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Understanding the Severity of Climate Loads for Moisture-related Design of Walls

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The fundamental function of the building envelope is its separation of the outside and the inside environments so that indoor conditions can be controlled to meet many requirements (for example, comfort and energy efficiency). The design and construction of durable, efficient walls requires consideration of the climate loads to which these building components will be exposed. A wall assembly that is trouble-free in one area of the country may not perform adequately in another. This is because, although the building physics do not change, the heat, air and moisture (liquid and vapour) control strategies may need to integrate different levels of redundancy for different climate conditions. The severity of the climate for a building site cannot be changed, but it needs to be acknowledged and be incorporated in the design of the wall assemblies. Understanding the climate loads acting on building components is an important step towards effective design of moisture-management strategies.

The Elements

Some of the basic elements of climate are temperature, atmospheric moisture, wind and precipitation. These factors have an effect on either the wetting or the drying of building elements, or both. Rainfall and wind characteristics provide a good indication of the wetting potential for a given location, while levels of atmospheric moisture affect the drying potential. Outdoor temperature, wind and atmospheric moisture are factors that can contribute to condensation on inside wall surfaces and inside walls.

Wetting Potential due to Rain

For most locations in Canada, liquid water in the form of rain forms the major source of moisture loading on exterior walls. The intensity, duration and frequency of rainfall determine the moisture load. Annual rainfall for a locality is a useful single and easy-to-obtain indicator of how wet a given climate is. Colour Plate 1 is a map of mean annual rainfall (mm/m^2 per year) for all locations listed in Appendix C of the 1995 National Building Code of Canada. Table 1 lists the mean annual rainfall for the 15 Canadian locations hosting the Building Science Insight 2003 Seminar Series, and includes both dry and wet climates.

Looking at Colour Plate 1 and Table 1 and recalling the significant premature envelope failures in Canada in the last twenty years, several observations can be made:

- Most severe climates in terms of potential wetting are the west and east coasts, with annual mean rainfalls of 1000 mm or more. Systematic premature envelope failures in Canada in the last twenty years have been in these regions. Therefore, rain penetration should rank amongst the higher priority concerns for design. A high level of design redundancy should be integrated into the rain penetration control strategies in these regions.
- Regions having annual rainfalls between 500 and 1000 mm include most of Quebec and Ontario. Although the moisture loading is lower than in the coastal regions, rain penetration is still a fairly significant design parameter, though a lower degree of protection against water ingress may be sufficient.
- Regions that receive 500 mm or less annual rainfall can be considered dry and hence forgiving with regard to the potential for rain penetration. However, dry regions can receive a large amount of rainfall for short periods of time and therefore rain penetration control needs to be considered, especially if moisture becomes trapped in interstitial spaces. The northern regions of the country are also dry and condensation control is especially important in these regions.

Table 1. Selected rainfall data for 15 Canadian locations

Location	Mean annual Rainfall, mm	Annual maximum15-Min Rainfall, mm, 1 in 10	Annual maximum 5-Min Rainfall, mm, 1 in 10	Heating Degree Days (HDD18)	MI index
Whitehorse	163	8	3	6900	0.49
Yellowknife	165	5	7	8520	0.58
Saskatoon	265	23	10	5950	0.41
Calgary	320	23	9	5200	0.37
Edmonton	375	23	10	5400	0.48
Winnipeg	416	28	13	5900	0.58
Toronto	684	25	13	3650	0.86
Ottawa	732	23	14	4600	0.84
Montreal	760	23	13	4550	0.85
Charlottetown	880	13	9	4600	1.09
Fredericton	886	23	11	4650	1.02
Quebec	924	20	11	5200	1.04
Vancouver	1155	10	5	2925	1.44
St John's	1191	18	8	4800	1.41
Halifax	1239	15	10	4100	1.48

The monthly mean rainfall amount is an indicator of the distribution of moisture loads over the year for a particular location. Combining this data with mean monthly temperature data provides an indication of the duration of simultaneous conditions of wetting and warm ambient temperature. Temperatures slightly above zero and elevated levels of moisture are two prerequisites for damage mechanisms such as metal corrosion and wood rot. Figure 1 provides monthly mean amount of rainfall and monthly mean temperature for Ottawa, Halifax and Vancouver showing quite different climate characteristics (plots for a dozen other Canadian locations are presented in the Appendix).

Compare the climates of Ottawa, Vancouver and Halifax. Ottawa is a typical cold continental climate, having cool summers. Most of the rain falls between April and the end of November when the mean temperatures are above zero. Vancouver is a cool marine climate. Notice that it rains throughout the year but the summer time is drier. The temperature variation is of particular interest: the mean monthly temperature in Vancouver is never below zero. The climate in Vancouver ensures a relatively constant source of moisture and consistently warm temperatures. This indicates an elevated risk for moisture problems. Now compare Vancouver and Halifax. Even though Vancouver and Halifax have similar total annual rainfall (10% difference), the distribution is different. In Vancouver, the peak rainfall occurs during the coldest months (no less than 3ºC) and the least rainfall during the summer months. Halifax does not experience such large variations in monthly rainfalls. However, Halifax experiences periods of temperature below zero. This type of analysis allows investigators to compare familiar climates for which they have a good grasp of the required level of protection against rain penetration with unfamiliar climates for which they need to select an optimum level of protection for a durable design.

Short duration rainfall events are also an indicator of climate characteristics. For instance, for Saskatoon, Table 1 indicates that the total annual rainfall is low compared to other locations – a dry climate; however, the 5-min and 15-min maximum annual rainfalls are in the top values of the list, indicating that when it does rain, it rains a lot for a short period. In other words, even though Saskatoon has a dry climate, i.e. the frequency of rain events is low, the rain delivery mode still presents a challenge for the design of wall systems to ensure that these large moisture loads do not get trapped in building assemblies.

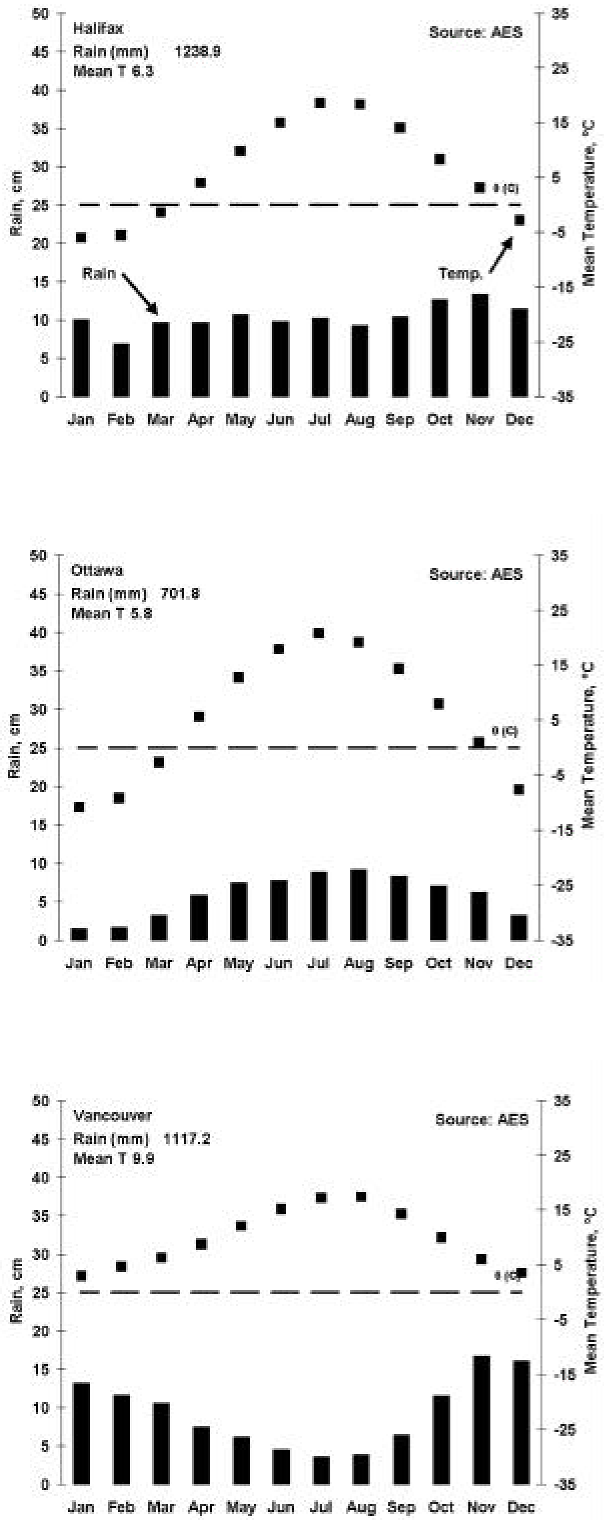

Figure 1. Mean monthly rainfall and temperature for Halifax, Ottawa and Vancouver

Wind-Driven Rain

Rainwater can get deposited on a vertical surface either as a result of wind or through a process of accumulation and redistribution on the façade. The combination of wind and rain will drive water horizontally to impinge on the building façade. Studies have shown that average wind speeds tend to be higher during rain events than during at other times. Maximum wind speeds during rain, however, tend to be lower than maximum wind speeds during periods without rain.

A long-standing indication of potential rain ingress through walls is the driving-rain index. The annual driving-rain index is simply the the product of annual average wind speed and average annual rainfall, and represents roughly the amount of water passing through a vertical plane or deposited on a wall. The higher the index value, the more severe the driving-rain conditions (Figure 2). Using Figure 2 to compare relative exposure, it is not surprising the coastal locations show the highest values while much lower values are common in the continental parts of the country.

Drying Potential due to Atmospheric Moisture

Atmospheric moisture is the amount of water vapour in the outdoor air. It can affect the ability of wet building materials to dry. Intuitively, it is known that wet materials in a humid environment will not dry as fast as they would in a dry environment. Air has a certain capacity to take up moisture up to a point of saturation. This ability to take up moisture depends on the air temperature, which dictates the moisture content at saturation, and the initial moisture content in ambient air. The difference between saturation moisture content and ambient moisture content at ambient temperature is related to the potential for evaporation offered by the climate.

There are many ways to express the moisture content in the air. Vapour pressure is the measure of the partial pressure exerted by water vapour in the total air mixture. This measure is useful in moisture transport calculations where the difference in vapour pressures is the gradient driving water vapour from the high vapour pressure areas to the regions with lower values. Vapour pressure was used as a basis for understanding the drying potential of outdoor climates.

IRC developed a map of the evaporative drying potential for Canadian climates (Colour Plate 2). The higher the values of the vapour pressure deficit, the higher the drying potential. The divisions shown on the map are arbitrary,

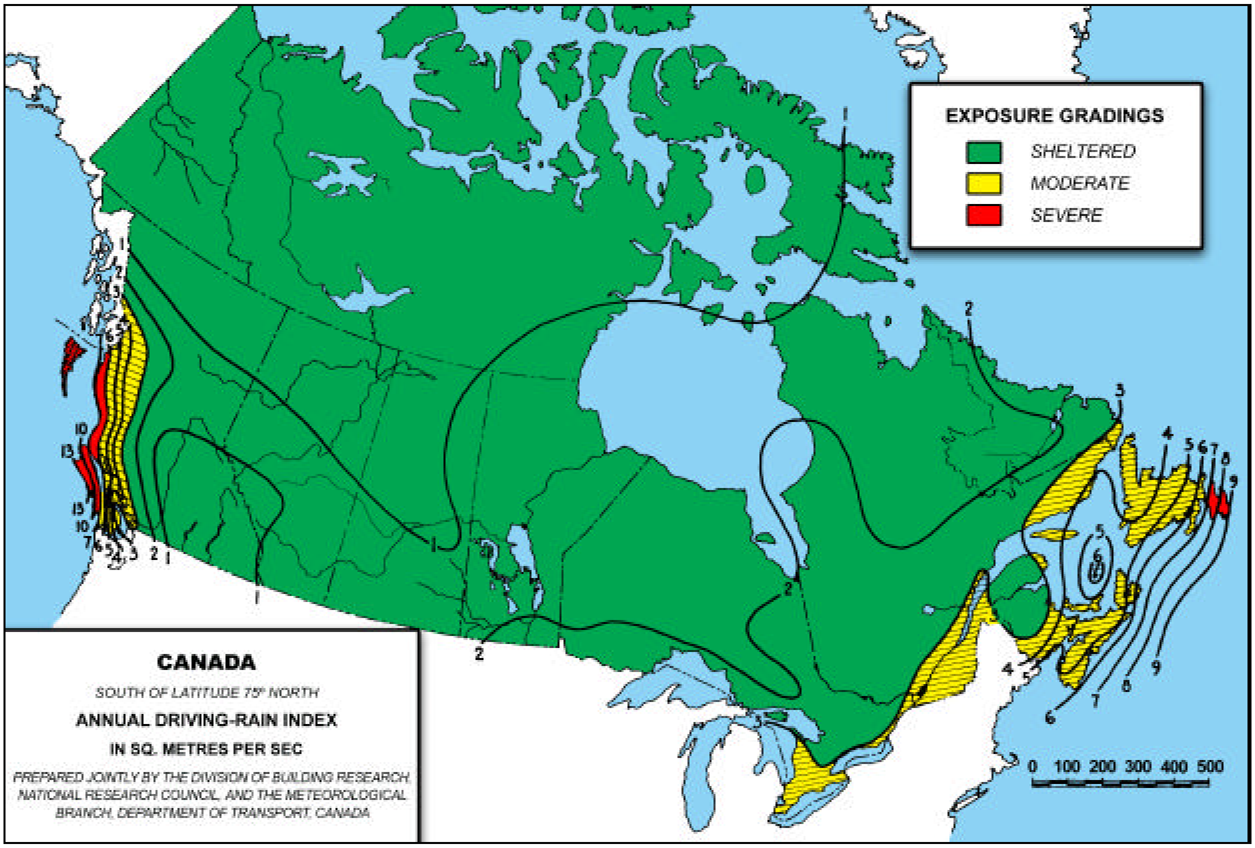

Figure 2. Annual Driving-Rain Index map of Canada after Boyd (see Further Reading).

starting from 0 to 0.5 g of water/kg of dry air and doubling every step (0.5 to 1, 1 to 2, 2 to 4, and 4 to 8). Not surprisingly, the map shows that the ability to dry in the coastal regions is low while parts of the Prairies show a high capacity for evaporation. Most of Canadian locations lie between 1 and 4. In northern regions, the potential for drying is low. Colder temperatures account for the reduced capacity of the air to hold water. Note that these are the mean annual values. The amount of water vapour in the atmosphere varies considerably between winter and summer.

Combining Wetting and Drying Potentials into one Index

As part of the recently completed consortium project on Moisture Management in Exterior Walls (MEWS), IRC researchers have studied the development of a simple indicator of the severity of the moisture loads inherent to the outdoor climate that considers both the wetting potential and drying potential. It is based on easily retrievable weather records available for a large number of Canadian locations. This index, called the Moisture Index (MI), was a prime indicator of the level of severity of net climate-related moisture loads for the MEWS project and has found other applications.

The Moisture Index combines a Wetting Index and a Drying Index into a single number, which characterizes the severity of the moisture-related climate loads specific to a locality. These two indices were given equal weight in the determination of the MI. The Wetting Index was defined as the average annual rainfall for each locality. The Drying Index is annual evaporation, based on the differential vapour pressure between ambient air and saturated air, at a given temperature. As the Wetting Index increased (higher annual rainfall), so did the severity of the climate moisture loads. As the Drying Index increased (higher potential for evaporation), the severity of the climate moisture loads decreased. To facilitate usage of MI, it was decided that an increase in its values would mean an increase in the net climate moisture loads. Therefore the Moisture Index for every location is a function of two normalized values: the Wetting Index and (1 minus the Drying Index). The higher the value of MI, the more severe is the moisture loading for a given locality. Table 1 provides the MI index for several Canadian cities. A map of Canadian MI values divided in four groups is presented in Colour Plate 3. One can see that the more severe moisture loads can be found in coastal climates.

Condensation Potential

Interstitial condensation can be both a winter and a summer phenomenon. For walls above grade, most Canadian research has traditionally focussed on winter condensation because the building heating period is generally longer than the cooling period. The environmental factors that affect the potential for condensation in wall assemblies are temperature, atmospheric moisture and wind.

Outdoor temperature often produces a thermal gradient across walls because the conditioned indoor space tends to be maintained at a different temperature. Materials closer to the outside of the walls will be colder than those located towards the inside, and these colder materials will be more susceptible to condensation if the right conditions are present. Outdoor temperature also affects the air pressure differential across the building envelope: in cold weather, temperature differential will cause cold air infiltration through openings located at the lower parts of the building enclosure and warm (and often humid) air exfiltration in openings at the top portion of the enclosure. This is referred to as stack effect.

Indicators of temperature severity in Appendix C of the 1995 NBC of Canada include design dry bulb temperatures (Jan-1% and 2.5%, and July 2.5%) and degree-days below 18ºC. Design temperatures are used for the design of heating and cooling systems. The January design temperature is defined as the lowest temperature at or below which only a certain small percentage of the hourly outside air temperatures in January occur. This certainly provides information on extreme temperature conditions, but the accumulation of condensate on a surface of the wall assembly during winter is affected by prolonged periods of cold. Degree-days is a useful relative indicator of climate severity, even though more sophisticated methods are now available. A degree-day for a given day is the number of Celsius degrees that the mean daily temperature is below or above a given threshold. Degree-days below 18ºC (HDD18) uses a threshold of 18ºC. The sum of these daily values can be computed monthly or yearly. As the HDD18 values increase, so does the level of exposure of the walls to cold weather conditions (in duration and/or magnitude). Table 1 shows the HDD18 for the 15 BSI seminar locations and Colour Plate 4 shown the variation of HDD18 across Canada.

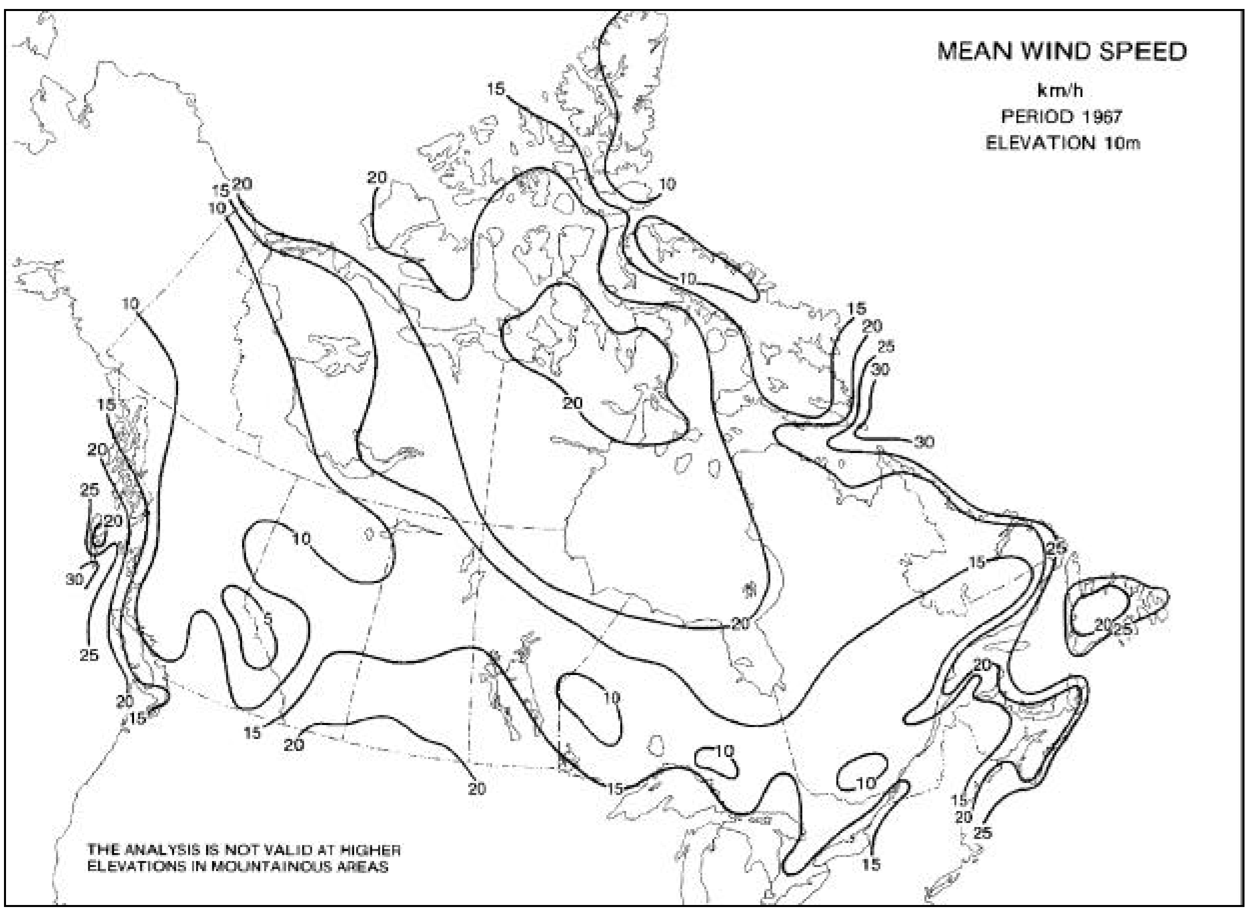

Figure 3. Annual wind speeds for Canada

Wind also affects the temperature of wall elements, as it creates air pressure differentials across the assembly, and if permitted, introduces outdoor air currents between materials of the wall assembly, possibly affecting the temperature distribution across the wall, and the location of the dew point temperature. Wind speed and direction affect the air pressure differential across the wall and hence, have an effect on the air infiltration/exfiltration patterns across the building envelope, which in turn can affect the condensation potential. The design of an air barrier system, which limits the air leakage rate through the building enclosure, includes requirements for structural capacity and rigidity to sustain 100% of the wind loads.

A map of mean annual wind speeds across the country is shown in Figure 3. Not surprisingly the coastal areas tend to be windier on average than the rest of the country with the exception of the southern Prairies. Appendix C of the NBC includes a table that provides conversion between wind speed to static pressure, using the following equation $C = \frac{1}{2} \rho \mathbf{v}^2$ where $\mathbf{v}$ is the wind speed (m/s) and ρ is the density of air in kg/m^3, which depends on temperature and atmospheric pressure.* Table 2 provides mean wind speed, direction and wind pressure for the BSI seminar locations as well as the 1 in 10 year hourly wind speed taken from Appendix C of the NBCC. Differentials in water vapour levels indoors and outdoors produce a force for moisture transport by diffusion. In cold weather the atmospheric moisture level tends to be lower than the moisture level indoors; this means that the flow of moisture via diffusion is from the interior to the exterior. In warmer weather, the flow may be reversed, as atmospheric moisture levels can be higher than in an indoor air-conditioned space.

Summary

- Each climate poses a particular challenge, whether it is cold and dry or mild and wet. Climates cannot be changed. However, designers need to understand the characteristics of the climate for their construction projects, and use this information for the design of effective moisture management strategies that account for those climate loads.
- Some of the basic factors of climatic exposure are temperature, atmospheric moisture, wind, and precipitation. They have an effect on either the wetting or the drying of building elements, or both. Rainfall and wind-driven rain characteristics provide a good indication of the wetting potential of the climate,

Table 2. Mean wind speed, predominant direction, and mean pressure for the BSI locations

Location	Mean Wind Speed, km/h	Most Frequent Direction	Mean Wind Pressure, Pa	Design Wind Pressure, Pa 1 in 10
Whitehorse	14	S	9	280
Yellowknife	15	E	10	340
Saskatoon	17	NW	13	360
Calgary	16	N	12	400
Edmonton	13	S	8	320
Winnipeg	18	S	15	350
Toronto	15	W	10	390
Ottawa	14	W	9	300
Montreal	15	W	10	310
Charlottetown	19	W	17	460
Fredericton	13	SW	8	300
Quebec	15	W	10	380
Vancouver	12	E	7	360
St John's	24	W	27	600
Halifax	18	S	15	400

* A good approximation is to assume that the density of air is 1.2 kg/m^3.

while levels of atmospheric moisture (governed by temperature) affect the drying potential. Outdoor temperature, wind pressures and atmospheric moisture play a role in condensation potential.

- Several indicators of climate severity that affect moisture control in walls are readily available and can be used to assess and compare climate characteristics. The Environment Canada website provides a large range of weather records for thousands of Canadian locations. Appendix C of the National Building Code of Canada provides ready access to certain climatological data referred in the code.
- Different moisture management strategies for wall design are required for different climate loads. The more severe the moisture loads, the more redundant the wall design needs to be to provide the required additional level of protection against water ingress. Over a yearly cycle, climate conditions exhibit constantly changing periods of wetting and drying potentials. Hygrothermal computer modelling studies can be used to assess and compare the moisture and temperature response of a wall assembly using different moisture management strategies to actual weather records for different localities.

Further Reading and Resources

Resources:

National Building Code of Canada 1995. Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, 1995. Appendix C - The National Building Code of Canada provides climate data such a maximum 15-minute and one-day rainfall and total annual precipitation (which includes snowfall).

http://climate.weatheroffice.ec.gc.ca/Welcome_e.html - The National Climate Data and Information Archive, operated and maintained by Environment Canada, contains official climate and weather observations for Canada. Climate elements, such as temperature, precipitation, relative humidity, atmospheric pressure, wind speed, wind direction, visibility, cloud types, cloud heights and amounts, soil temperature, evaporation, solar radiation and sunshine as well as occurrences of thunderstorms, hail, fog or other weather phenomena are warehoused in a digital database. Access to selected portions of this data, as well as related products such as CD-ROMs and climate normals and averages are available on this web site. Information regarding obtaining extremes, monthly summaries, microfilm, microfiche, paper documents and technical documents, is also available.

http://www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html -Regional Climate Centers for the United States; National Climate Data Center is the world's largest active archive of weather data. NCDC produces numerous climate publications and responds to data requests from all over the world. NCDC operates the World Data Center for Meteorology which is collocated at NCDC in Asheville, North Carolina, and the World Data Center for Paleoclimatology which is located in Boulder, Colorado. NCDC supports a three-tier national climate services support program – the partners include NCDC, Regional Climate Centers, and State Climatologists.

http://atlas.gc.ca/site/english/archives/5thedition/index_html – The Fifth Edition of the National Atlas of Canada consisted of 93 separate, stand-alone maps that were published between 1978 and 1995. The maps covered a wide range of subjects, but there was a slight emphasis on environmental issues. Although the map sheets varied considerably in their overall size, the format of nearly all the maps consisted of a central map at scale 1: 7,500,000, accompanied by a legend, a source list and extensive notes. The maps contained in this section are scans of the original printed maps.

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Related IRC Publications:

http://irc.nrc-cnrc.gc.ca/publications.html – Full text versions for most of the following are available here.

Canadian Building Digests – a collection of 250 4-page articles containing background information and practical guidelines on virtually every aspect of building design and construction in Canada, published between 1960 and 1990.

CBD-14. Weather and Building, D. W. Boyd.
CBD-28. Wind on Buildings, W. A. Dalgliesh and D. W. Boyd.
CBD-34. Wind Pressures on Buildings, W. A. Dalgliesh and W. R. Schriever.
CBD-47. Extreme Temperatures at the Outer Surfaces of Buildings, D.G. Stephenson.
CBD-48. Requirements for Exterior Walls, N.B. Hutcheon.
CBD-68. Wind Pressures and Suctions on Roofs, W.A. Dalgliesh and W.R. Schriever.
CBD-117. Weathering of Organic Building Materials, H.E. Ashton.

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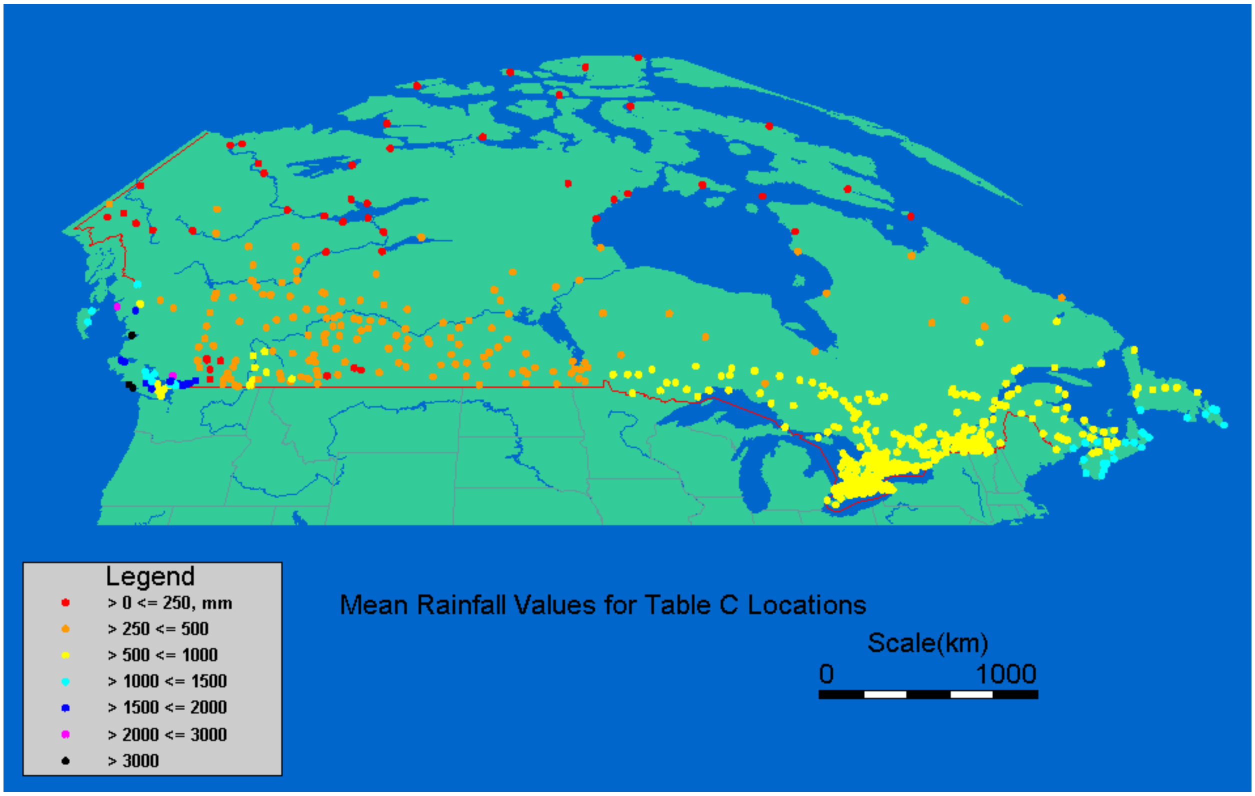
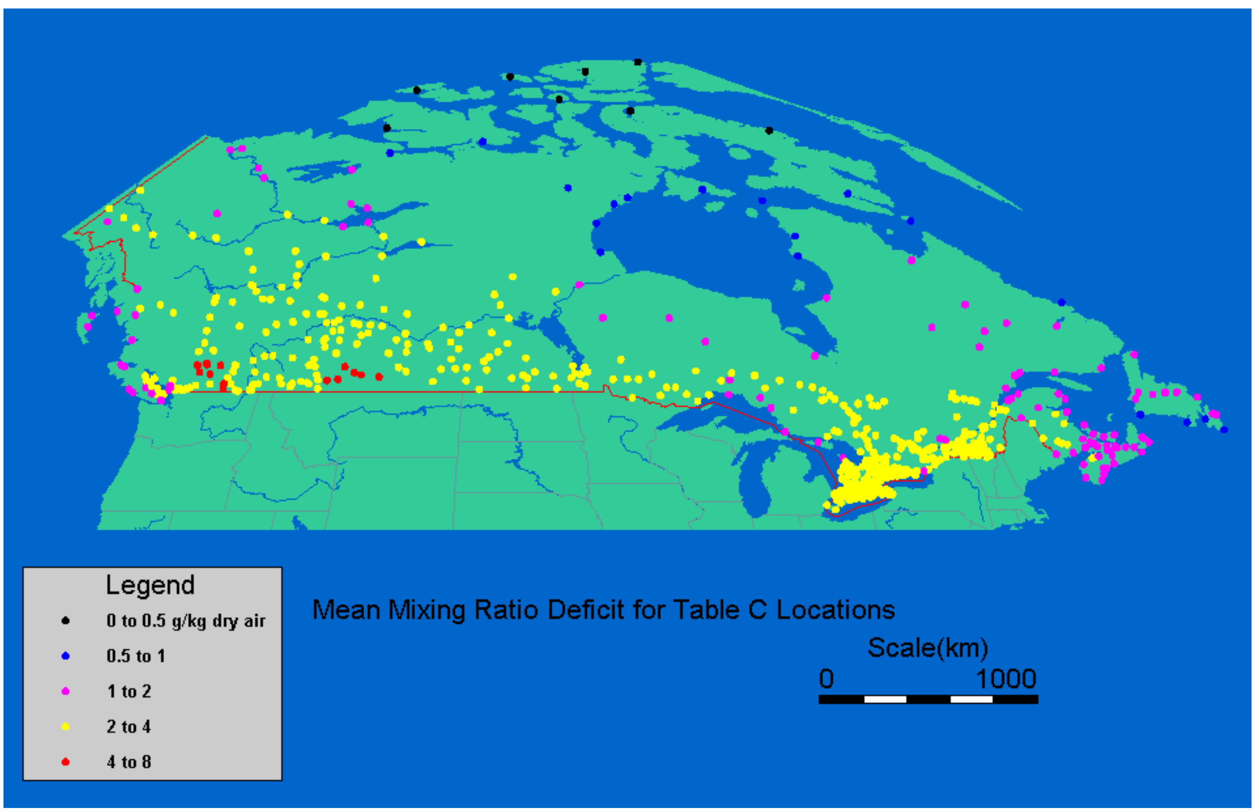
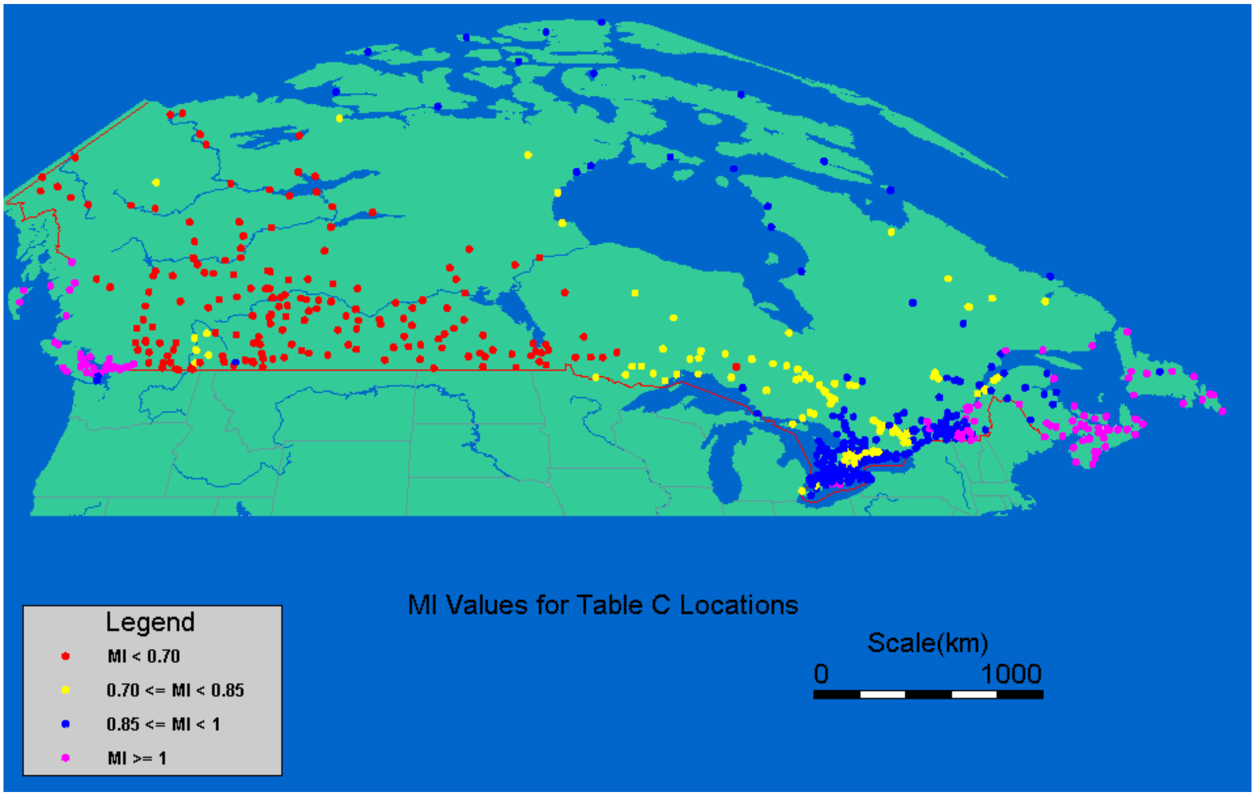


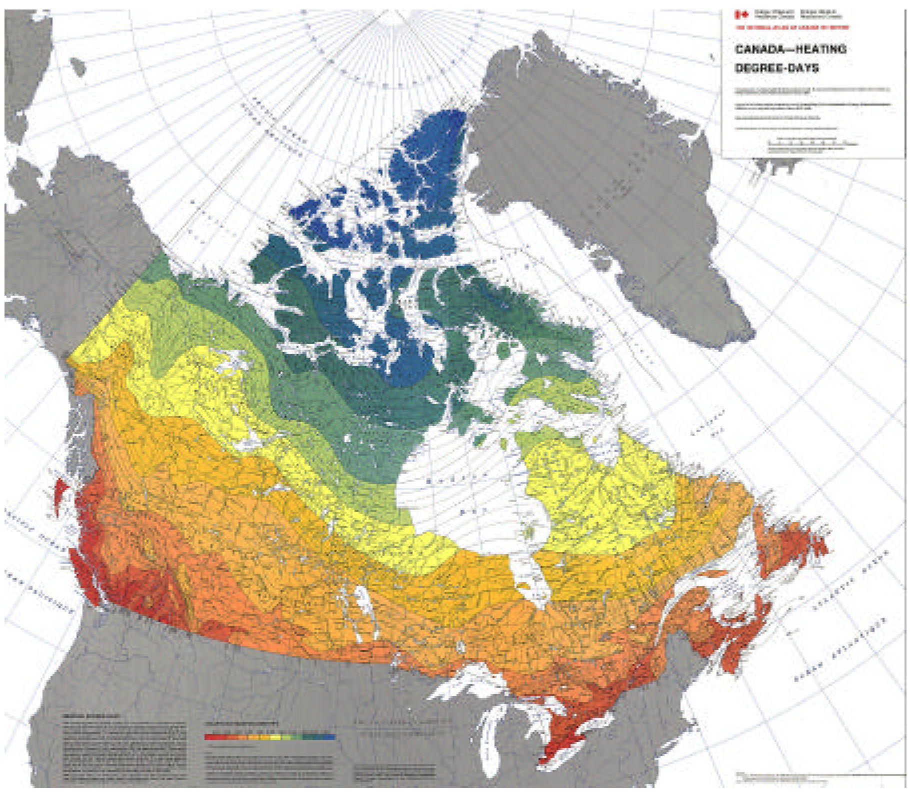
Colour Plate 1. Mean annual rainfall for the locations listed in the National Building Code of Canada.



Colour Plate 2. Map of Canada showing the potential for evaporation offered by the outdoor climate for all locations listed in Appendix C of the 1995 National Building Code of Canada. The larger the values, the higher the potential for evaporation.



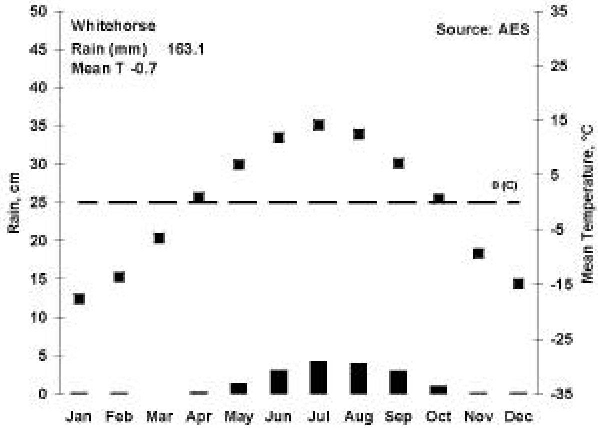
Colour Plate 3. Moisture Index for the locations listed in Appendix C of the NBCC.

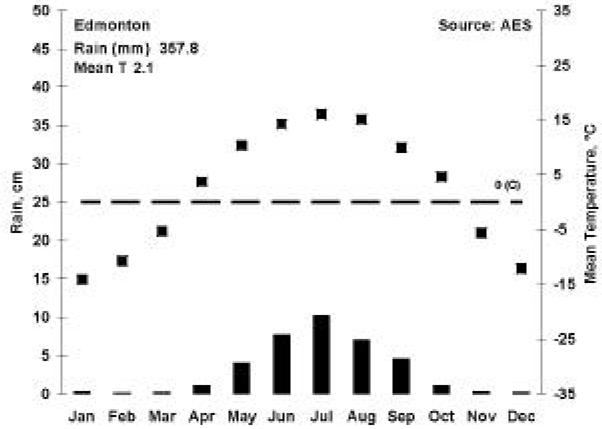


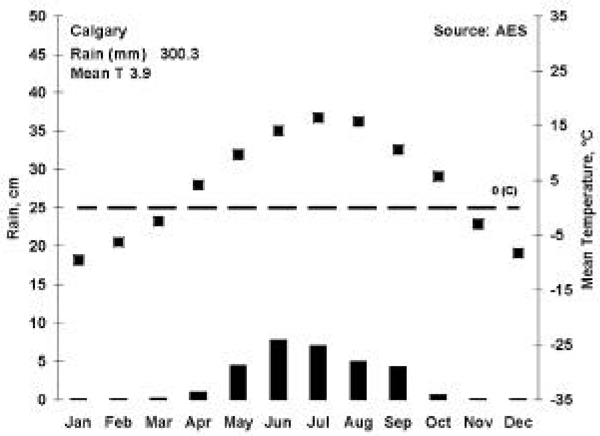
Colour Plate 4. HDD18 map of Canada. The map shows the zonal distribution of temperature. From the National Atlas of Canada, 5th Edition (see Further Reading).

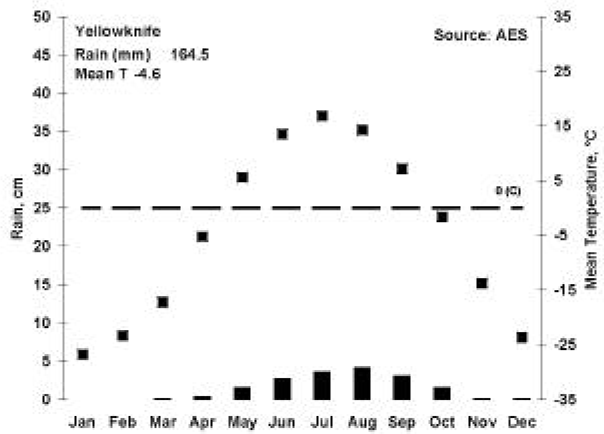
Appendix: Monthly Mean Rainfall and Monthly Mean Temperature Plots

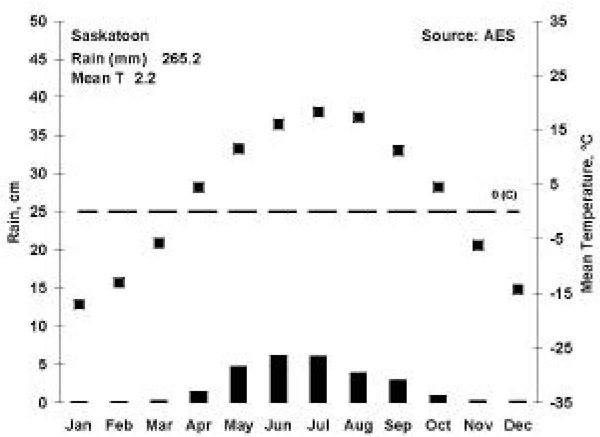
Western Locations

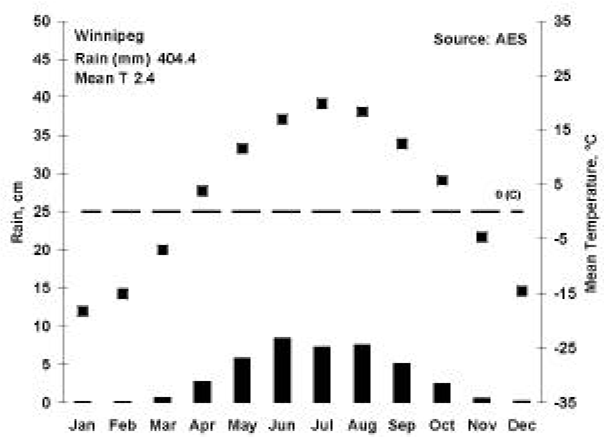












Appendix: Monthly Mean Rainfall and Monthly Mean Temperature Plots

Eastern Locations