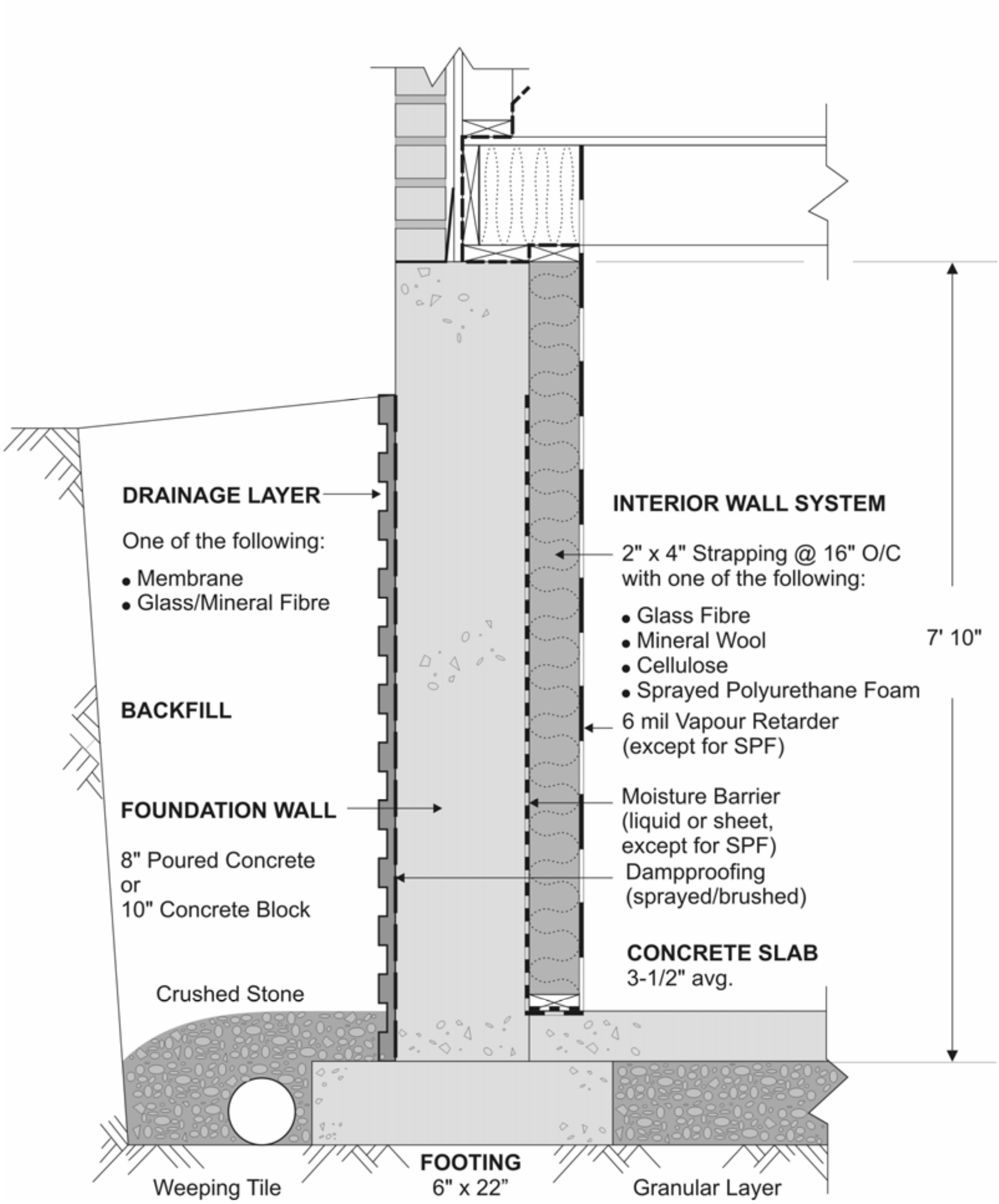


Figure 6.6 Basement system based on framing and interior placement of thermal insulation.

Note: For higher levels of thermal insulation, the framing is assumed to be offset from the interior surface of the foundation wall.

Another approach to the interior placement of thermal insulation is the use of plastic foam insulation panels fastened to the concrete wall, which are then protected against flame spread by gypsum drywall or a similar rated material. Figure 6.7 depicts the conventional arrangement of the materials within the assembly for this type of basement system, and also indicates a drainage layer, consistent with the system in Figure 6.6.

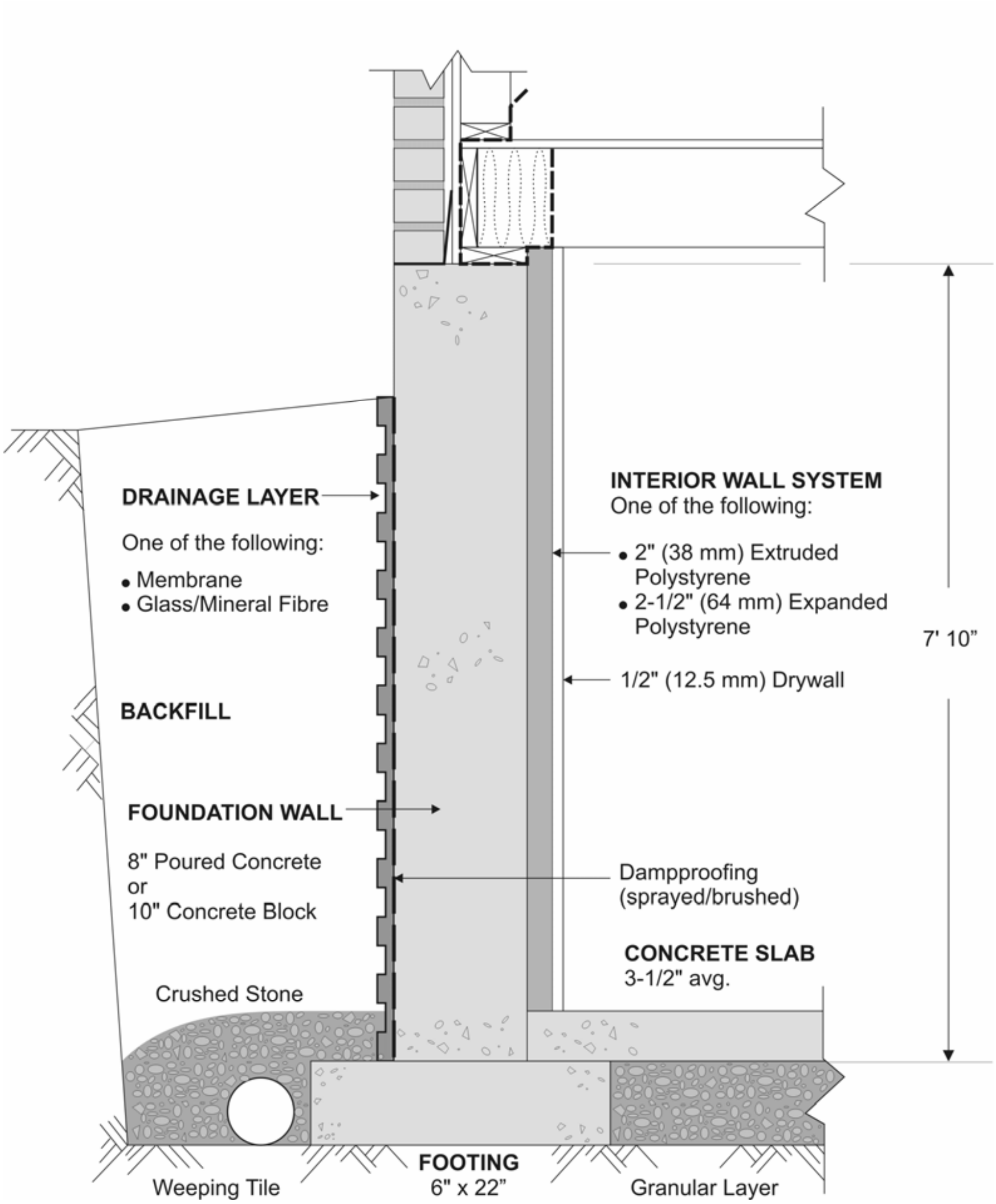


Figure 6.7 Basement system based on interior placement of plastic thermal insulation.

Figure 6.8 depicts an exterior insulation placement for the basement system. Exterior insulation schemes tend to involve the use of proprietary insulation systems, and remain confined to expanded and extruded polystyrene boards, rigid glass fibre or mineral wool panels, or sprayed polyurethane foam. Attachment of the board and panel type insulation to the foundation wall involves either the use of mechanical fasteners or a mastic-type adhesive. In the case of extruded polystyrene and sprayed polyurethane foam products, dampproofing of the foundation wall is not required. All systems require a suitable form of exterior protection of the exposed insulation, and when masonry veneers are used for upper floors, special details are required to preserve a marketable appearance to the dwelling.

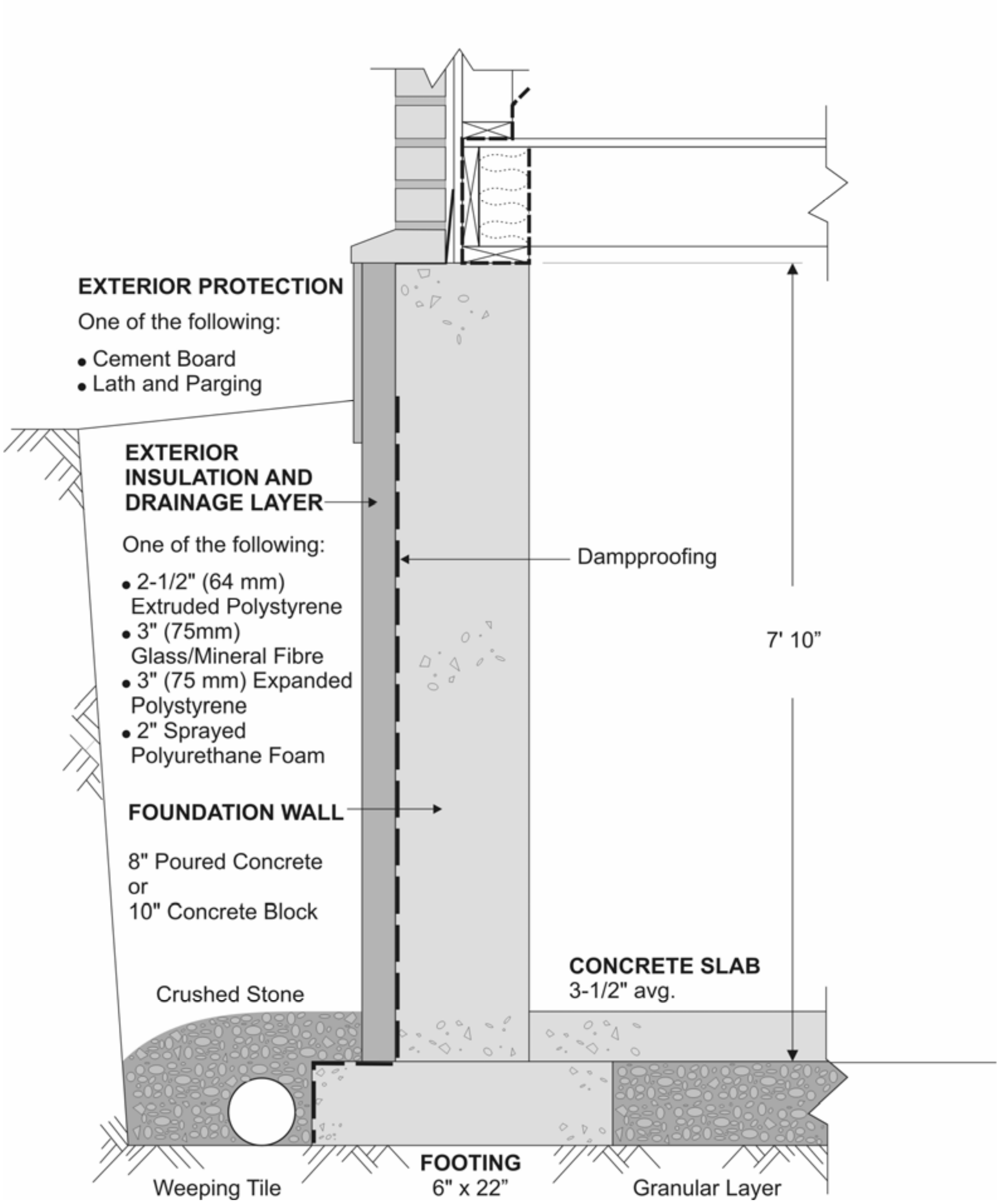


Figure 6.8 Basement system based on exterior placement of thermal insulation.

A relatively novel approach to the construction of basement systems is the use of insulated concrete form systems (ICFs). These pre-engineered, proprietary systems utilize expanded or extruded polystyrene forms to cast-in-place reinforced concrete to satisfy the structural requirements – the forms remain to provide thermal protection. ICFs require exterior protection of the exposed insulation above-grade. Most ICFs incorporate special forms which permit the casting of supports for masonry veneers; however, the thermal bridging associated with these approaches tends to be similar to that depicted in Figure 6.9 below. A foundation drainage layer is normally provided for these systems. On the interior of ICF systems, the insulation (form) must be protected against flame spread by gypsum drywall or a similar rated material.

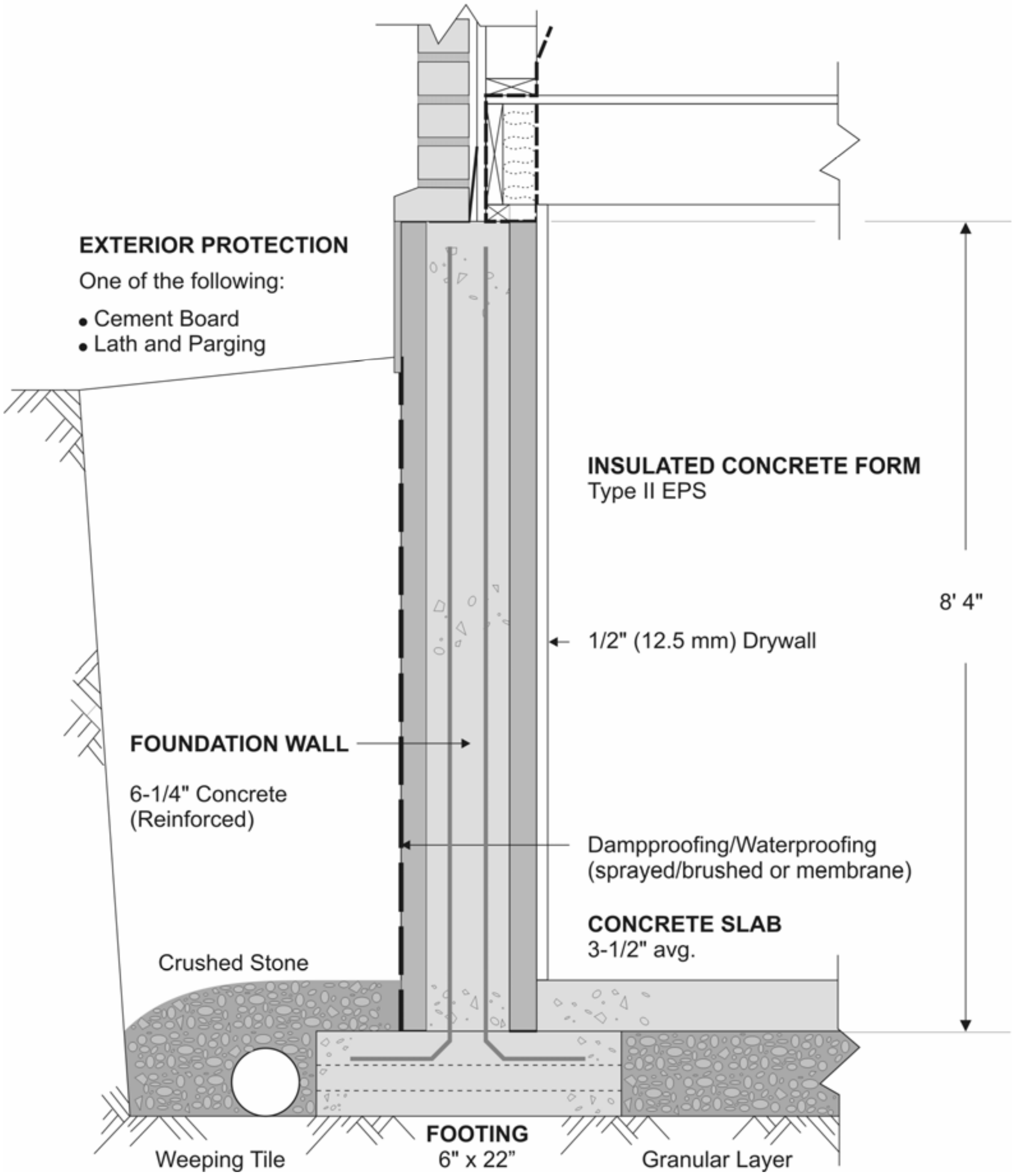


Figure 6.9 Basement system based on utilization of insulated concrete forms.

ICFs are normally used to construct the below and above-grade walls of residential buildings, and the isolation of the below-grade portion for this study cannot fully assess all of the benefits of a whole-house system.

BASECALC

Version 1.0d of BASECALC™ software was used to perform all operating energy simulations. Documentation on the technical features of BASECALC is available from Natural Resources Canada (CANMET) and published literature.[Ψ]

Using the National Research Council of Canada's Mitalas method as a starting point, CANMET has developed a new numerical technique to model basement and slab-on-grade heat losses. BASECALC was created to allow researchers, building-simulation software developers and users, code writers and enforcers, insulation and building-component manufacturers, builders, and others to apply this new heat-loss technique easily and efficiently.

Version 1.0d of BASECALC performs a series of detailed finite-element calculations to estimate heat losses through residential foundations. The software can be used to assess the energy impact of new insulation placements and products, to develop building- and energy-code requirements, to perform research, and to develop improved foundation heat-loss models for whole-building simulation programs. BASECALC has been applied in a number of code-related projects, including: an analysis of inside/outside "combination" insulation for the National Energy Code for Houses; a comparison of insulation options for the Ontario Building Code; and an analysis of insulation options for heated slabs for the National Energy Code for Houses.

Given the above noted economic measures and techniques, a number of assessment scenarios were developed. These are further discussed in the following section.

[Ψ] Ian Beausoleil-Morrison, *BASECALC™:A Software Tool for Modeling Residential-Foundation Heat Losses*, Proc. Third Canadian Conference on Computing in Civil and Building Engineering, Concordia University, Montréal Canada (1996) 117-126.

I. Beausoleil-Morrison, G.P. Mitalas, and H. Chin, *Estimating Three-Dimensional Below-Grade Heat Losses from Houses Using Two-Dimensional Calculations*, Proc. Thermal Performance of the Exterior Envelopes of Buildings VI, ASHRAE, Clearwater Beach FL, USA, (1995) 95-99.

I. Beausoleil-Morrison, G.P. Mitalas, and C. McLarnon, *BASECALC: New Software for Modeling Basement and Slab-on-Grade Heat Losses*, Proc. Building Simulation '95, International Building Performance Simulation Association, Madison WI, USA, (1995) 698-700.

Economic Assessment Scenarios

Several types of economic assessments have been performed within these *Guidelines.* They do not include the case studies of failures or statistics gathered in an earlier, associated, study.[7] However, these data have been used in the assessment of consulting engineering cost effectiveness vis-à-vis structural failures. Three types of economic assessments have been performed:

1. Packaged system assessments which deal with the basement-as-a-system;
2. Material/component/subsystem assessments which deal with technological improvements to aspects of the basement; and
3. Better practice assessments, which focus on the cost effectiveness of exceeding minimum standards or to applying higher levels of quality control.

Packaged System Assessments

A series of upgrades to basement systems are estimated for several types of generic basement packages corresponding to the classification system defined in Table 6.3.

	ECONOMIC PERSPECTIVE /MEASURE		
SCENARIO	**BUILDER**	**CONSUMER**	**SOCIETAL**
1. Class C (cellar) to Class B (conventional)	IRR	SPB	LCC
2. Class B (conventional) to Class A-3 (near-livable)	IRR	SPB	LCC
3. Class B (conventional) to Class A-2 (livable space)	IRR	SPB	LCC
4. Class B (conventional) to Class A-1 (dwelling unit)	IRR	SPB & AIRR	LCC
IRR - Internal Rate of Return; SPB - Simple Payback; LCC - Life Cycle Cost (MUPW)			

Table 6.3 Packaged system economic assessment scenarios.

Material/Component/Subsystem Assessments

In response to various technical developments presented to the *Guidelines* project Steering Committee, economic assessments were suggested for items such as high performance concrete, Covercrete, and engineered foundation drainage systems. Due to the absence of documented data, only the last item was assessed as indicated in Table 6.4.

	ECONOMIC PERSPECTIVE /MEASURE		
SCENARIO	**BUILDER**	**CONSUMER**	**SOCIETAL**
5. Engineered Foundation Drainage Systems	IRR	SPB	LCC
IRR - Internal Rate of Return; SPB - Simple Payback; LCC - Life Cycle Cost (UPW)			

Table 6.4 Material/component/subsystem economic assessment scenarios.

Better Practice Assessments

In recognition of the pivotal role of workmanship in the long-term performance of basement systems, a number of better on-site practices were also identified during the first two phases of the *Guidelines* project. It was only possible to consider the practice of employing consulting engineering to avoid structural foundation failures, as depicted in Table 6.5.

	ECONOMIC PERSPECTIVE /MEASURE		
SCENARIO	**BUILDER**	**CONSUMER**	**SOCIETAL**
6. Consulting Engineering (structural failures)	IRR	SPB	LCC
IRR - Internal Rate of Return; SPB - Simple Payback; LCC - Life Cycle Cost (UPW)			

Table 6.5 Better practices economic assessment scenarios.

Required Data Collection

In order to perform the analyses associated with these scenarios, the following data sets were collected and interpreted:

- ☐ Capital costs of basement systems and improvements.
- ☐ Builder carrying costs/profit margins.
- ☐ Energy prices and forecasts.

Computer Simulations and Analyses

A large number of computer simulations were also performed using BASECALC™ to determine the energy performance of the various basement systems in the following five geographic locations:

- ☐ Vancouver BC
- ☐ Winnipeg MN
- ☐ Toronto ON
- ☐ Ottawa ON / Hull PQ
- ☐ Halifax NS

It is important to note that collected data listed previously also correspond to these locations.

Sources of Information

A number of published and unpublished sources were used in the assessment of the various economic scenarios.

Material Cost Survey
A limited survey was performed in the Toronto area in 2000 to obtain prices for the various materials comprising the basement systems considered in this study. For some materials (e.g., sprayed-in-place insulation) quotes for material and labour were obtained from qualified contractors since this reflects normal practice. For validation purposes, the material was then summarized into unit costs that could easily be checked against prices reported by builders.

Builder Survey
To obtain realistic costs and builder perspectives on basement construction, a survey was administered to a cross-section of eight builders in Ontario. The demographics of the survey sample is representative of Ontario climate and geography, and also the range of economic conditions within communities. Builders who demonstrated efficient cost accounting systems were given preference to improve the accuracy of the data. Cost data from the Canadian Centre for Housing Technology were also contributed to this study.

Energy Pricing
Energy pricing used in the assessment of life cycle operating costs, and energy pricing forecasts were obtained through Natural Resources Canada, Statistics Canada and fuel energy associations. Regional costs and forecasts were utilized where applicable.

Construction Cost Data
Costs derived for basement construction in Ontario were adjusted for other parts of Canada using data published in *Residential Costs* by the R.S. Means Co. This source of information has been used in a number of similar studies and has proven acceptable to stakeholders and reviewers.

A valuable source of information included a large number of helpful individuals who volunteered their knowledge and expertise. This diverse group provided a range of perspectives on the subject of the study, and the major contributors are listed in the acknowledgements. In addition to individuals, several product manufacturers and trade associations contributed information that would otherwise be practically unattainable.

More detailed technical information on the methodology and sources of information associated with each task of the study is presented, as deemed appropriate, in subsequent sections of this part of the Guidelines.

General Commentary on Supporting Study

With regard to the development of the model basement for the supporting study and the preparation of the underlying assumptions for the economic assessments performed therein, readers should be aware of the following issues:

1. In selecting a small basement model with a minimal above-grade exposure, the benefits associated with thermal upgrades are conservatively estimated. Hence, if a thermal upgrade is cost effective in a small basement, it is generally more cost effective in a larger basement. The development of a small basement study model was deliberate in order to avoid possible criticisms associated with the use of a large, highly exposed basement, which would tend to skew results in favour of higher levels of thermal insulation and energy efficiency.

2. The base case scenario in the packaged system assessments is the Class C basement – an uninsulated basement with no explicit drainage layer. This base case violates the minimum standard, a Class B basement, that is enforced in many regions of Canada. However, because there are regions of Canada that permit the construction of Class C basements, this was deemed the effective minimum standard.

3. Many of the design and practice scenarios are based on information gathered through builder surveys. As the sample size for the survey was limited by time and economic constraints, it cannot be considered statistically significant. However, the scenarios are derived from actual builder perspectives from a group of builders with decades of experience operating reputable and financially viable enterprises. Readers should expect that many other perspectives may also be considered equally valid, but remain beyond the scope of discussion within these guidelines.

Further and more specific commentary regarding these issues may be found in the parts of these Guidelines that follow.

6.2 Construction Costs

In order to perform the economic assessments for the various scenarios described earlier, cost data for the various basement systems and materials were gathered according to the following sequence of tasks:

1. A survey of building material suppliers was conducted to derive unit costs for the various materials corresponding to the basement systems considered in this study;
2. A survey of builders selected from across Ontario was conducted to obtain the costs of basement systems currently constructed within the respective market areas;
3. The averaged cost data from Tasks 1 and 2 above were applied to estimate the cost of the structural basement foundation less any moisture and thermal protection;
4. The cost data from Tasks 1 and 2 were further applied to estimate the cost of various thermal and moisture protection options currently available to Canadian home builders; and
5. A survey of builders was conducted to determine the cost of basement finishing above and beyond the cost of the structural foundation and moisture and thermal protection options considered in Tasks 3 and 4.

These costs were assembled into an electronic spreadsheet to support various economic assessments.

Materials Survey

In March 1999, a survey of material costs was performed in the greater Toronto area. A list of the various materials used in residential basement construction was prepared and several large building material suppliers were contacted for prices. Where more than one manufacturer supplied a particular material product, costs for each manufacturer's product were obtained and then averaged. Builder discounts, as quoted by the suppliers, were applied to the list prices followed by a provincial tax surcharge. GST was not applied to these prices as this tax component is later rolled into the cost of the basement system paid by the consumer.

In the case of cast-in-place concrete, prices were supplied by the Ready Mix Concrete Association of Canada, and reflected Ontario averages. It is important to note that due to various local market conditions, the volume of concrete purchased (small versus large builder), and the cost of transportation, prices in a given Ontario market area may differ significantly from the provincial averages reported in this study.

The summary of the building materials survey is found in Table 6.6.

Survey of Basement Material Costs

This summary of building material costs is based on a survey conducted in Toronto during March 1999. While specific products and suppliers were surveyed, these are reported below generically without reference to the manufacturers.

COST OF CONCRETE AND CONCRETE BLOCK

Concrete	m^3	per ft^2 *	NOTE:
15 MPa	$90.00	$1.70	Additional charges are presented for information only, and were not factored in to costs derived later in this study.
20 MPa	$97.00	$1.83	
Additional Charges			
Air Entrainment	$3.00		
Calcium Chloride 2%	$3.50		
Superplasticizer	$7.00		
Winter Heat	$8.00		
Concrete Block	**each**	**per ft^2**	
8"	$1.52	$1.70	
10"	$1.93	$2.18	
12"	$2.25	$2.53	

* Based on 8" thick concrete wall.

COST OF THERMAL/MOISTURE PROTECTION

Insulation Option	Price	Area ft^2	Cost/ft^2	R-Value
1 - Exterior extruded polystyrene - 2-1/2"	$20.80	16	$1.30	12
2 - Exterior glass/mineral fibre - 1"	$9.08	24	$0.38	3.3
3 - Exterior expanded polystyrene - 3"	$11.36	16	$0.71	11.25
4 - Ext. sprayed polyurethane foam - 2"	$1.50	1	$1.50	12
5 - Interior glass/mineral fibre - 3-1/2"	$16.28	74	$0.22	12
6 - Interior cellulose - 3-1/2"	$0.26	1	$0.26	12
7 - Interior ext. polystyrene - 2"	$17.25	16	$1.08	10
8 - Interior exp. polystyrene - 2-1/2"	$9.46	16	$0.59	9.4
9 - Int. sprayed polyurethane foam - 2"	$1.50	1	$1.50	12
10 - Insulated concrete forms	$22.75	5	$4.27	22

MOISTURE PROTECTION & MISCELLANEOUS MATERIALS

Material	Area (ft^2)	Price	Cost/ft^2
Vapour Barrier	500	$20.10	$0.04
Glass/Mineral Drainage Board	24	$9.08	$0.38
Plastic Drainage Membrane	393.6	$154.00	$0.47
Strapping (2x4@16)	320	$123.66	$0.48
Drywall (1/2")	32	$5.89	$0.18
Lath and Parging (incl. masonry cove and flashing)			$5.30*

* The unit cost of exterior lath and parging, assuming brick veneer, is derived from the average cost for a 2-foot-high application of parging. For smaller basements, like the one used in his study, the unit cost may actually be higher since the cost of the cove and flashing predominate.

Table 6.6 Survey of basement material costs.

Builder Survey

A mail survey of selected builders was conducted during the Winter of 1999. Builders were selected on the basis of a proven track record (i.e., more than 10 years experience), a good warranty program record, and acceptable cost accounting practices. These criteria were established in order to obtain reliable cost data which reflected proper basement construction practices by profitable building businesses.

Following receipt of the mail survey, follow-up telephone interviews were conducted to clarify information and to obtain further insights on basement system selection and construction.

Table 6.7 shown below indicates additional information gathered from the follow-up telephone surveys. It summarizes the average unit labour costs for the installation of various materials and assemblies.

Miscellaneous Unit Labour Costs		
The following costs were reported for various work based on a unit measure (\$/ft^2).		
Material or Assembly Installation		
Studs, Insulation, Poly	$0.46	**NOTE:** Costs are for labour only. Builder supplies all materials and provides electrical power, access, etc.
Exterior Insulation/Drainage Layers	$0.53	
Foam Insulation, Strapping, Drywall	$0.64	
Drywall (untaped)	$0.20	

Table 6.7 Summary of builder survey costs for miscellaneous labour.

On the following page, Table 6.8 summarizes the results of the basement system costs reported by the builders that responded to the survey. Due to the confidentiality of the builder surveys, information profiling the location of the builders has been withheld; however, general information has been provided to contextualize the reported cost data.

Survey of Builder Costs

	Builder #1	Builder #2	Builder #3	Builder #4	Builder #5	Builder #6	AVG.
Basement Class	A-3	A-3	A-3	A-3	A-3	A-2	
Basement Floor Area (ft^2)	1733	2050	1128.5	2016	2100	840	
Basement Perimeter	178	150	135	180	230	131.6	
Excavation	$1,000.00	$800.00	$940.00	$925.00	$1,000.00	$929.00	
Volume Excavated (yd^3)	396	380	293	448	467	286	
Unit Cost ($/yd^3)	$2.53	$2.11	$3.21	$2.06	$2.14	$3.25	***$2.55***
Footings (Formed & Poured)	$0.00	$1,450.00	$0.00	$1,608.00	$1,621.00	$1,114.00	
Length (ft)	N/A	208	N/A	180	230	131.6	
Unit Cost ($/ft)	$0.00	$6.97	$0.00	$8.93	$7.05	$8.47	***$7.85***
Foundation Walls	$11,800.00	$4,350.00	$4,730.00	$5,958.00	$6,486.00	$4,200.00	
Area (ft^2)	1394	999	1057	1409	1801	930	
Unit Cost ($/ft^2)	$8.47	$4.36	$4.47	$4.23	$3.60	$4.51	***$4.23***
Dampproofing	$0.00	$100.00	$0.00	$121.50	$400.00	$100.00	
Area (ft^2)	N/A	N/A	N/A	N/A	N/A	N/A	
Unit Cost (lump sum)	$0.00	$100.00	$0.00	$121.50	$400.00	$100.00	***$180.38***
Weeping Tile/Crushed Stone	$0.00	$600.00	$360.00	$728.00	$0.00	$500.00	
Length (ft)	N/A	150	135	180	230	132	
Unit Cost ($/ft)	$0.00	$4.00	$2.67	$4.04	$0.00	$3.80	***$3.63***
Basement Floor Slab/Gravel	$2,000.00	$1,650.00	$1,000.00	$1,353.00	$3,706.00	$900.00	
Area (ft^2)	1448	2050	1128.5	2016	2100	840	
Unit Cost ($/ft^2)	$1.38	$1.80	$1.89	$1.67	$1.76	$1.07	***$1.60***
Drainage Layer	$0.00	$1,200.00	$790.00	$365.00	$1,280.00	$700.00	
Area (ft^2)	1448	750	810	720	1380	789.6	
Unit Cost ($/ft^2)	$0.00	$1.60	$0.98	$0.51	$0.93	$0.89	***$0.98***
Basement Insulation	$630.00	$1,100.00	$600.00	$663.00	$600.00	$700.00	
Area (ft^2)	712	1200	1080	1440	1840	1052.8	
Unit Cost ($/ft^2)	$0.88	$0.92	$0.56	$0.46	$0.33	$0.66	***$0.63***
Interior Finishes	$0.00	$0.00	$0.00	$0.00	$0.00	$800.00	
Area (ft^2)	N/A	N/A	N/A	N/A	N/A	1052.8	
Unit Cost ($/ft^2)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.76	***$0.76***
Backfilling	$500.00	$500.00	$200.00	$1,382.00	$800.00	$820.00	
Length (ft)	178	150	135	180	230	131.6	
Unit Cost ($/ft)	$2.81	$3.33	$1.48	$7.68	$3.48	$6.23	***$4.17***
Windows and Doors		$750.00	$372.00	$200.00	$600.00	$450.00	
Area (ft^2)	N/A	30	6	4	20	26.3	
Unit Cost	$0.00	$25.00	$62.00	$50.00	$30.00	$17.11	***$30.69***
Basement Plumbing	$800.00	$600.00	$360.00	$360.00	$350.00	$1,500.00	***$661.67***
Basement Electrical	$250.00	$300.00	$430.00	$430.00	$200.00	$1,500.00	***$518.33***
Miscellaneous Costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
Basement System Cost	**$17,489**	**$13,802**	**$10,075**	**$14,516**	**$17,554**	**$14,639**	***$14,679***
Basement Unit Cost ($/ft^2)	**$10.09**	**$6.73**	**$8.93**	**$7.20**	**$8.36**	**$17.43**	***$9.79***
Class A-3 Average Unit Cost							***$8.26***

Table 6.8 Summary of builder survey costs for basement systems.

Summary of Builder Profiles

BUILDER #1
This custom builder typically constructs a fully insulated, poured concrete basement without drywall finish. The foundation walls package includes footings, foundation walls, dampproofing and drainage layer. Nearly all of the basement system construction is subcontracted.

BUILDER #2
A builder who builds a variety of home types to cater to various market segments. Basement systems are typically constructed from block, insulated full height but without drywall finish. Granular backfill is used for a drainage layer. Most of the basement system construction is subcontracted.

BUILDER #3
A builder who builds mostly for a move-up homebuyer market. Basement systems are usually poured concrete, insulated full-height but without drywall. A dimpled, plastic membrane is used as a drainage layer. Most of the basement system construction is subcontracted.

BUILDER #4
This custom builder typically constructs a fully insulated, poured concrete basement without drywall finish. A glass fibre insulation board is used as a drainage layer. Nearly all of the basement system construction is carried out by the builder's own forces.

BUILDER #5
A custom builder who builds many home types to suit various market segments. Basement systems typically consist of a poured concrete foundation, insulated full-height but without drywall finish. Both a glass fibre insulation board and granular backfill are used for the drainage layer. Nearly all of the basement system construction is subcontracted.

BUILDER #6
A builder who builds a variety of home types to cater to various market segments. This builder typically constructs a fully insulated, poured concrete basement which is almost completely finished. A glass fibre insulation board is used as a drainage layer. Nearly all of the basement system construction is subcontracted.

SURVEY SYNOPSIS
In reviewing and comparing the cost data reported by builders, the interesting points to observe are:

1. Prices vary depending on the economic conditions within a locality. Areas with growing economies tend to have higher labour costs, which translate into higher basement system costs.
2. Core costs for items such as excavation, backfilling, sewer and water hook-ups tend to remain constant no matter the size of the basement, small or average.
3. Costs associated with a completely or almost completely finished basement tend to push the costs much higher, approximately doubling the cost per square foot for an average basement system.
4. Basement systems represent a significant cost component relative to the cost of the entire house.

Cost of Structural Foundation

To obtain the cost of structural foundations, two methods were followed:

1. The first method employed was intended for cast-in-place concrete or concrete block foundations. The average costs obtained from the builder survey were applied to the study model basement.
2. The second method targeted basements constructed using insulated concrete form systems, and was based on a separate survey of foundation contractors conducted after the builder survey. It should be noted that due to the high activity levels in the Ontario residential construction industry, considerable time and effort was required to obtain reasonable estimates of unit costs.

Table 6.9 summarizes the unit and model basement costs for the structural foundation.

Breakdown of Structural Foundation Costs

The costs for cast-in-place concrete and concrete block foundations are calculated below. Model basement parameters are applied to unit costs derived from the material and builder surveys. Based on the limited number of builders and markets surveyed, the difference in cost between these two structural foundation systems was found to be negligible.

Cast-In-Place Concrete or Concrete Block

Item	Exc.	Footings	Walls	Damp.	Weepers	Slab	Backfill	
Unit Cost	$2.55	$7.85	$4.23	$180.38	$3.63	$1.60	$4.17	
Unit	cu. yd.	lin. foot	ft^2	lump sum	lin. ft.	ft^2	lin. ft	**TOTAL**
Model Basement Cost	$516	$817	$3,523	$180	$377	$1,073	$434	***$6,920***

Insulated Concrete Form System

Item	Exc.	Footings	Walls*	Damp.	Weepers	Slab	Backfill	
Unit Cost	$2.55	$7.85	$8.16	N/A	$3.63	$1.60	$4.17	
Unit	cu. yd.	lin. foot	ft^2	N/A	lin. ft.	ft^2	lin. ft	**TOTAL**
Model Basement Cost	$516	$817	$6,785	N/A	$377	$1,073	$434	***$10,001***

* Walls include cost of ICFs, concrete and reinforcing steel.

NOTE: Dampproofing and foundation drainage (weepers) are normally considered part of the basic basement structural package, recognizing that these are actually part of the thermal and moisture protection measures.

Table 6.9 Breakdown of structural foundation costs for study model basement.

The higher cost for the ICF basement reflects the provision of thermal insulation as an integral part of this type of basement system.

Cost of Moisture and Thermal Protection

The cost of thermal and moisture protection was estimated for the 10 insulation options considered in this study. All of the cases listed in Table 6.10 below represent full-height basement insulation. The total cost for moisture and thermal protection for each option is based on the study model basement parameters found in Figure 6.4.

Cost of Moisture and Thermal Protection

Full-Height Basement Insulation

Insulation Option		**Insulation**	**V.B. & Strapping**	**Drywall**	**Drainage Layer**	**Parging**	**TOTAL**
1	Exterior extruded polystyrene	$1,523	N/A	N/A	Integral	$551	**$2,074**
2	Exterior glass/mineral fibre*	$1,385	N/A	N/A	Integral	$551	**$1,936**
3	Exterior expanded polystyrene	$1,031	N/A	N/A	Integral	$551	**$1,583**
4	Ext. sprayed polyurethane foam	$1,248	N/A	N/A	Integral	$551	**$1,799**
5	Interior glass/mineral fibre	$566	$436	N/A	$353	N/A	**$1,355**
6	Interior cellulose	$599	$436	N/A	$353	N/A	**$1,389**
7	Interior ext. polystyrene (XPS)	$1,429	N/A	$320	$353	N/A	**$2,102**
8	Interior exp. polystyrene (EPS)	$1,025	N/A	$320	$353	N/A	**$1,697**
9	Int. sprayed polyurethane foam	$1,248	$403	$320	$353	N/A	**$2,324**
10	Insulated concrete forms**	Included	N/A	$320	$353	$551	**$1,224**

* Assumes 3-inch thickness of application.

** For ICFs, in lieu of a drainage layer, an exterior moisture protection membrane on the below-grade, exterior foundation wall is commonly recommended, at a comparable cost to the drainage layer.

IMPORTANT NOTE: The applicable measures indicated above are based on the requirements of the Ontario Building Code, and reflects the practices of the Ontario builders that were surveyed. Requirements in other regions of Canada may differ.

Table 6.10 Derived costs of thermal and moisture protection options for study model basement.

Cost of Basement Finishing

Having derived the costs of the structural foundation system, and the moisture and thermal protection options, the builders were surveyed to determine the cost of basement finishing options. The rounded results are listed in Table 6.11 below.

<table>
<tr><th colspan="3">Cost of Basement Finishing Options</th></tr>
<tr><td colspan="3">This table contains data on the cost of finishing a basement for two intended uses:
1 - as a fully separate dwelling unit, and
2 - as a livable space within a dwelling.
These uses correspond to Class A-1 and Class A-2, respectively, as defined in Table 1.2.</td></tr>
<tr><td colspan="3">ASSUMPTIONS & LIMITATIONS
1. These costs were derived through a builder survey, where builders assumed a full-height insulated basement as a starting point for the incremental price.
2. Costs may vary significantly depending on site and market conditions.</td></tr>
<tr><td></td><td>$/ft²</td><td rowspan="3"></td></tr>
<tr><td><i>Class A-1 Upgrade</i></td><td>$25.00</td></tr>
<tr><td><i>Class A-2 Upgrade</i></td><td>$15.00</td></tr>
<tr><td colspan="3">NOTE: The Class A-1 upgrade accounts for fire separation, noise dampening, access/egress, and provision of a kitchen, bathroom and separate heating system.</td></tr>
</table>

Table 6.11 Estimated costs of basement finishing options for study model basement.

It is important to note that the variability in the prices provided by the builders was relatively high. The finishing of basements was found to be extremely market sensitive. While some builders reported that it was an item that was only offered at a significant price premium, others reported that it was used as a loss leader during periods of low market activity to induce sales. All builders indicated that the pricing of basement finishing was dependent on time of year and the stage of subdivision development. For these reasons the reported pricing was rounded, acknowledging that the rounding error was less significant than the variance in prices reported across Ontario.

With this stage of the study complete, it was possible to continue with a derivation of costs for the various assessment scenarios outlined in Tables 6.3, 6.4 and 6.5.

6.3 Costs of Basement System Alternatives

Various assessment scenarios were analyzed according to the 10 thermal/moisture protection options for each of the five basement classes (A-1, A-2, A-3, B, C). Class D and E basements were not considered in this study as they do not represent a significant proportion of total annual basement construction.

Cost of Selected Basement Classes

Table 13 summarizes the cost of five selected basement classes in Toronto, Ontario, according to the 10 thermal/moisture protection options described in Section 6.1.

Compared Cost of Selected Basement Classes - Ontario

Builder costs for each basement class and thermal/moisture protection option are derived from the previous data. In the case of the Class A-1 basement, it was assumed that half of the basement was converted into a separate dwelling unit. For Class A-2 basements, one-third of the basement was finished.

	Thermal/Moisture Protection Option									
Basement Class	***Ext XPS*** ***1***	***Ext Fibre*** ***2***	***Ext EPS*** ***3***	***Ext SPF*** ***4***	***Int Fibre*** ***5***	***Int Cell.*** ***6***	***Int XPS*** ***7***	***Int EPS*** ***8***	***Int SPF*** ***9***	***ICFs*** ***10***
A-1	$17,393	$17,256	$16,902	$17,119	$16,675	$16,708	$17,422	$17,017	$17,643	$19,625
A-2	$12,353	$12,216	$11,862	$12,079	$11,635	$11,668	$12,382	$11,977	$12,603	$14,585
A-3	$8,993	$8,856	$8,502	$8,719	$8,275	$8,308	$9,022	$8,617	$9,243	$11,225
B	N/A	N/A	N/A	N/A	$7,244	$7,261	$7,618	$7,415	N/A	N/A
C	N/A	N/A	N/A	N/A	$6,920	$6,920	$6,920	$6,920	N/A	N/A
Special*					$7,156					

N/A signifies that this class of basement system is not normally constructed with this type of insulation option.

NOTES:
(1) Class C basements are normally not permitted in Ontario.
(2) All Class C basements are without thermal/moisture protection and identical for each option.
(3) Due to applicable Code requirements, ICF basements are minimum A-3 class.
* Special case based on 4 feet wide insulation blanket with integral poly wrapped around basement interior.

LEGEND:

1. Ext XPS	Exterior extruded polystyrene insulation
2. Ext Fibre	Exterior glass/mineral fibre semi-rigid draining insulation and dampproofing
3. Ext EPS	Exterior expanded polystyrene insulation and dampproofing
4. Ext SPF	Exterior sprayed polyurethane foam
5. Int Fibre	Interior glass/mineral fibre batt insulation, strapping, vapour barrier, dampproofing, drainage layer
6. Int Cell.	Interior cellulose insulation, strapping, vapour barrier, dampproofing and drainage layer
7. Int XPS	Interior extruded polystyrene insulation, strapping, drywall, dampproofing and drainage layer
8. Int EPS	Interior expanded polystyrene insulation, strapping, drywall, dampproofing and drainage layer
9. Int SPF	Interior sprayed polyurethane foam, strapping, drywall, dampproofing and drainage layer
10. ICFs	Insulated concrete forms, exterior moisture protection, interior drywall

Table 6.12 Cost of selected basement classes for study model basement – Ontario.

Regional Energy and Construction Costs

To assess the costs associated with the space heating of the various model basement configurations, it was necessary to establish regional residential energy prices for each of the primary sources. Houses may be heated by natural gas, oil, propane, electricity or wood, but only the first four energy sources were considered. Variations in the price, energy content and conversion efficiency of wood fuels, and a lack of reliable data, excluded this fuel from the study.

Construction costs also vary from region to region and it was necessary to translate prices obtained in one location to the other locations considered in this study. A methodology consistent with that used in developing the National Energy Code for Houses was employed. Residential construction cost location factors were applied to the costs determined from the Ontario builder survey.

Table 6.13 lists the regional energy and construction costs used in the economic assessments performed later in this study. Energy prices were obtained from Natural Resources Canada, Statistics Canada and several fuel energy associations. Construction cost location factors were obtained from *Residential Cost Data 1999*, published by R.S. Means Co. A complete listing of the factors may be found on Sheet 18 of the electronic spreadsheet.

Retail Energy Prices and Residential Construction Cost Location Factors					
	ENERGY PRICE ($/GJ)				**LOCATION FACTOR**
LOCATION	**Gas**	**Oil**	**Propane**	**Electricity**	
Toronto	6.98	9.76	16.42	25.64	1.14
Ottawa	6.98	9.76	16.42	20.44	1.11
Halifax	N/A	9.47	18.34	26.11	0.98
Edmonton	4.64	7.97	13.09	20.86	1.01
Victoria*	6.98	10.56	16.83	17.00	1.07
* BC average price for natural gas cited in this study.					

Table 6.13 1999 energy prices and construction cost location factors.

Basement Operating Costs - TORONTO

In order to obtain the annual space heating energy demand, and annual operating energy costs for each basement class and thermal/moisture protection option, simulations using the study model basement parameters were performed using BASECALC™ software. The results for Toronto are presented in Table 6.14.

TORONTO - Basement System Operating Costs

Annual energy demand was estimated for each basement option using BASECALC software.

The annual cost of operation was calculated using the energy prices listed below.

Space Heating	
Energy	**$/GJ**
Gas (80%)	**8.73**
Oil (80%)	**12.20**
Prop. (80%)	**20.53**
Elec. (100%)	**25.64**

The costs of various types of space heating energy are based on 1999 data, and reflect the space heating system efficiency as noted in parentheses.

ANNUAL ENERGY DEMAND (GJ) AND OPERATING COSTS - TORONTO

Classes A-1, A-2, A-3 Basement Systems

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	**12.4**	**13.1**	**12.6**	**12.6**	**9.8**	**9.8**	**10.6**	**10.8**	**9.8**	**7.7**
Gas (80%)	$108	$114	$110	$110	$86	$86	$92	$94	$86	$67
Oil (80%)	$151	$160	$154	$154	$120	$120	$129	$132	$120	$94
Prop. (80%)	$255	$269	$259	$259	$201	$201	$218	$222	$201	$158
Elec. (100%)	$318	$336	$323	$323	$251	$251	$272	$277	$251	$197

Class B Basement Systems

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	**13.5**	**13.5**	**13.9**	**14.1**	N/A	N/A
Gas (80%)	N/A	N/A	N/A	N/A	$118	$118	$121	$123	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$165	$165	$170	$172	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$277	$277	$285	$289	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$346	$346	$356	$362	N/A	N/A

Class C Basement Systems

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	**28.6**	**28.6**	**28.6**	**28.6**	N/A	N/A
Gas (80%)	N/A	N/A	N/A	N/A	$250	$250	$250	$250	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$349	$349	$349	$349	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$587	$587	$587	$587	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$733	$733	$733	$733	N/A	N/A

NOTE: The Class C basement system is actually the base case basement system without thermal/moisture protection.
N/A signifies that the class of basement cannot normally be upgraded to this thermal/moisture protection option.

Table 6.14 Annual energy demand and operating costs for selected basement classes – Toronto.

It should be noted that all of the Class A basement systems are equivalent with respect to thermal and moisture protection features (full-height insulation and drainage layer, integral or separate). The Class B basement systems are partially insulated to 2 feet (600 mm) below grade, and the Class C basement is completely uninsulated, serving as a cellar.

Life Cycle Cost –- TORONTO

Having established the capital and operating costs of the various basement classes and thermal/moisture protection options, this part of the study presents a life cycle analysis of each resulting combination. The rationale and methodology employed in this process is consistent with that forming the basis for the 1995 National Energy Code for Houses.

Applicable taxes and profit, and the construction cost location factor were also applied to the builder costs for the various basement systems to arrive at consumer (new home buyer) costs for the basement systems in each locality. The life cycle parameters, taxes and profit, and location factor used in the life cycle analyses are noted below.

Life Cycle Parameters		**Taxes and Profit**
Interest	**4%**	
Escalation	**1%**	**12%**
Period (years)	**30**	
TORONTO - Construction Cost Location Factor		**1.036**

The life cycle costs for the Class A-1 basement systems are presented in Table 6.15 below. The range of basement system consumer costs range from $19,355 to $22,779, representing a 17.7% relative difference. Life cycle costs are based on 4 space heating energy sources most commonly purchased in Canada, along with their respective conversion efficiencies. The life cycle costs range from $21,037 to $26,664. This $5,627 difference indicates the significance of basement system and space heating energy choices among consumers (new home buyers).

Class A-1 Basement Systems										
	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	12.4	13.1	12.6	12.6	9.8	9.8	10.6	10.8	9.8	7.7
System Cost	$20,189	$20,029	$19,619	$19,870	$19,355	$19,394	$20,222	$19,752	$20,479	$22,779
Life Cycle Cost										
Gas (80%)	$22,318	$22,278	$21,782	$22,033	$21,037	$21,076	$22,042	$21,606	$22,161	$24,101
Oil (80%)	$23,166	$23,174	$22,644	$22,895	$21,707	$21,746	$22,767	$22,345	$22,832	$24,628
Prop. (80%)	$25,197	$25,320	$24,707	$24,959	$23,313	$23,351	$24,503	$24,114	$24,437	$25,889
Elec. (100%)	$26,445	$26,638	$25,976	$26,227	$24,299	$24,338	$25,570	$25,201	$25,423	$26,664

Table 6.15 Life cycle costs for Class A-1 basement systems – Toronto.

It is important to note in the above, and all subsequent life cycle assessments, that the cost of the heating and ventilation systems was not considered. Due to the numerous methods of delivering heating and ventilation to the basement, it was not possible to specify and price each of the conceivable options.

An interesting relationship worth noting, however, is that when electric resistance heating is used to heat the basement space, this alternative is on average $3,634 more expensive than natural gas over the 30-year study period, $2,898 more expensive than oil, and $1,099 more expensive than propane. The use of separately controlled electric baseboard heaters in the basement is a popular choice in finished basements due to separate controls and low first costs, but when less expensive energy sources are available, this approach may not prove to be the most cost effective to consumers. It is also revealing that as the thermal efficiency of the basement system increases, the difference in life cycle costs between fuel types significantly diminishes. These relationships hold true for all Class A basements.

Life cycle costs for the Class A-2 basement systems are presented in Table 6.16. The range of basement system costs to consumers range from $13,505 to $16,929. The life cycle costs range from $15,187 to $20,814. On a comparative basis, the highest priced Class A-2 basement system is 25.4% greater than the lowest priced Class A-2 basement system. The absolute difference between the minimum and maximum life cycle costs for Class A-2 basements remains the same for all Class A basement systems, but the relative difference between Class A-2 options represents a 37.1% premium with respect to the minimum cost system.

Class A-2 Basement Systems										
	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	12.4	13.1	12.6	12.6	9.8	9.8	10.6	10.8	9.8	7.7
System Cost	$14,339	$14,179	$13,769	$14,020	$13,505	$13,544	$14,372	$13,902	$14,629	$16,929
Life Cycle Cost										
Gas (80%)	$16,468	$16,428	$15,932	$16,183	$15,187	$15,226	$16,192	$15,756	$16,311	$18,251
Oil (80%)	$17,316	$17,324	$16,794	$17,045	$15,857	$15,896	$16,917	$16,495	$16,981	$18,778
Prop. (80%)	$19,347	$19,469	$18,857	$19,109	$17,463	$17,501	$18,653	$18,264	$18,587	$20,039
Elec. (100%)	$20,595	$20,788	$20,126	$20,377	$18,449	$18,488	$19,720	$19,351	$19,573	$20,814

Table 6.16 Life cycle costs for Class A-2 basement systems – Toronto.

Life cycle costs for the Class A-3 basement systems are presented in Table 6.17. The range of basement system costs to consumers range from $9,605 to $13,029. The life cycle costs range from $11,287 to $16,914. As a relative comparison, the highest basement system capital cost is 35.6% greater than the lowest priced basement system. The absolute difference between the minimum and maximum life cycle costs for Class A-3 basements remains the same for all Class A basement systems; however, the relative difference represents a 49.9% premium with respect to the minimum cost system.

Class A-3 Basement Systems										
	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	12.4	13.1	12.6	12.6	9.8	9.8	10.6	10.8	9.8	7.7
System Cost	$10,439	$10,279	$9,869	$10,120	$9,605	$9,644	$10,472	$10,002	$10,729	$13,029
Life Cycle Cost										
Gas (80%)	$12,568	$12,528	$12,032	$12,283	$11,287	$11,326	$12,292	$11,856	$12,411	$14,351
Oil (80%)	$13,416	$13,424	$12,893	$13,145	$11,957	$11,996	$13,017	$12,594	$13,081	$14,878
Prop. (80%)	$15,447	$15,569	$14,957	$15,209	$13,563	$13,601	$14,753	$14,364	$14,687	$16,139
Elec. (100%)	$16,695	$16,888	$16,225	$16,477	$14,549	$14,588	$15,820	$15,450	$15,673	$16,914

Table 6.17. Life cycle costs for Class A-3 basement systems – Toronto.

Life cycle costs for the Class B basement systems are presented in Table 6.18. The basement system costs to consumers range from $8,408 to $8,842. The life cycle costs range from $10,726 to $15,720, a $4,994 difference. On a comparative basis, the highest priced Class B basement system is 5.2% greater than the lowest-priced basement system. The relative difference between the minimum and maximum life cycle costs for Class B basements represents a 46.6% premium with respect to the minimum cost system. The analysis indicates that the Class B basement system becomes less cost effective over its life cycle as space heating energy costs increase. It should be noted in the table below that N/A signifies that the Class B basement system (i.e., insulation to 2 feet below grade) cannot normally be upgraded to a higher basement class using this thermal/moisture protection option.

Class B Basement Systems										
	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	N/A	N/A	N/A	N/A	13.5	13.5	13.9	14.1	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$8,408	$8,428	$8,842	$8,607	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$10,726	$10,745	$11,228	$11,028	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$11,649	$11,668	$12,179	$11,992	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$13,860	$13,880	$14,455	$14,301	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$15,219	$15,238	$15,854	$15,720	N/A	N/A

Table 6.18 Life cycle costs for Class B basement systems – Toronto.

Life cycle costs for the Class C basement systems are presented in Table 6.19. The cost of each basement system is identical, $8,032, as this configuration represents the base case scenario – an uninsulated, cellar-type basement. Similarly, the life cycle costs are also identical across options, and range from $12,942 to $22,460, a $9,518 difference. The relative difference between the minimum and maximum life cycle costs for Class C basements represents a 73.5% premium with respect to the minimum cost system, all of which is accounted for by differences in energy prices. The analysis indicates that the Class C basement system becomes significantly less cost effective over its life cycle as space heating energy costs increase. It should be noted that N/A signifies that the Class C basement cannot normally be upgraded to a higher basement class using this thermal/moisture protection option.

Class C Basement Systems										
	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	N/A	N/A	N/A	N/A	28.6	28.6	28.6	28.6	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$8,032	$8,032	$8,032	$8,032	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$12,942	$12,942	$12,942	$12,942	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$14,897	$14,897	$14,897	$14,897	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$19,582	$19,582	$19,582	$19,582	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$22,460	$22,460	$22,460	$22,460	N/A	N/A

Table 6.19 Life cycle costs for Class C basement systems – Toronto.

Brief summaries of the operating life cycle cost analyses performed for Ottawa, Halifax, Edmonton and Victoria now follow.

Ottawa –- Operating and Life Cycle Costs

Annual operating costs for Ottawa are slightly higher than those estimated for Toronto due to a colder climate (this may be inferred from the difference between the annual energy demand for this city compared with Toronto), with the exception of electrically heated basements where the lower cost of electricity in Ottawa offsets climatic differences.

Based on the Ottawa construction cost location factor, basements are less expensive to construct than in Toronto (the highest cost basements in the study) and the narrower spread in prices between the lowest and highest priced energy sources render the differences in life cycle costs within and between basement options less significant. However, Class A basement systems still provide cost effective value within this market across all energy sources.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	14.6	15.4	14.9	14.6	9.8	11.7	12.5	12.8	11.7	9.3
System Cost	$18,968	$18,818	$18,432	$18,669	$18,184	$18,221	$18,999	$18,557	$19,240	$21,402
Life Cycle Cost										
Gas (80%)	$21,474	$21,462	$20,990	$21,175	$20,193	$20,229	$21,145	$20,755	$21,249	$22,998
Oil (80%)	$22,473	$19,121	$18,726	$18,956	$18,377	$18,451	$19,245	$18,809	$19,471	$21,585
Prop. (80%)	$24,864	$25,037	$24,450	$24,565	$22,909	$22,946	$24,047	$23,727	$23,966	$25,157
Elec. (100%)	$24,840	$25,011	$24,425	$24,540	$22,890	$22,926	$24,026	$23,705	$23,946	$25,142

Table 6.20 Life cycle costs for Class A-1 basement systems – Ottawa.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	14.6	15.4	14.9	14.6	11.7	11.7	12.5	12.8	11.7	9.3
System Cost	$13,472	$13,322	$12,936	$13,172	$12,688	$12,725	$13,503	$13,061	$13,744	$15,905
Life Cycle Cost										
Gas (80%)	$15,978	$15,965	$15,494	$15,679	$14,697	$14,733	$15,649	$15,259	$15,753	$17,502
Oil (80%)	$16,976	$17,018	$16,513	$16,677	$15,497	$15,533	$16,503	$16,134	$16,553	$18,138
Prop. (80%)	$19,368	$19,541	$18,954	$19,069	$17,413	$17,450	$18,551	$18,230	$18,469	$19,661
Elec. (100%)	$19,344	$19,515	$18,929	$19,044	$17,394	$17,430	$18,530	$18,209	$18,450	$19,646

Table 6.21 Life cycle costs for Class A-2 basement systems – Ottawa.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	14.6	15.4	14.9	14.6	9.8	11.7	12.5	12.8	11.7	9.3
System Cost	$9,808	$9,657	$9,272	$9,508	$9,024	$9,060	$9,839	$9,397	$10,080	$12,241
Life Cycle Cost										
Gas (80%)	$12,314	$12,301	$11,830	$12,015	$11,033	$11,069	$11,985	$11,594	$12,089	$13,838
Oil (80%)	$13,312	$13,354	$12,849	$13,013	$11,833	$11,869	$12,839	$12,470	$12,889	$14,474
Prop. (80%)	$15,704	$15,877	$15,289	$15,404	$13,749	$13,785	$14,887	$14,566	$14,805	$15,997
Elec. (100%)	$15,679	$15,851	$15,264	$15,380	$13,729	$13,766	$14,866	$14,545	$14,786	$15,981

Table 6.22 Life cycle costs for Class A-3 basement systems – Ottawa.

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	16.0	16.0	16.5	16.7	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$7,900	$7,918	$8,307	$8,086	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$10,647	$10,665	$11,140	$10,953	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$11,741	$11,759	$12,268	$12,095	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$14,361	$14,380	$14,971	$14,831	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$14,335	$14,353	$14,943	$14,803	N/A	N/A

Table 6.23 Life cycle costs for Class B basement systems – Ottawa.

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	33.3	33.3	33.3	33.3	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$7,546	$7,546	$7,546	$7,546	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$13,263	$13,263	$13,263	$13,263	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$15,540	$15,540	$15,540	$15,540	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$20,994	$20,994	$20,994	$20,994	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$20,939	$20,939	$20,939	$20,939	N/A	N/A

Table 6.24 Life cycle costs for Class C basement systems – Ottawa.

Halifax – Operating and Life Cycle Costs

Due to the unavailability of natural gas in Halifax, the lowest price fuel (oil) is significantly more expensive than the lowest priced fuel (natural gas) in all of the other study locations. When this factor is coupled to the Halifax climate, basement operating costs are relatively high compared to other parts of Canada.

Halifax was estimated to have the lowest basement capital costs, but among the highest life cycle costs, signifying that Class A basements (full-height insulation) represent a highly cost effective alternative to Class B and C basement systems.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	14.1	14.7	14.3	14.1	9.8	11.3	12.1	12.1	11.3	9.1
System Cost	$16,747	$16,614	$16,274	$16,482	$16,055	$16,087	$16,774	$16,384	$16,987	$18,895
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oil (80%)	$20,031	$16,903	$16,555	$16,760	$16,248	$16,309	$17,012	$16,622	$17,209	$19,074
Prop. (80%)	$23,107	$23,245	$22,724	$22,842	$21,152	$21,184	$22,232	$21,842	$22,084	$23,000
Elec. (100%)	$23,990	$24,166	$23,620	$23,726	$21,860	$21,892	$22,990	$22,600	$22,792	$23,570

Table 6.25 Life cycle costs for Class A-1 basement systems – Halifax.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int. Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	14.1	14.7	14.3	14.1	11.3	11.3	12.1	12.1	11.3	9.1
System Cost	$11,894	$11,761	$11,421	$11,630	$11,202	$11,234	$11,921	$11,532	$12,135	$14,043
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oil (80%)	$15,178	$15,185	$14,752	$14,914	$13,834	$13,866	$14,740	$14,350	$14,766	$16,162
Prop. (80%)	$18,254	$18,392	$17,871	$17,990	$16,299	$16,331	$17,379	$16,989	$17,232	$18,147
Elec. (100%)	$19,138	$19,313	$18,768	$18,873	$17,007	$17,040	$18,138	$17,748	$17,940	$18,718

Table 6.26 Life cycle costs for Class A-2 basement systems – Halifax.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	14.1	14.7	14.3	14.1	9.8	11.3	12.1	12.1	11.3	9.1
System Cost	$8,659	$8,526	$8,186	$8,395	$7,967	$7,999	$8,686	$8,297	$8,900	$10,808
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oil (80%)	$11,943	$11,950	$11,517	$11,679	$10,599	$10,631	$11,505	$11,115	$11,531	$12,927
Prop. (80%)	$15,019	$15,157	$14,636	$14,755	$13,064	$13,096	$14,144	$13,754	$13,997	$14,912
Elec. (100%)	$15,903	$16,078	$15,533	$15,638	$13,772	$13,804	$14,903	$14,513	$14,705	$15,483

Table 6.27 Life cycle costs for Class A-3 basement systems – Halifax.

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	15.4	15.4	15.8	16.0	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$6,975	$6,991	$7,334	$7,139	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$10,562	$10,578	$11,014	$10,866	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$13,921	$13,937	$14,461	$14,356	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$14,886	$14,902	$15,451	$15,359	N/A	N/A

Table 6.28 Life cycle costs for Class B basement systems – Halifax.

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	31.3	31.3	31.3	31.3	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$6,662	$6,662	$6,662	$6,662	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$13,953	$13,953	$13,953	$13,953	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$20,781	$20,781	$20,781	$20,781	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$22,742	$22,742	$22,742	$22,742	N/A	N/A

Table 6.29 Life cycle costs for Class C basement systems – Halifax.

Edmonton – Operating and Life Cycle Costs

Edmonton represents the coldest climate location in the study, but the lowest energy prices. To put this relationship into a simple perspective, Edmonton is similar to Toronto in terms of the cost effectiveness of full-height basement insulation.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	18.1	19.0	18.3	18.1	9.8	14.5	15.4	15.8	14.5	11.6
System Cost	$17,259	$17,122	$16,772	$16,987	$16,546	$16,579	$17,287	$16,886	$17,507	$19,474
Life Cycle Cost										
Gas (80%)	$19,325	$19,291	$18,860	$19,052	$18,201	$18,234	$19,045	$18,689	$19,162	$20,797
Oil (80%)	$20,807	$20,847	$20,359	$20,535	$19,388	$19,422	$20,306	$19,983	$20,349	$21,747
Prop. (80%)	$23,086	$23,239	$22,663	$22,814	$21,214	$21,247	$22,245	$21,972	$22,175	$23,208
Elec. (100%)	$24,688	$24,921	$24,283	$24,416	$22,498	$22,531	$23,608	$23,371	$23,458	$24,235

Table 6.30 Life cycle costs for Class A-1 basement systems – Edmonton.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	18.1	19.0	18.3	18.1	14.5	14.5	15.4	15.8	14.5	11.6
System Cost	$12,258	$12,121	$11,771	$11,986	$11,545	$11,578	$12,286	$11,885	$12,506	$14,472
Life Cycle Cost										
Gas (80%)	$14,324	$14,290	$13,859	$14,051	$13,200	$13,233	$14,044	$13,688	$14,161	$15,796
Oil (80%)	$15,806	$15,846	$15,358	$15,534	$14,387	$14,420	$15,305	$14,982	$15,348	$16,746
Prop. (80%)	$18,085	$18,238	$17,662	$17,813	$16,213	$16,246	$17,244	$16,971	$17,174	$18,207
Elec. (100%)	$19,687	$19,920	$19,282	$19,415	$17,496	$17,530	$18,607	$18,369	$18,457	$19,234

Table 6.31 Life cycle costs for Class A-2 basement systems – Edmonton.

	Thermal/Moisture Protection Option									
	Ext XPS	***Ext Fibre***	***Ext EPS***	***Ext SPF***	***Int Fibre***	***Int Cell.***	***Int XPS***	***Int EPS***	***Int SPF***	***ICFs***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Demand (GJ)	18.1	19.0	18.3	18.1	9.8	14.5	15.4	15.8	14.5	11.6
System Cost	$8,924	$8,787	$8,437	$8,652	$8,211	$8,244	$8,952	$8,550	$9,172	$11,138
Life Cycle Cost										
Gas (80%)	$10,990	$10,956	$10,525	$10,717	$9,866	$9,899	$10,710	$10,354	$10,827	$12,462
Oil (80%)	$12,472	$12,512	$12,024	$12,200	$11,053	$11,086	$11,971	$11,648	$12,014	$13,412
Prop. (80%)	$14,751	$14,904	$14,328	$14,479	$12,879	$12,912	$13,910	$13,637	$13,840	$14,873
Elec. (100%)	$16,353	$16,586	$15,948	$16,081	$14,162	$14,195	$15,273	$15,035	$15,123	$15,899

Table 6.32. Life cycle costs for Class A-3 basement systems – Edmonton.

	Thermal/Moisture Protection Option									
	Ext XPS 1	*Ext Fibre 2*	*Ext EPS 3*	*Ext SPF 4*	*Int Fibre 5*	*Int Cell. 6*	*Int XPS 7*	*Int EPS 8*	*Int SPF 9*	*ICFs 10*
Demand (GJ)	N/A	N/A	N/A	N/A	19.5	19.5	20.1	20.3	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$7,188	$7,205	$7,559	$7,358	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$9,414	$9,430	$9,853	$9,675	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$11,011	$11,027	$11,499	$11,337	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$13,466	$13,483	$14,030	$13,893	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$15,192	$15,208	$15,809	$15,690	N/A	N/A

Table 6.33 Life cycle costs for Class B basement systems – Edmonton.

	Thermal/Moisture Protection Option									
	Ext XPS 1	*Ext Fibre 2*	*Ext EPS 3*	*Ext SPF 4*	*Int Fibre 5*	*Int Cell. 6*	*Int XPS 7*	*Int EPS 8*	*Int SPF 9*	*ICFs 10*
Demand (GJ)	N/A	N/A	N/A	N/A	39.7	39.7	39.7	39.7	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$6,866	$6,866	$6,866	$6,866	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$11,397	$11,397	$11,397	$11,397	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$14,648	$14,648	$14,648	$14,648	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$19,648	$19,648	$19,648	$19,648	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$23,161	$23,161	$23,161	$23,161	N/A	N/A

Table 6.34 Life cycle costs for Class C basement systems – Edmonton.

Victoria – Operating and Life Cycle Costs

Victoria climatic conditions cause the least annual basement space heating energy demand among the five locations studied. As a result, the cost of heating basements is generally the lowest estimated in this study.

The range of energy prices is narrower than most locations in Canada, and the construction costs are nearly average. Given these circumstances, Class A basements are less cost effective from a thermal efficiency perspective, compared to the other locations considered in this study. However, given the cost of serviced land in lower British Columbia the inclusion of livable space within the basement may prove more affordable, especially as evidenced in the raised foundation construction traditionally favoured in this region.

	Thermal/Moisture Protection Option									
	Ext XPS 1	*Ext Fibre 2*	*Ext EPS 3*	*Ext SPF 4*	*Int Fibre 5*	*Int Cell. 6*	*Int XPS 7*	*Int EPS 8*	*Int SPF 9*	*ICFs 10*
Demand (GJ)	10.0	10.5	10.2	10.0	9.8	8.1	8.7	8.8	8.1	6.5
System Cost	$18,285	$18,140	$17,768	$17,996	$17,529	$17,564	$18,314	$17,889	$18,547	$20,630
Life Cycle Cost										
Gas (80%)	$20,001	$19,942	$19,519	$19,713	$18,920	$18,955	$19,808	$19,399	$19,938	$21,746
Oil (80%)	$20,882	$18,346	$17,969	$18,193	$17,722	$17,724	$18,486	$18,062	$18,707	$20,758
Prop. (80%)	$22,424	$22,486	$21,990	$22,135	$20,882	$20,917	$21,916	$21,531	$21,900	$23,321
Elec. (100%)	$21,629	$21,652	$21,180	$21,341	$20,239	$20,274	$21,225	$20,832	$21,257	$22,805

Table 6.35 Life cycle costs for Class A-1 basement systems – Victoria.

	Thermal/Moisture Protection Option									
	Ext XPS 1	*Ext Fibre 2*	*Ext EPS 3*	*Ext SPF 4*	*Int Fibre 5*	*Int Cell. 6*	*Int XPS 7*	*Int EPS 8*	*Int SPF 9*	*ICFs 10*
Demand (GJ)	10.0	10.5	10.2	10.0	8.1	8.1	8.7	8.8	8.1	6.5
System Cost	$12,986	$12,841	$12,470	$12,698	$12,231	$12,266	$13,016	$12,591	$13,249	$15,332
Life Cycle Cost										
Gas (80%)	$14,703	$14,644	$14,221	$14,414	$13,621	$13,657	$14,510	$14,101	$14,639	$16,448
Oil (80%)	$15,584	$15,569	$15,119	$15,295	$14,335	$14,370	$15,276	$14,876	$15,353	$17,020
Prop. (80%)	$17,126	$17,188	$16,692	$16,837	$15,584	$15,619	$16,617	$16,233	$16,602	$18,023
Elec. (100%)	$16,331	$16,354	$15,882	$16,043	$14,940	$14,975	$15,926	$15,534	$15,958	$17,506

Table 6.36 Life cycle costs for Class A-2 basement systems – Victoria.

	Thermal/Moisture Protection Option									
	Ext XPS 1	*Ext Fibre 2*	*Ext EPS 3*	*Ext SPF 4*	*Int Fibre 5*	*Int Cell. 6*	*Int XPS 7*	*Int EPS 8*	*Int SPF 9*	*ICFs 10*
Demand (GJ)	10.0	10.5	10.2	10.0	9.8	8.1	8.7	8.8	8.1	6.5
System Cost	$9,454	$9,309	$8,938	$9,166	$8,699	$8,734	$9,484	$9,058	$9,717	$11,800
Life Cycle Cost										
Gas (80%)	$11,171	$11,112	$10,689	$10,882	$10,089	$10,124	$10,978	$10,569	$11,107	$12,916
Oil (80%)	$12,051	$12,036	$11,587	$11,763	$10,803	$10,838	$11,744	$11,344	$11,821	$13,488
Prop. (80%)	$13,594	$13,656	$13,160	$13,305	$12,052	$12,087	$13,085	$12,701	$13,070	$14,491
Elec. (100%)	$12,799	$12,821	$12,350	$12,510	$11,408	$11,443	$12,394	$12,002	$12,426	$13,974

Table 6.37 Life cycle costs for Class A-3 basement systems – Victoria.

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	11.0	11.0	11.4	11.4	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$7,615	$7,633	$8,008	$7,795	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$9,504	$9,521	$9,965	$9,752	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$10,472	$10,490	$10,969	$10,756	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$12,168	$12,186	$12,727	$12,514	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$11,295	$11,312	$11,821	$11,608	N/A	N/A

Table 6.38 Life cycle costs for Class B basement systems – Victoria.

	Thermal/Moisture Protection Option									
	Ext XPS 1	***Ext Fibre 2***	***Ext EPS 3***	***Ext SPF 4***	***Int Fibre 5***	***Int.Cell. 6***	***Int XPS 7***	***Int EPS 8***	***Int SPF 9***	***ICFs 10***
Demand (GJ)	N/A	N/A	N/A	N/A	22.2	22.2	22.2	22.2	N/A	N/A
System Cost	N/A	N/A	N/A	N/A	$7,274	$7,274	$7,274	$7,274	N/A	N/A
Life Cycle Cost										
Gas (80%)	N/A	N/A	N/A	N/A	$11,085	$11,085	$11,085	$11,085	N/A	N/A
Oil (80%)	N/A	N/A	N/A	N/A	$13,040	$13,040	$13,040	$13,040	N/A	N/A
Prop. (80%)	N/A	N/A	N/A	N/A	$16,463	$16,463	$16,463	$16,463	N/A	N/A
Elec. (100%)	N/A	N/A	N/A	N/A	$14,700	$14,700	$14,700	$14,700	N/A	N/A

Table 6.39 Life cycle costs for Class C basement systems – Victoria.

The section which follows deals with an assessment of various basement systems, materials and practices.

6.4 Economic Assessment of Selected Basement Systems, Materials and Practices

This stage of the supporting study required that the data gathered and the costs derived be integrated into six economic assessment scenarios. Each scenario would feature three economic perspectives: 1) builder; 2) consumer; and 3) societal. These scenarios and the associated assessments and measures are listed in Tables 6.3, 6.4 and 6.5.

The packaged system assessments are somewhat regionally sensitive because the construction costs, severity of climate, and regional energy prices can impact the cost effectiveness of thermal insulation. However, in these Guidelines a detailed discussion is only presented for the Toronto area, recognizing its significant contribution to new housing starts in Canada. It is important to note that given the recent volatility in fossil fuel prices in Canada, the data and assumptions used in this study may have to be periodically re-examined.

In the case of the material/component/sub-system assessments, the variation in associated costs and benefits is not significant across the five regions. Hence, only a representative assessment is required for each scenario of this type. The same reasoning applies to the better practice assessments, which are not regionally sensitive although they may be regionally specific due to site conditions and/or local building practices.

Packaged System Assessments

The packaged system assessments comprise Scenarios #1 through #4, inclusive. The intent of this series of assessments is to determine the cost effectiveness of upgrading to various basement classes from two minimum levels corresponding to various regions of Canada. The first minimum level is the Class C basement, which is effectively an uninsulated cellar. The second minimum level is the Class B basement, which is the minimum standard in provinces such as Ontario.

Basic assumptions used in all assessment scenarios considered in this study are as follows:

Cost of Construction Financing (per annum)	8%
Taxes	7%
Profit	5%

Scenario # 1 - Class C (cellar) to Class B (conventional)

The results of the assessments for Scenario #1 are presented in Table 6.40. It should be noted that only the tangible costs and benefits are presented in Table 6.40, and the non-tangible benefits are further discussed within this part of the report.

From the builder perspective, the carrying cost associated with construction financing, whether through the builder's own funds or a financial institution, represents a cost to be minimized. In this first packaged system scenario, the sensitivity of time to sale is examined. It is assumed that by offering a Class B basement instead of a Class C basement, a house being built on speculation may sell as much as one month earlier. The additional investment in the cost of the basement upgrade is compared to the reduction in interest charges on a construction loan. It has been assumed that the basement is being upgraded at the tail end of the construction process when the construction financing has reached a level of $60,000. The analysis indicates that the return on this investment is 21% under these circumstances. If the builder can find a better return on this investment, then the Class B basement upgrade is not cost effective.

Turning to the consumer perspective, a simple payback calculation indicates that for a dwelling heated with natural gas, the payback period for the additional investment in the Class B basement upgrade is 2.8 years. This information, if made available to the prospective homebuyer, could bolster the marketability of the builder's home featuring this upgrade. The basement would also be warmer and less susceptible to condensation in the above grade portions of the walls during winter.

From a societal perspective, the long-term cost effectiveness of the Class B basement upgrade is preferable to the life cycle cost associated with the uninsulated basement. The Class B basement not only has a life cycle cost which is $2,216 lower than the Class C basement, but also contributes to lower greenhouse gas emissions.

Scenario # 1 – Class C (cellar) to Class B (conventional)

Builder Perspective

A builder may construct a Class C (cellar) basement, but wants to determine if it is more cost effective to upgrade its quality to a Class B (conventional) system.

Builder Cost of Class C Basement	$6,920
Builder Cost of Class B Basement	$7,250
Difference	$330

Several factors may be considered by the builder:

1) Can the $330 difference provide a better rate of return in an alternative investment?
2) Does a Class B basement make the home more marketable (i.e., sell faster)?
3) Does the Class B basement perform better than the Class C basement?

The answer to these questions will depend on the nature of the builder (e.g., small custom versus large tract) and the types of basement systems offered in the local housing market.
Assume a builder carries $60,000 construction financing per year for every home under construction.
The monthly carrying charges must be weighed against the time the house remains on the market.
Assuming the house with the Class B basement sells 1 month earlier than the house with the Class C basement:

Cost of basement upgrade	-$330
Savings in construction financing	400
Internal Rate of Return	21%

Consumer Perspective

A consumer who is considering the upgrade wants to know what the payback will be on the added cost to the house. Assuming 12% mark-up for taxes and profit, the

Class B basement system upgrade costs =	$369.60
Annual energy savings =	$132.00
Payback period on upgrade =	2.8 years

Societal Perspective

From a societal perspective, a housing agency wishes to determine if over the long term it is better to require a Class C or a Class B basement system.

Life Cycle Cost of Class C Basement	$12,942.00
Life Cycle Cost of Class B Basement	$10,726.00
Net Present Value of Class B Basement Benefits	$2,216

Over the 30-year study period, the consumer living in the house with the Class B basement would have $2,216 more disposable income than a person with a Class C basement.

Table 6.40 Scenario #1 – Class C to Class B basement system upgrade – Toronto.

Scenario # 2 - Class B (conventional) to Class A-3 (near livable)
The results of the assessments for Scenario #2 are presented in Table 6.41. Again, three economic perspectives are considered in the assessments.

As in Scenario #1, the carrying cost associated with construction financing, whether through the builder's own funds or a financial institution, represents a cost to be minimized. In this second packaged system scenario, the sensitivity of the annual number of projected house sales is examined. It is assumed that by offering a Class A-3 basement instead of a Class B basement, the builder may sell 25 units a year instead of 24. The reduced cost of callbacks due to the provision of a drainage layer is also a consideration. The additional investment in the cost of the basement upgrade takes place at the end of the construction process prior to closing. Hence, it is assumed that one month's interest on the cost of the basement is added to the difference in cost between the Class B and Class A-3 basement systems. The avoided cost due to callbacks for water leakage has been assumed to average $200 per house over 24 units constructed with Class B basements. The analysis indicates that the return on this investment is 21% for a single house, 41% over the 25 homes, and 59% when the avoided costs of water leakage callbacks are considered. If the builder can find a better return on this investment, then the Class A-3 basement upgrade is not cost effective. It should be noted that even when the builder sells only 24 homes with Class A-3 basements, the rate of return remains at 41% due to the consumer subsidy of avoided water leakage callbacks. In effect, the purchaser is paying for an upgrade that saves the builder money during the normal warranty period.

From the consumer perspective, a simple payback calculation indicates that for a dwelling heated with natural gas, the payback period for the additional investment in the Class A-3 basement over a Class B basement is 7.2 years. This assumes that the homeowner can recover 80% of the upgrade value (present worth) at the time of resale. (As noted earlier in this study, the use of a small basement that is deep in the ground tends to conservatively estimate the cost effectiveness of thermal insulation upgrades. Also, the payback measure is misleading because the cost of moisture protection, which has no direct thermal contribution, is being factored into the payback analysis). A near-livable basement represents a cost-effective alternative to an above-grade addition, and is sufficiently comfortable to permit its use as a play and/or hobby area. Based on current mortgage rates, the upgrade translates into less than a $10 higher monthly payment. It is interesting to note that based on the survey of builders conducted within this study, virtually all of their basements were insulated full-height in response to market demand.

From a societal perspective, the long-term cost effectiveness of the Class A-3 basement upgrade is dependent on the cost of energy and the resale value adjustment. For houses heated with natural gas, the Class A-3 basement represents a $326 lower cost over its Class B counterpart. In electrically heated houses, it is $1,619 less costly. The Class A-3 basement is the lowest contributor of greenhouse gas emissions among the three basement classes, as are all of the Class A basements.

Scenario # 2 – Class B (conventional) to Class A-3 (near livable)

Builder Perspective

A builder may construct a Class B (conventional) basement, but wants to determine if it is more cost effective to upgrade its quality to a Class A-3 (near-livable) system.

Builder Cost of Class B Basement	$7,250
Builder Cost of Class A-3 Basement	$8,275
Difference	$1,025

Several factors may be considered by the builder:
1) Can the $1025 difference provide a better rate of return in an alternative investment?
2) Does a Class A-3 basement make the home more marketable (i.e., sell faster)?
3) Does the Class A-3 basement perform better than the Class B basement?
The answer to these questions will depend on the nature of the builder (e.g., small custom versus large tract) and the types of basement systems offered in the local housing market.

Assume the builder carries construction financing for every home under construction. The monthly carrying charges must be weighed against the time the house remains on the market, and the number of potential sales.
Later, the cost of defects must also be considered during the warranty period.

Assumed annual sales for homes with Class A-3 basements = 25
Assumed annual sales for homes with Class B basements = 24
Assumed sale price of home with Class B basement = $80,000.00
Assumed profit for home with Class B basement = $5,000.00
Assumed sale price of home with Class A-3 basement = $81,250.00
Assumed profit for home with Class A-3 basement = $5,225.00
Avoided cost of water leakage defects per house = $200.00

	Each	Total	Defects
Cost of basement upgrade + financing	-$1,031.83	-$25,795.83	-$25,795.83
Revenue (cost + profit)	$1,250.00	$36,250.00	$41,050.00
Internal Rate of Return	21%	41%	59%

Consumer Perspective

A consumer who is considering the upgrade wants to know what the payback will be on the added cost to the house. Assuming 12% mark-up for taxes and profit, the
Class A-3 basement system upgrade costs = $1,148.00
Upgrade resale value $918.40
Annual energy savings = $32.00
Payback period on upgrade = 7.2 years

Societal Perspective

From a societal perspective, a housing agency wishes to determine if over the long term it is better to require a Class A-3 or a Class B basement system?

	Gas (80%)	Elec. (100%)
Life Cycle Cost of Class B Basement	$10,165.00	$14,882.00
Life Cycle Cost of Class A-3 Basement	$10,757.00	$14,181.00
Upgrade Resale Value Adjustment	$918.40	$918.40
Net Present Value of Class A-3 Basement Benefits	$326	$1,619

Over the 30-year study period, the consumer living in the house with the Class A-3 basement and natural gas heating, would have $326 more disposable income than a person with a Class B basement.

Over the 30-year study period, the consumer living in the house with the Class A-3 basement and electric heating, would have $1,619 more disposable income than a person with a Class B basement.

Table 6.41 Scenario #2 – Class B to Class A-3 basement system upgrade – Toronto.

Scenario # 3 – Class B (conventional) to Class A-2 (livable)

Economic assessments associated with Scenario #3 are presented in Table 6.42. Scenario #3 examines a case where a conventional basement is being compared to a basement that is insulated full-height with one third of the floor area completely finished and livable (e.g., extra bedroom, den, recreation room, etc.).

Similar to the previous scenario, the sensitivity of the number of prospective sales is being assessed against the carrying costs of the additional investment and the reduction in water leakage callbacks. However, the difference in cost is significantly greater than the previous scenario due to the cost of basement finishing.

For each housing unit sold, the builder stands to earn a rate of return of 13% on the $4,414.23 additional investment (cost of upgrade + cost of financing). This is substantially greater than the rate of return for the house with the Class B basement ($5,000/$80,000 = 6.25%). The reason for this is that the upgrade and financing costs for the upgrade are not incurred until the end of the construction process. As well, builders reported that upgrades may usually be priced at higher margins without jeopardizing the competitiveness of the base model price in the new home market. Therefore, fully finished basements tend to be sold at a premium and carried at less cost than all of the construction performed prior to the finishing of the basement. It was also noted during telephone interviews that when construction activities are extremely high, and the availability of sub-contractors to complete construction to meet closing dates is low, then extras such as finished basements are discouraged with excessive premiums in order to avoid additional workload. Benefits to the builder due to increased sales potential and reduction in defects are similar to those in the previous scenario.

Looking at the consumer perspective, and erroneously factoring in the entire cost of the finished basement, the payback period due to energy savings for this upgrade is about 31 years (the actual payback on the additional thermal insulation associated with going from Class B to any Class A basement is in the order of 5 to 10 years). Another way to view this investment in a finished basement, however, is to examine its comparative value to a living space of comparable utility. For example, based on current mortgage rates, the monthly payment premium for the finished basement is under $50. If the household contains a college or university student seeking more private accommodation, then it is unlikely a residence or shared accommodation could be purchased for less than the monthly mortgage premium. This relationship may be extended to include livable spaces such as home offices.

From a societal perspective, taking capital and operating energy costs along with resale value into consideration, the Class A-2 basement is only slightly less cost effective than the Class B basement when heated with natural gas. When electricity is used for space heating, the Class A-2 basement is more cost effective than the Class B basement. When all fuel types are considered, and the higher resale price of a home with a finished basement is taken into account, the livable basement represents no significant additional cost to society. To determine the true cost effectiveness of livable basements, additional factors such as infrastructure savings due to intensification, and lower greenhouse gas emissions due to decreased demand on personal transportation, would have to be carefully considered.

Scenario # 3 – Class B (conventional) to Class A-2 (livable)

Builder Perspective

A builder may construct a Class B (conventional) basement, but wants to determine if it is more cost effective to upgrade its quality to a Class A-2 (livable) system.

Builder Cost of Class B Basement	$7,250
Builder Cost of Class A-2 Basement	$11,635
Difference	$4,385

Several factors may be considered by the builder:
1) Can the $4,385 difference provide a better rate of return in an alternative investment?
2) Does a Class A-2 basement make the home more marketable (i.e., sell faster)?
3) Does the Class A-2 basement perform better than the Class B basement?
The answer to these questions will depend on the nature of the builder (e.g., small custom versus large tract) and the types of basement systems offered in the local housing market.

Assume the builder carries construction financing for every home under construction. The monthly carrying charges must be weighed against the time the house remains on the market, and the number of potential sales.
Later, the cost of defects must also be considered during the warranty period.

Assumed annual sales for homes with Class A-2 basements =	25
Assumed annual sales for homes with Class B basements =	24
Assumed sale price of home with Class B basement =	$80,000.00
Assumed profit for home with Class B basement =	$5,000.00
Assumed sale price of home with Class A-2 basement =	$85,000.00
Assumed profit for home with Class A-2 basement =	$5,615.00
Avoided cost of water leakage defects per house =	$200.00

	Each	Total	Defects
Cost of basement upgrade + financing	-$4,414.23	-$110,355.83	-$110,355.83
Revenue (cost + profit)	$5,000.00	$130,000.00	$134,800.00
Internal Rate of Return	13%	18%	22%

Consumer Perspective

A consumer who is considering the upgrade wants to know what the payback will be on the added cost to the house. Assuming 12% mark-up for taxes and profit, the

Class A-3 basement system upgrade costs =	$4,911.20
Upgrade resale value	$3928.96
Annual energy savings =	$28.00
Payback period on upgrade =	30.7 years

Societal Perspective

From a societal perspective, a housing agency wishes to determine if over the long term it is better to require a Class A-2 or a Class B basement system?

	Gas (80%)	Elec. (100%)
Life Cycle Cost of Class B Basement	$10,165.00	$14,882.00
Life Cycle Cost of Class A-2 Basement	$14,520.00	$17,944.00
Upgrade Resale Value Adjustment	$3,928.96	$3,928.96
Net Present Value of Class A-2 Basement Benefits	-$426	$867

Over the 30-year study period, the consumer living in the house with the Class A-2 basement and natural gas heating, would have $426 less disposable income than a person with a Class B basement. Over the 30-year study period, the consumer living in the house with the Class A-2 basement and electric heating, would have $867 more disposable income than a person with a Class B basement.

Table 6.42 Scenario #3 – Class B to Class A-2 basement system upgrade – Toronto.

Scenario # 4 – Class B (conventional) to Class A-1 (dwelling unit)
Economic assessments associated with Scenario #4 are presented in Table 6.43. Scenario #4 examines the case where a conventional basement is being compared to a basement which is insulated full-height and a completely separate dwelling unit.

Similar to the previous two scenarios, the sensitivity of the number of prospective sales is being assessed against the carrying costs of the additional investment and the reduction in water leakage callbacks. However, the difference in cost is significantly greater than the previous scenario due to the cost of constructing a separate dwelling unit in the basement, provided by-laws permit.

For each housing unit sold, the builder stands to earn a rate of return of 5% on the $9,487.83 additional investment (cost of upgrade + cost of financing). This is less than the rate of return for the house with the Class B basement ($5,000/$80,000 = 6.25%). The reason for this is that the upgrade and financing costs for the upgrade are incurred throughout the construction process, and in this example, the builder does not wish to cross a given price threshold ($90,000). The increased number of projected sales was kept the same as in previous examples to examine the desirability of a builder offering this upgrade package to prospective buyers. It is observed that the rate of return after considering reductions in defects is only 10%, compared to 22% in the case of Class A-2 basements, and 59% for Class A-3 basement upgrades. In all cases the rate of return is higher than the 6.25% realized for the houses with Class B basements. However, this assumes that the upgrade generates one additional sale per year. If the normally projected number of homes was constructed (24), then the return on investment would drop to 5% without factoring for avoided defects, and rise to 8% after factoring for avoided defects. This relationship indicates that drainage layers provide builders with significant benefits that increase in relative importance as the cost of basement upgrades increases.

From the consumer perspective, the simple payback period due to energy savings for this upgrade is about 66 years (as mentioned earlier, the actual payback on the additional thermal insulation associated with going from Class B to any Class A basement is in the order of 5 to 10 years). Clearly, consumers do not upgrade their basements only to save energy. However, similar to the previous example, it is possible to compare the value to a living space of comparable utility, and possibly income potential. Based on current mortgage rates, the monthly payment premium for the Class A-1 basement is $100. If the household was to rent the basement dwelling unit, the return on investment would likely be strongly positive, and render the housing more affordable.

From a societal perspective, taking capital and operating energy costs along with resale value into consideration, the Class A-1 basement is the least cost effective of all basement classes. However, when a net monthly rental income of $400 is assumed for the basement dwelling unit, the life cycle cost becomes a life cycle saving (income) of $74,279. Separate basement dwelling units make housing more affordable because the homeowner can leverage the cost of the basement upgrade against rental income. To determine the true cost effectiveness of separate dwelling units in basements, income potential, tax implications and the additional factors mentioned for Class A-2 basements would have to be fully considered.

Scenario # 4 – Class B (conventional) to Class A-1 (dwelling unit)

Builder Perspective

A builder may construct a Class B (conventional) basement, but wants to determine if it is more cost effective to upgrade its quality to a Class A-1 (dwelling unit) system.

Builder Cost of Class B Basement	$7,250
Builder Cost of Class A-1 Basement	$16,675
Difference	$9,425

Several factors may be considered by the builder:
1) Can the $9425 difference provide a better rate of return in an alternative investment?
2) Does a Class A-1 basement make the home more marketable (i.e., sell faster)?
3) Does the Class A-1 basement perform better than the Class B basement?
The answer to these questions will depend on the nature of the builder (e.g., small custom versus large tract) and the types of basement systems offered in the local housing market.

Assume the builder carries construction financing for every home under construction. The monthly carrying charges must be weighed against the time the house remains on the market, and the number of potential sales.
Later, the cost of defects must also be considered during the warranty period.

Assumed annual sales for homes with Class A-2 basements =	25
Assumed annual sales for homes with Class B basements =	24
Assumed sale price of home with Class B basement =	$80,000.00
Assumed profit for home with Class B basement =	$5,000.00
Assumed sale price of home with Class A-1 basement =	$90,000.00
Assumed profit for home with Class A-1 basement =	$5,575.00
Avoided cost of water leakage defects per house =	$200.00

	Each	Total	Defects
Cost of basement upgrade + financing	-$9,487.83	-$237,195.83	-$237,195.83
Revenue (cost + profit)	$10,000.00	$255,000.00	$259,800.00
Internal Rate of Return	5%	8%	10%

Consumer Perspective

A consumer who is considering the upgrade wants to know what the payback will be on the added cost to the house. Assuming 12% mark-up for taxes and profit, the

Class A-1 basement system upgrade costs =	$10,556.00
Resale value adjustment	$8,444.80
Annual energy savings (gas - 80%) =	$32.00
Payback period on upgrade =	66.0 years

Societal Perspective

From a societal perspective, a housing agency wishes to determine if over the long term it is better to require a Class A-1 or a Class B basement system?

	Gas (80%)	Elec. (100%)
Life Cycle Cost of Class B Basement	$10,165.00	$14,882.00
Life Cycle Cost of Class A-1 Basement	$20,165.00	$23,590.00
Upgrade Resale Value Adjustment	$8,444.80	$8,444.80
Net Present Value of Class A-1 Basement Benefits	-$1,555	-$263

Assuming no rental savings or avoided costs for the basement dwelling unit:

Over the 30-year study period, the consumer living in the house with the Class A-1 basement and natural gas heating, would have $1,555 less disposable income than a person with a Class B basement.

Over the 30-year study period, the consumer living in the house with the Class A-1 basement and electric heating, would have $263 less disposable income than a person with a Class B basement.

Table 6.43 Scenario #4 – Class B to Class A-1 basement system upgrade – Toronto.

Material, Component and Sub-System Assessments

Based on the earlier discussion of issues, it was only possible to consider Scenario #5 under the Material, Component and Sub-System Assessments. The results are presented in Table 6.44.

Scenario #5 - Engineered Foundation Drainage Systems

During interviews with builders, it was reported that engineered foundation drainage systems are required by some municipalities, such as Mississauga, Ontario, to deal with silty soils that tend to plug conventional foundation drainage systems. It was further reported that in the case of Mississauga, the building department retained an engineering firm to prepare specifications to form part of a building by-law governing problem soil areas. The systems typically consist of smooth-walled plastic drainage piping with a minimum 2% grade, and geotextile fabric laid over the piping to filter out fine particles. Builders participating in the survey were asked to price such a system; however, only two builders were able to obtain prices from their sub-contractors for this item. For the study model basement, the averaged cost of an engineered foundation drainage system was $875, representing a $498 premium over the estimated cost of a conventional system.

From the builder perspective, the cost of callbacks during the warranty period and the potential loss of reputation are critical concerns. In this scenario, it has been assumed 1 in 10 conventional foundation drainage systems become plugged and require complete replacement within the warranty period. It costs the builder $501.32 to install and finance the engineered foundation drainage system, and it is sold to the consumer at a 4% profit. Assuming that all 30 houses require the upgraded system, the builder still only nets a 4% profit. However, when the avoided cost of defects is factored in, the return on investment is 44%. Clearly, engineered foundation drainage systems, where required, are cost effective for the builder. Sensitivity analysis indicates that when only 1 in 30 foundation drainage systems fail, the return on investment for the engineered system is 18%. Further, if loss of reputation due to failed drain pipe systems and basement water damage reduces home sales by 10% per year, then the return on investment in the engineered system rises to 104% without consideration of defects, and to 117% when defects are taken into account. It should be noted that interactivity has been built into the electronic spreadsheet to examine these sensitivities.

From the consumer perspective, assuming the failed drain pipe system is replaced by the builder during the warranty period, the deductible portion of the home insurance claim is still normally borne by the consumer. The Insurance Bureau of Canada reported that the most common deductible amount is $500 per occurrence. The consumer must attempt to decide whether the investment in the engineered foundation drainage system is cost effective, bearing in mind the 10% risk of failure, and also the risk of incurring the full cost of the foundation drainage system replacement following expiration of the warranty period. The payback is practically instantaneous if the house has a failed system, but much longer if the 10% risk is taken into account. Given these economic probabilities, it is obvious why some municipalities mandate this better practice rather than permitting the consumer or builder to elect the upgrade.

From a societal perspective, when the entire population of basements in this area is considered over a 30-year study period, the life cycle cost of the engineered foundation drainage system yields a positive result ($526.04). Hence, it is cost effective, and based on the underlying assumptions, supports mandatory requirements in areas with adverse soil conditions.

Scenario #5 – Engineered Foundation Drainage Systems

Builder Perspective

A builder is constructing homes in an area with fine silty soils. Based on local experience, it is found that about one-tenth of the foundation drainage systems become plugged with silt and require replacement within the warranty period. The builder is considering the use of an engineered foundation drainage system.

Builder Cost of Conventional Foundation Drainage System	$377
Builder Cost of Engineered Foundation Drainage System	$875
Difference	$498
Cost of replacing defective foundation drainage system	$2,000

Several factors may be considered by the builder:
1) Does the cost of the upgraded drainage system offset the cost of repairing defective systems?
2) How do the drainage system defects affect reputation, and hence sales?

Assumed annual sales for homes =	30
Assumed annual sales of homes due to loss of reputation =	30
Number of drainage systems requiring replacement =	3
Assumed sale price of home with conventional system =	$80,000.00
Assumed profit for home with conventional system =	$5,000.00
Assumed sale price of home with engineered system =	$80,525.00
Assumed profit for home with engineered system =	$5,025.00
Avoided cost of drainage system defects per house =	$200.00

	Each	Total	Defects
Cost of system upgrade + financing	-$501.32	-$15,039.60	-$15,039.60
Additional Revenue (cost + profit)	$523.00	$15,690.00	$21,690.00
Internal Rate of Return	4%	4%	44%

Consumer Perspective

A prospective new home buyer is comparing between alternative foundation drainage systems offered by competing builders. Which one is more cost effective?

Cost of drainage system upgrade =	$557.76
Cost of deductible for water damage insurance claim =	$500.00
Payback period (assuming annual risk of water damage) =	1.12
Payback period (assuming 10% annual risk of water damage) =	11.16

Societal Perspective

From a societal perspective, a municipality wishes to determine whether or not to pass a by-law governing foundation drainage systems for localities within its jurisdiction that possess adverse soil conditions. A life cycle analysis is performed using the following parameters:

Interest	4%
Escalation	1%
Period	30

Frequency of drainage system failures =	10%
Frequency of drainage system failures after warranty period =	50%
Initial cost of drainage system upgrade =	-$557.76
Average annual avoided cost of water damage claims =	$50.00
Average avoided cost of drainage system replacement =	$100
Life cycle cost of improved foundation drainage system =	$526.04

Table 6.44 Scenario #5 – engineered foundation drainage systems.

Better Practice Assessments

Based on the earlier discussion of issues, it was only possible to consider Scenario #6 under the Better Practice Assessments.

Scenario #6 – Consulting Engineering (structural failures)
In this scenario, data from *Survey to Characterize the Causes of 1994 and 1995 Foundation Failures in New Residential Construction*, Report No. 39604.00, July 1997, was used to assess the cost effectiveness of consulting engineering services with respect to problem soil and groundwater conditions. The results are presented in Table 6.45.

From a builder perspective, major structural failures average $11,776 to repair within the warranty period. The estimated cost of avoidance has been reported as $6,000 on average. When the builder encounters an unusual or problematic soil condition, three options are available: 1) to proceed with normal construction practices; 2) follow an engineered method of construction witnessed locally; or 3) retain an engineer to advise on, and possibly design a suitable foundation structure.

In the first case, it is assumed the builder is inclined to construct an over-designed foundation. Given a typical cost of $300 for a site visit and cursory investigation by an experienced engineer, the return on investment in the engineering services is 1900% if the engineered foundation system is not required. In the second case, it is assumed the builder is ambivalent and seeks professional advice. If the engineered foundation is warranted, the return on investment is 96% assuming a major structural failure is avoided. In all cases, it is cost effective for the builder to retain engineering services when unusual or problematic soil conditions are encountered.

An economic assessment from a consumer perspective is difficult to model given the intrinsic value of human health and safety, and other variables such as warranty protection and quality of property insurance. It is likely that the vast majority of consumers are severely adverse to a major structural failure in their dwelling, and most would elect to pay a reasonable price to avoid this situation rather than deal with fallout from such an event.

Societally, it is difficult to gauge the cost effectiveness of investments aimed at reducing the annual reported cost of $2 million for residential foundation structural failures.

Scenario #6 – Consulting Engineering (structural failures)

A recent survey of foundation failures in new residential construction (see NRC Report No. 39604.00) determined the following:

Cost per failure 1994 =	$10,849
Cost per failure 1995 =	$12,703
Average cost per failure =	$11,776
Estimated cost of avoidance =	$6,000

Key to the avoidance of structural failures was having an engineering assessment of the site conditions and foundation design performed.

Builder Perspective

A builder is planning to construct a house on a site with unusual soil conditions. He wants to decide whether to proceed with normal construction practice, or to follow an engineered method of construction used by another local builder, or to retain an engineer for advice and possibly design services.

There are two considerations in this case:

1) Is the retaining of the engineer cost effective?; and

2) Is constructing the basement foundation according to the engineered design cost effective?

Estimated cost of engineering field review =	-$300
Estimated cost premium of engineered foundation =	$6,000
Rate of return on engineering assuming premium not required =	1900%
Estimated cost premium of engineered foundation =	-$6,000
Estimated cost of structural failure avoidance =	$11,776
Rate of return on engineered foundation =	96%

Consumer Perspective

The economic analysis from the consumer perspective is complex due to various assumptions regarding warranty protection and the quality of house insurance the homeowner has purchased. Obviously, assuming the house is repaired and the cost of interim lodging, etc. is covered by the insurance, it is likely most homeowners would have elected to pay the higher price for the new home than suffer the disruptions associated with a major structural failure.

Societal Perspective

Based on the findings of the above-noted study, a balanced preventative approach to structural failures in the form of builder and building official training is needed to reduce the average annual cost of $2,000,000 for structural failures in Canada.

Table 6.45 Scenario #6 – consulting engineering (structural failures).

6.5 Conclusions

Based on the findings of the cost/benefit analyses, several key relationships emerge from the supporting study:

1. From a builder perspective, it may be more profitable to construct Class A basements because the provision of an explicit drainage layer reduces the cost of callbacks and helps maintain an established reputation, and presumably sales. When avoided cost savings are combined with the additional profit generated by basement upgrading, Class A basements provide a significantly higher rate of return than Class C and Class B basement systems. However, to consistently achieve a higher rate of return, structural integrity and moisture/thermal protection measures must be systematically addressed to achieve levels of performance acceptable to consumers and society.

2. From the consumer perspective, upgrades to basements represent high marginal benefits because relatively small incremental premiums provide additional livable space more cost effectively than other forms of building enlargements. In addition to realizing reasonable payback periods on thermal insulation upgrades, consumers enjoy improved thermal comfort while contributing positively to environmental conservation. However, to fully realize these benefits, the basement system must be stable, durable and free from moisture problems over its useful life.

3. From a societal perspective, structurally sound, moisture protected and thermally efficient basements represent significant life cycle benefits, a more efficient use of energy, land and infrastructure, and can increase the utility and/or affordability of housing. This relationship is premised on acceptable performance over the life cycle of the basement system.

4. Based on these observations, the need for technology transfer aimed at optimizing the cost and performance of residential basement systems and materials remains significant.

5. Present data highlights the need for and importance of future research, development and demonstration of improved basement products and systems, as the payback periods at current costs exceed 60 years.

Basements systems represent a significant proportion of the cost of new homes in Canada. They serve as the foundation supporting the house structure, and increasingly are used as livable space. The cost effectiveness of basement system alternatives must be premised on well-performing systems, which are warm, dry and free from mould and other contaminants. Meaningful comparisons may only be carried out after having satisfied these basic performance requirements. It is important to recognize that while the cost/benefit analyses presented in this part of the Guidelines indicate strong trends, users of these Guidelines are urged to review costs and benefits at the local level to obtain more relevant and reliable results.

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