Performance evaluation of proprietary drainage components and sheathing membranes when subjected to climate loads, task 5: defining exterior climate loads

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Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads

Task 5 — Defining Exterior Climate Loads

Steven M. Cornick and Khaled Abdulghani

28 February, 2013

National Research Council Canada
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Canada

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Summary

The first objective of this work was to determine the environmental loads to be used for testing wall configurations as part of the project “Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads” heretofore known as A1-00030 (B1264). The appropriate wind-driven rain loads, expressed in terms of a combination of water spray rate and pressure difference, for key locations in Canada were determined.

All the Canadian locations having a MI value of one or greater and with a least 8 years of hourly climate data were identified. Eleven MI bands between MI ≥ 1 and MI ≥ 2 were defined and representative locations within each band were identified. Two criteria were used to select representative locations within a band, greatest MI value within the band and highest annual Driving Rain Index. If the two highest values did not correspond to a single location then both locations were selected. The method is summarized below.

- Divide the range of MI > 1 into small bands, eleven in number.
- Within each band select the location with the highest MI.
- Select the location with the highest annual driving-rain index.
- If the locations are different select both locations for analysis.

The proposed list of Canadian locations is given below. Although not meeting the criteria Vancouver BC was also included because of the history of moisture related problems in Vancouver.

Station	MI	Rainfall, mm	Wind speed, km/h	aDRI, m^2/s
Tofino A. BC	3.36	3257	10.6	9.6
Port Hardy A. BC	1.92	1808	11.4	5.7
Abbotsford A. BC	1.59	1508	8.8	3.7
Halifax Int'l. NS	1.49	1239	16.8	5.8
Vancouver Int'l. BC	1.44	1155	11.8	3.8
St. John's A. NL	1.41	1191	23.3	7.7
Sydney A. NS	1.36	1213	18.6	6.3
Saint John A. NB	1.27	1148	16.1	5.1
Stephenville A. NL	1.19	985	19.2	5.3
Bonavista NL	1.11	816	31.7	7.2
Terrace A. BC	1.08	970	13.4	3.6
Summerside A. PE	1.03	806	20	4.5

To extend the results of this project to the U.S. and to select appropriate U.S. locations for comparison the following criteria were used:

- Degree-days above 18°C > 2500; i.e. upper half IECC climate zone 4
- MI values as defined by the NBCC must be greater than 0.9 or 1 according to NBCC 9.27.2.2.5 (a) or (b) modifying clause (a) to read "greater than 2500 Degree-days above 18°C."

A database of hourly data for each Canadian and U.S. location was produced. Statistical analysis of the datasets produced the following values for Wind-Driven Rain (WDR) and Driving-Rain Wind Pressure (DRWP) respectively:

- Mean
- Median
- Standard deviation
- Maximum DRWP and WDR observed and coincident WDR or DRWP
- 98-percentile value of DRWP and WDR and coincident mean WDR or DRWP
- 1 in 50-year return period value

For all the Canadian locations analysed a spray of 1 l/min-m^2 (or 60 l/hr-m^2) was sufficient to cover all locations and conditions for WDR. Similarly a differential pressure of 500 Pa was sufficient to cover all values of DRWP. Note that the values of these thresholds are limited to height of 10m or less and time averages of 1-hour.

The second objective of the work was to provide the weather data for the hygrothermal simulation portion of the project; i.e. select Moisture Design Reference Years (MDRYs) for the simulation task. Appropriate climate data for this task was provided for the locations identified in first part of the work. After reviewing several published methods for selecting weather years for hygrothermal simulation a small comparison study was undertaken. It was concluded that the MI MEWS method was appropriate to use for this project. MI MEWS rankings were produced for all the years in the climate record for each location selected. Three MI MEWS years, *wet* (maximum), *average* (median), and *dry* (minimum), were generated and converted to an acceptable format for hygrothermal analysis. As a by-product of the task hygrothermal years using the other methods considered were also produced as well as a 10-year sequence of the most recent years for each location. A sample table of the data generated for a typical location is shown below. This information forms part of the climate database generated for the project.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1953	2004	1966
90%	1955	1997	1961
Median	1983	1963	1983
10%	1996	1975	2004
Min	2004	1955	1985
10-year run	1996-2005		

Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task – Defining Exterior Climate Loads

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A Report for the

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28 February, 2013

Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads –

Task – Defining Exterior Climate Loads

Final Report Forming Part of Task 5

Steven M. Cornick and Khaled Abdulghani

1. Introduction

The first objective of this work was to determine the climate loads to be used for testing wall configurations as part of project "Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads" heretofore known as A1-000030 (B1264). Specifically, the appropriate wind-driven rain loads, expressed in terms of a combination of water spray rate and driving-rain wind pressure, for key locations in Canada were determined.

The second objective of the work was to determine and provide the weather data for the hygrothermal simulation task of the project. Data was provided for the locations identified in first part of the work.

2. Climate Loads for Wall Testing

The objective of this portion of the work was to determine the climate loads to be used for testing wall configurations as part of the project. The task involved collecting the appropriate weather data from vetted sources, identifying the locations of interest for the project, producing datasets for each location, and performing statistical analysis on each dataset to determine the exterior loading for each location.

2.1 Data Processing

The major part of this task involved data processing, the two most time consuming tasks being the collection and compilation of the data and performing quality assurance on the data sets.

2.1.1 Collection of data

Data for Canada and United States were collected from three main sources, Environment Canada [1], the National Climate Data Center [2] and the National Renewable Energy Laboratory [3]. The selection criteria were:

1. Locations in Canada and the United States where the Moisture Index (MI) as defined by the National Building Code of Canada 2010 (NBCC) [4] is greater or equal to 1.
2. Hourly data available, although 3-hourly data is acceptable.
3. A period of record at least 8 years in length.
4. The number of missing records for any one parameter in any one year shall not be excessive.
5. Enough information should be provided such that the following hourly parameters can be calculated:
   a. Dry bulb temperature
   b. Relative humidity
   c. Wind speed
   d. Wind direction
   e. Global solar radiation on the horizontal
   f. Diffuse radiation on the horizontal
   g. Cloud index*
   h. Rainfall*

   *Of Note: The Cloud index was defined as the amount of cloud covering the sky dome in eighths, 8 being completely obscured by clouds and 0 being a clear sky; Rainfall and not precipitation was of importance; precipitation includes solid forms of precipitation such as snow and was not of concern for this project. The determination of rainfall amounts is treated in Appendix 2 of this report.

2.1.1.a Canadian Climate Data

The source of weather data for Canada was the 2005 Canadian Weather Energy and Engineering Data Sets (CWEEDS), published by Environment Canada. Excerpts from the User's Manual are appended to this document. The file format is Weather Years for Energy Calculations 2 (WYEC2) and is described in Appendix 1. There data comprised three basic files, a data file and two metadata files giving summary statistics. A list of CWEEDS locations and years for locations with a Moisture Index ≥ 1 (as defined by the NBCC), taken from the User's Manual is reproduced in Table 1.

[1] Canadian Weather Energy and Engineering Datasets (CWEEDS), National Climate Data and Information Archive, Environment Canada, CWEEDS Documentation Release

[2] National Oceanic and Atmospheric Administration, Integrated Surface Hourly (DSI-3505), National Climatic Data Center Federal Building151 Patton Avenue Asheville NC 28801-5001 http://gcmd.nasa.gov/records/GCMD_gov.noaa.ncdc.C00532.html

[3] NSRDB, National Solar Radiation Database, National Solar Radiation Laboratory, http://rredc.nrel.gov/solar/old_data/nsrdb/

[4] Canadian Commission on Building and Fire Codes, National Research Council of Canada. National Building Code of Canada 2010. Ottawa, Volume 2: Division B, Clauses 9.27.2.2.5.(a) and (b), p. 9-173.

Table 1: List of CWEEDS locations with MI ≥ 1

Station	WBAN	LAT	LONG	TZ	FY	LY	N
Abbotsford A	24288	49.02	122.37	120	1953	2005	52
Argentia A	CAN85	47.3	54	60	1953	1969	16
Bonavista	14522	48.7	53.08	60	1960	1994	34
Buchans A	CAN87	48.85	56.83	60	1953	1964	11
Charlottetown Cda	14688	46.25	63.13	60	1953	2005	52
Debert	CAN80	45.42	63.45	60	1953	1960	7
Fredericton Cda	14670	45.92	66.62	60	1953	2005	52
Gander Int'l. A	14509	48.95	54.57	60	1953	2005	52
Greenwood A	14636	44.98	64.92	60	1953	2005	52
Halifax Int'l. A	14673	44.88	63.52	60	1961	2005	44
Moncton A	14625	46.12	64.68	60	1953	2005	52
Nanaimo A	CAN20	49.05	123.87	120	1954	1967	13
Port Hardy A	25223	50.68	127.37	120	1953	2005	52
Prince Rupert A	25353	54.3	130.43	120	1961	2005	44
Quebec A	4708	46.8	71.38	75	1953	2005	52
Saint John A	14643	45.32	65.88	60	1953	2005	52
Sandspit A	25346	53.25	131.82	120	1953	2005	52
Sept-Iles Ua	77912	50.22	66.25	75	1953	2005	52
Sherbrooke A	4785	45.43	71.68	75	1963	1994	31
St. Anthony	CAN92	51.37	55.58	60	1953	1965	12
St. John's A	14506	47.62	52.75	60	1953	2005	52
Ste. Agathe Des Monts	4790	46.05	74.28	75	1967	1991	24
Stephenville A	14503	48.53	58.55	60	1954	2005	51
Summerside A	14645	46.43	63.83	60	1953	1990	37
Sydney A	14646	46.17	60.05	60	1953	2005	52
Terrace A	25229	54.47	128.58	120	1955	2005	50
Tofino A	94234	49.08	125.77	120	1960	2005	45
Truro	14675	45.37	63.27	60	1961	1976	15
Vancouver Int'l.	24287	49.25	123.25	120	1953	2005	52
Yarmouth A	14647	43.83	66.08	60	1953	2005	52

Meta data from the CWEEDS datasets for locations can be used to quickly check the quality of the data sets at a glance, as shown in the following bar charts (Figure 1 through Figure 3). The first bar chart, Figure 1, shows the number of missing records for a particular element, dry bulb in this case. The second bar chart, Figure 2, shows basic statistics for the same element, min, max, and mean. The three small charts in Figure 3 show the averaged radiation profiles, maximum and mean, for global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal radiation (DHI) irradiance for the four seasons. The charts allow for a quick visual quality check of the data.

2.1.1.b United States Climate Data

The main source of data for the United States was the National Climatic Data Center, specifically the Integrated Surface Hourly (ISD) database. This database however does not contain solar radiation database and consequently must be combined the National Solar Radiation Database (NSRDB) available from National Renewable Energy Laboratory (NREL). Both databases have been obtained and are available, however since the scope of the project was limited to Canadian locations a limited amount processing of the data for the United States was undertaken. A list of possible locations for the United States is discussed in the section on selecting U.S. locations (Section 2.1.3.b).

2.1.2 Quality Control Procedures: Interpolation and Filling of Missing Data

The Canadian and United States weather data sets are fully populated: i.e. they do not contain any blank entries. There can be missing values however, usually entered as a series of 9's coupled with an alphanumeric code, 9, indicating that the value is missing. The number of missing elements is usually recorded in the metadata file for a given location. For example in Figure 1 the years 1961 and 2005 show a large number of missing dry bulb values. The years 1962 and 1995 also show a large number of missing dry bulb temperatures. These years might be excluded from any analysis. If the missing values are distributed throughout the year this however may not be a problem. The criteria for rejecting years were therefore based on two tests; an absolute threshold and the longest streak of missing values. If more than 5800 records from a given year were missing then the year was rejected; this is equivalent to having a reading once every 3 hours. Finally if more than 744 records were missing in sequence from a year the year was rejected; this represents a month of missing data. The key parameters checked were wind speed and direction, dry bulb temperature, dew point (or equivalent), rainfall, and the present weather condition.

The first pass for quality control consisted of filling in missing data and correcting any incorrect values in the data sets. The data files were fixed before generating simulation or load input files. A second pass for quality control was done after generating simulation/load input files. Most of the data filling methods used for the project were taken from three sources, ASHRAE 1477 Research Project [5] and Baltazar and Claridge [6] [7].

Gaps of more than 168 consecutive hours, one week, for dry bulb, dew point, wind speed, were flagged and dealt with manually. A complete description of the quality control procedures is given in Appendix 2.

[5] Huang, J., 2011. "ASHRAE Research Project 1477-RP Development of 3,012 typical year weather files for international locations" Final Report, Amer. Soc. of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta GA. 92 Pgs.

[6] Baltazar, J. and Claridge, D. 2002. "Restoration of Short Periods of Missing Energy Use and Weather Data Using Cubic Spline and Fourier Series Approaches: Qualitative Analysis". Proc. 13th Symposium on Improving Building Systems in Hot and Humid Climates, May 20-23, 2002, Houston, TX, pp. 213-218.

[7] Baltazar, J. and Claridge, D. 2002. "Study of Cubic Splines and Fourier Series as Interpolation Techniques for Filling in Short Periods of Missing Building Energy Use and Weather Data," ASME Proceedings of Solar 2002, Reno, NV, June 15-20, 2002, Conservation and Solar Buildings Paper 3, pp. 1-7.

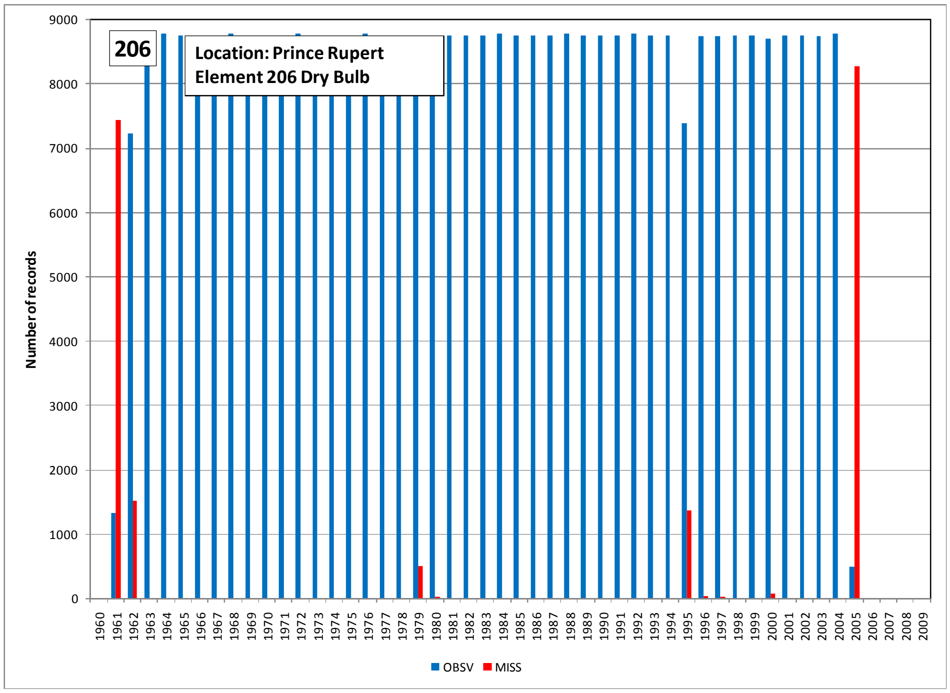

Figure 1 – Dataset statistics for a typical CWEEDS location showing observed and missing values

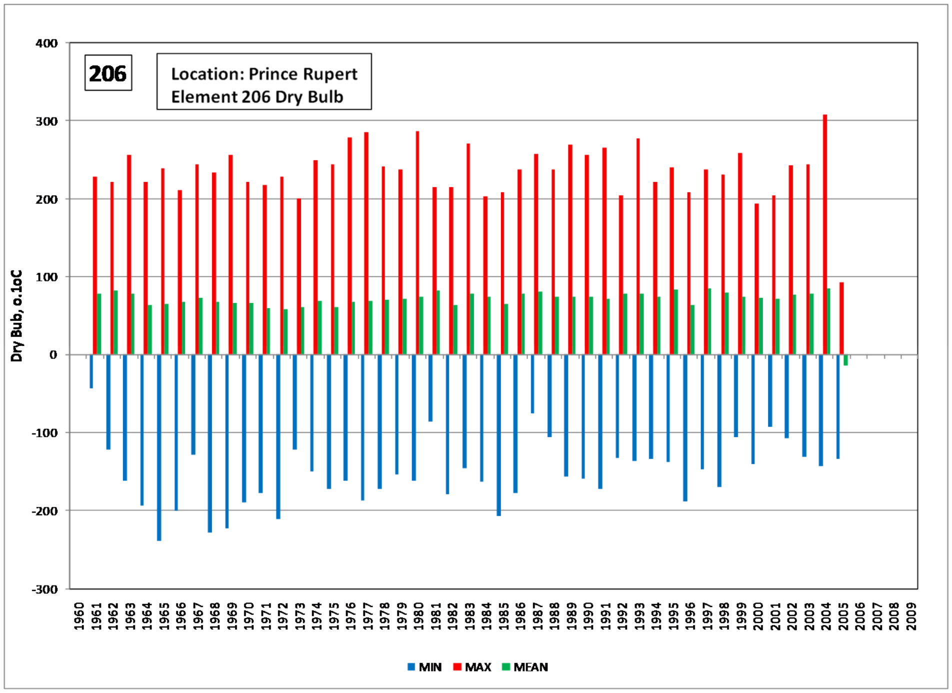

Figure 2 – Dataset statistics for a typical CWEEDS location showing minimum, maximum, and mean values

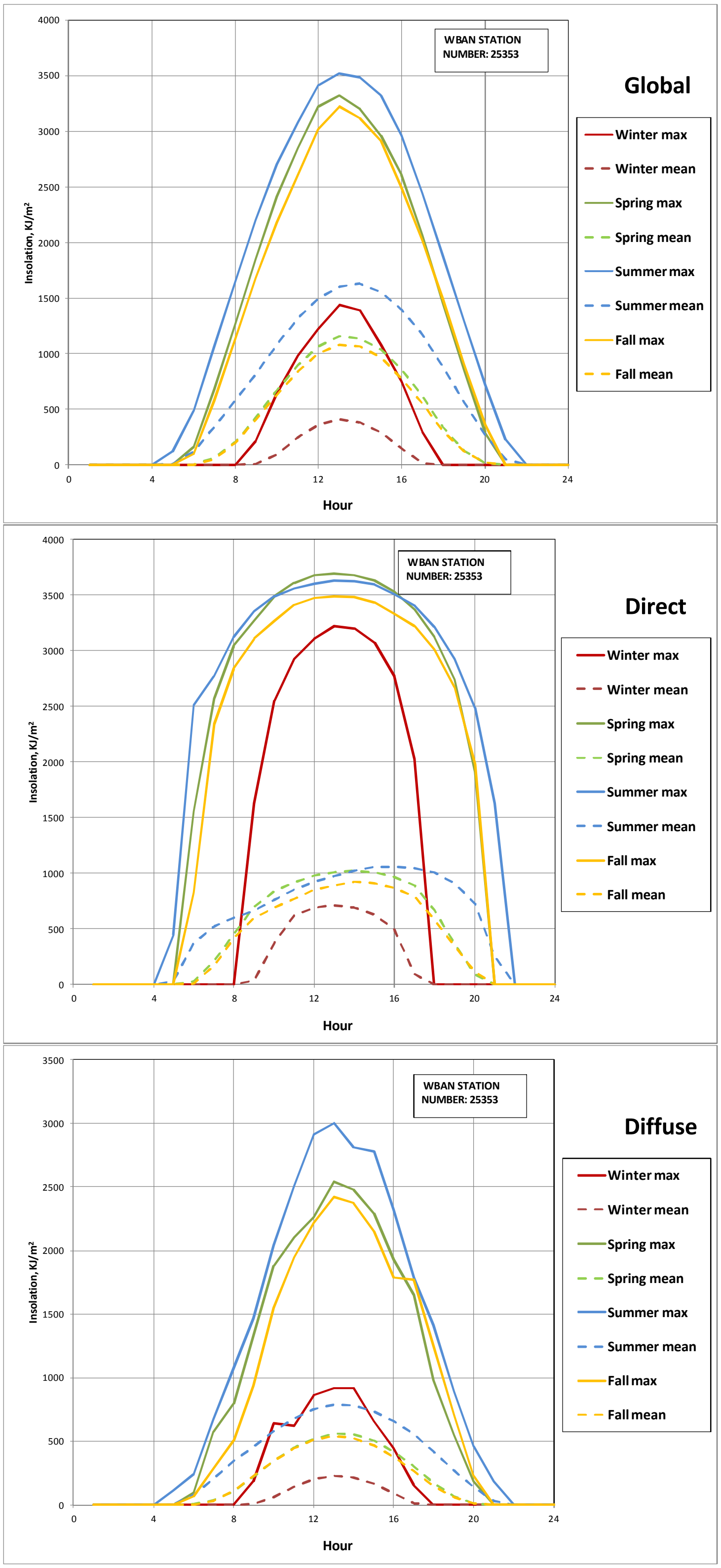

Figure 3 – Dataset statistics for a typical CWEEDS location showing solar profile, GHI, DNI, and DHI

2.1.3 Selection of locations

2.1.3.a Locations in Canada

A number of Canadian locations were selected to establish the loads for the drainage and drying experiments.

The locations were selected using the following criteria:

1. The MI value as defined by the NBCC 2010 was greater than 1.
2. Hourly data was available from the 2005 CWEEDS data set from Environment Canada.
3. The minimum period of record was 8 years.

There are 640 locations listed in Table C-2 of the NBCC. Upon review, 117 locations with MI > 1 were identified. Of those locations there are 30 locations in Table C-2 for which there is hourly data in the CWEEDS 2005 data set. The locations are given in Table 1.

Distribution of locations in Canada

Not surprisingly most of the locations with MI > 1 are located on the Atlantic and Pacific coasts of Canada. This can be seen in Figure 4. Statistical summaries showing the distribution of locations with MI values of 1 or greater are given in Table 2 through Table 5. The range of MI values between 1 and 2 was divided in to 11 bands. Locations below 1 were not considered in this study, the assumption being that there was a lower risk of moisture related damage[8]. Locations with MI values above 2 were grouped together, the assumption being that all locations where the value is greater than 2 have an elevated risk of moisture related damage.

Table 6 shows the number and distribution of locations sorted into bins or bands of MI = 0.1.

Table 2 – Provinces or territories for which there are no locations with MI>1

Province		Number of locations	Minima	Maxima
Nunavut		16	0.84	0.95
North West Territories		15	0.56	0.94
Yukon		7	0.49	0.57
Alberta		54	0.23	0.63
Saskatchewan		31	0.28	0.56
Manitoba		24	0.51	0.82
	□	147		

Table 3 – Provinces for which there are few locations with MI>1

Province		Number of locations	Minima	Maxima
Ontario		2/222	0.64	1.05
Quebec		21/119	0.80	1.18
	□	23/341		

[8] There is an exception in the NBCC for the southern tip of Vancouver Island. Here values of MI > 0.9 are considered at greater risk, however the exception is limited to warmer regions; i.e. less than 3400 degree-days below 18°C. Environmental conditions in these locations were considered to be less severe than those being considered.

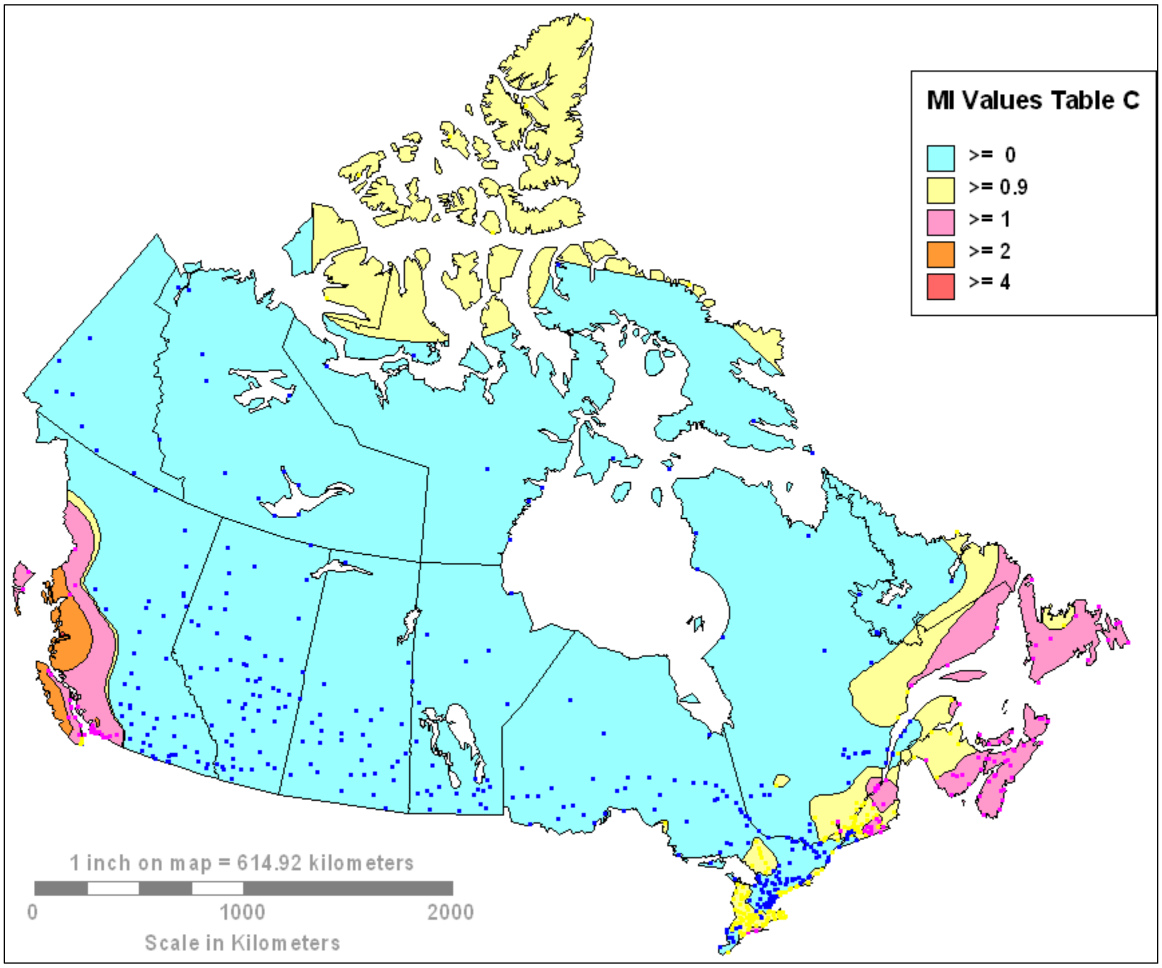

Figure 4 – Distribution of locations having MI > 1

Table 4 – Provinces for which there are several locations with MI>1

Province	Number of locations	Minima	Maxima
British Columbia	41/91	0.23	4.21
New Brunswick	8/15	0.93	1.32
Newfoundland	12/18	0.82	1.66
□	61/124		

Table 5 Provinces for which all locations have MI>1

Province	Number of locations	Minima	Maxima	Mean
Nova Scotia	25/25	1.05	1.48	1.28
Prince Edward Island	4/4	1.01	1.14	1.07
□	29			

Table 6 – Division of the MI > 1 locations into MI Bands

Province	Number of locations*	MI									
		≤ 1.1	≤ 1.2	≤ 1.3	≤ 1.4	≤ 1.5	≤ 1.6	≤ 1.7	≤ 1.8	≤ 1.9	≤ 2
Nova Scotia	25	3	7	3	4	8					
Prince Edward Island	4	3	1	0	0	0					
Newfoundland	12	4	2	0	1	3	1	1			
New Brunswick	8	4	2	1	1	0					
British Columbia	41	2	4	2	1	6	6	2	2	3	13
Quebec	24	22	2	0	0	0					
Ontario	2	2	0	0	0	0					
□	116	40	18	6	7	17	7	3	2	3	13
% locations MI>1 covered		34	50	55	61	76	82	85	86	89	100

* Within each band there may be a number of locations

Method for selecting locations

The MI band definitions are shown in Table 7. Table 8 shows the 30 CWEEDS locations with MI greater than 1 sorted by MI value. MI was calculated as per the NBCC. Mean annual rainfall was calculated from the data set used to calculate MI. Mean annual wind speed was obtained from Environment Canada's climate normal data for 1971-2001 [9]. Blank entries indicate that there was no wind data available. The annual driving-rain index (aDRI) was calculated as the product of mean annual rainfall and mean annual wind speed. The aDRI is a useful indictor of the severity of wind-driven rain (WDR) on building facades since all methods of calculating wind-driven rain, except for simulation methods based on computational fluid dynamics, are based on the product of wind speed and rainfall. Population data was obtained from Wikipedia. Where a MI band contains one location the choice of locations is obvious. When a MI band contains more than one location a method must be developed for selecting the appropriate location(s).

Table 7 – MI bands

Bands	MI >=	MI <
11	2	n/a
10	1.9	2
*9**	*1.8*	*1.9*
*8**	*1.7*	*1.8*
*7**	*1.6*	*1.7*
6	1.5	1.6
5	1.4	1.5
4	1.3	1.4
3	1.2	1.3
2	1.1	1.2
1	1.00	1.1

* – No CWEEDS locations in this band.

[9] Environment Canada, Climate Normals and Averages, http://climate.weatheroffice.gc.ca/climate_normals/index_e.html

Table 8 – CWEEDS locations with MI ≥ 1 sorted by MI

Station	MI	Rainfall, mm	Wind speed, km/h	aDRI, m^2/s	Pop.
Tofino A	3.36	3257	n/a	n/a	1655
Prince Rupert A	2.84	2469	13.1	9.0	12815
Port Hardy A	1.92	1808	11.4	5.7	3864
Abbotsford A	1.59	1508	8.8	3.7	123864
Halifax Int'l. A	1.49	1239	16.8	5.8	119292
Sandspit A	1.47	1341	19.4	7.2	538
Argentia A	1.47	n/a	n/a	n/a	4400
Vancouver Int'l.	1.44	1155	11.8	3.8	578041
St. John's A	1.41	1191	23.3	7.7	100646
Sydney A	1.36	1213	18.6	6.3	105968
Yarmouth A	1.32	1103	18.1	5.5	7162
Saint John A	1.27	1148	16.1	5.1	72043
Stephenville A	1.19	985	19.2	5.3	6588
Debert	1.16	1014	n/a	n/a	n/a
Truro	1.16	991	n/a	n/a	22777
Nanaimo A	1.13	1078	n/a	n/a	78692
Bonavista	1.11	816	31.7	7.2	3764
Charlottetown Cda	1.09	880	17.4	4.3	32174
Terrace A	1.08	970	13.4	3.6	11320
St. Anthony	1.07	799	n/a	n/a	2476
Greenwood A	1.05	910	15.3	3.9	4500
Quebec A	1.04	924	13.6	3.5	491142
Buchans A	1.04	873	n/a	n/a	761
Sherbrooke A	1.03	874	9.4	2.3	147427
Summerside A	1.03	806	20	4.5	14500
Moncton A	1.02	865	16.6	4.0	64128
Fredericton Cda	1.02	886	12.4	3.1	50535
Sept-Iles Ua	1.01	757	14.7	3.1	25514
Gander Int'l. A	1.01	772	20.5	4.4	9951
Ste. Agathe des Monts	1.00	821	10.4	2.4	9679

Two possible parameters for selecting locations suggested themselves. Recall that the project was concerned with wind-driven rain on building façades. An obvious and common measure would be annual rainfall.

Figure 5 shows the correlation between MI and annual rainfall. The correlation between MI and rainfall is obvious and expected since annual rainfall is one of the independent parameters used to calculate MI. Selecting a location based on rainfall, or the amount of water available to the building façade is generally equivalent to picking the location with the highest within a MI band.

It was also possible to use driving-rain as a selection criterion. The amount of water striking a vertical façade is significantly affected by wind speed. It is possible for facades to be subjected to more driving-rain in locations that have lower rainfall and higher wind speeds than locations with higher rainfall and lower wind speeds.

From Table 8 it can be seen that it can be see that Vancouver Int'l airport, BC has approximately the same amount of rainfall as St. John's airport, NL but a significantly lower aDRI. Thus one would expect a

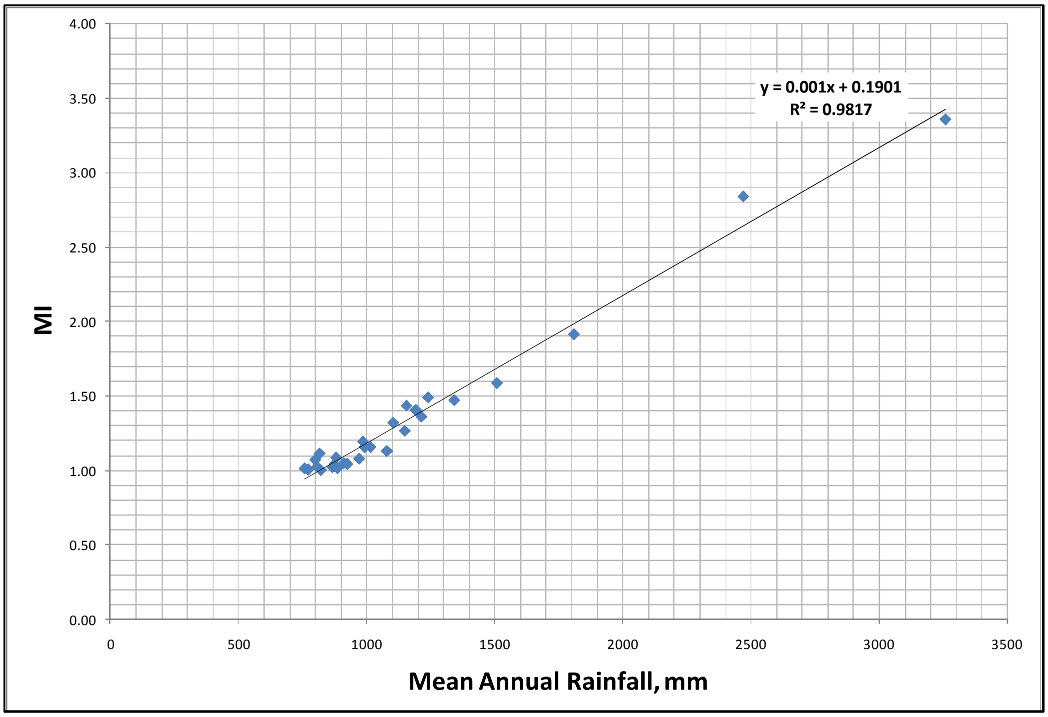

Figure 5 – Relationship between MI and mean annual rainfall

façade to see more water impinging on the surface in St. John's than in Vancouver and as well as a higher driving-rain wind pressure which could lead to greater water penetration in St. Johns NL. Figure 6 shows the correlation between MI and aDRI. When compared with aDRI the general trend is apparent, MI increases in a non-linear fashion with aDRI but there is considerably more scatter in this case.

Since the objective of the project was to characterize the behaviour of the facades with respect to drainage, the amount of water potentially impinging on a wall was therefore of equal importance as MI. MI is a measure, in part, of the capacity of the climate for drying as well as wetting. In the situation where the locations with highest MI and the highest aDRI within a band are not coincident, both locations were selected for analysis. The method for selecting locations is summarized below:

1. Define MI bands
2. For each MI band selection the location with highest MI and the location with highest aDRI

The Canadian locations selected for the study are given in Table 9. Two items are of note in the table. First, Charlottetown, PE was been replaced with Terrace, BC because Charlottetown is too similar and too geographically close to the highest aDRI location, Summerside, PE. The locations are 71 km apart. Second, Vancouver was added to the list of locations of interest because of its large population and history of moisture related failures even though it falls within the middle of a band when considering MI and aDRI values.

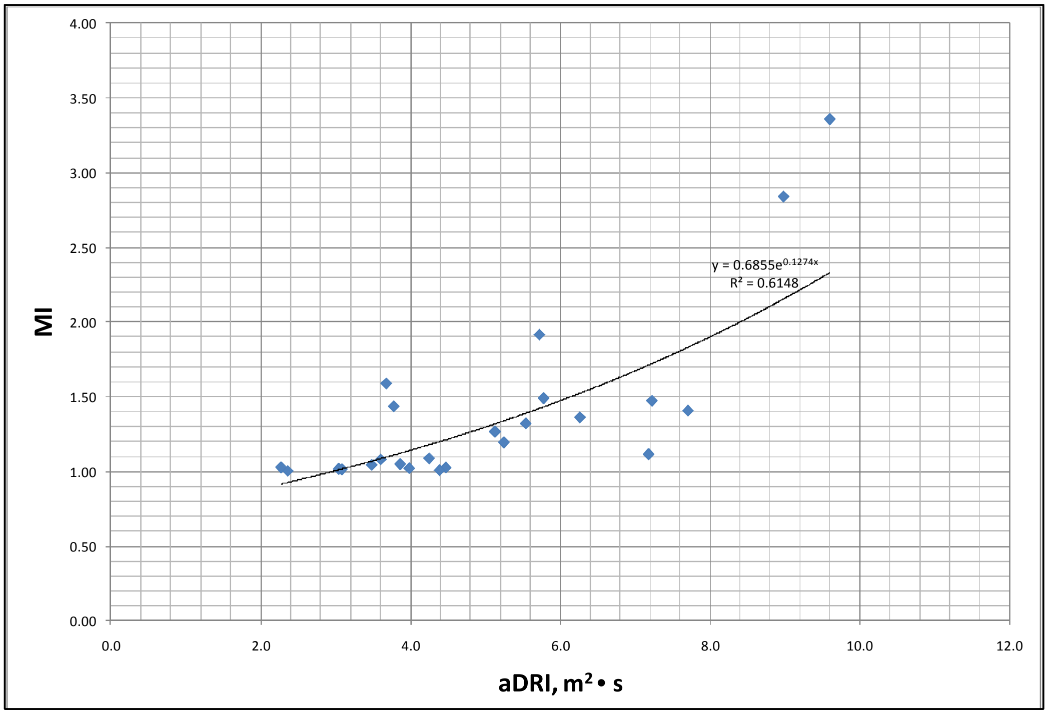

Figure 6 – Relationship between MI and aDRI

Table 9 – Canadian locations selected for analysis

Station	MI	Rainfall, mm	Wind speed, km/h	aDRI, m^2/s
Tofino A. BC	3.36	3257	10.6	9.6
Port Hardy A. BC	1.92	1808	11.4	5.7
Abbotsford A. BC	1.59	1508	8.8	3.7
Halifax Int'l. NS	1.49	1239	16.8	5.8
Vancouver Int'l. BC	1.44	1155	11.8	3.8
St. John's A. NL	1.41	1191	23.3	7.7
Sydney A. NS	1.36	1213	18.6	6.3
Saint John A. NB	1.27	1148	16.1	5.1
Stephenville A. NL	1.19	985	19.2	5.3
Bonavista NL	1.11	816	31.7	7.2
Terrace A. BC	1.08	970	13.4	3.6
Summerside A. PE	1.03	806	20	4.5

2.1.3.b Locations in the United States

In this project, focus was primarily on evaluation of envelope performance for Canadian locations based on Canadian Codes, Regulations, and Standards. Specifically, the main objective of the project was to demonstrate that the proposed wall constructions meet the NBCC Part 9 requirements by demonstrating equivalency to an accepted NBCC solution defined as a reference. There was however interest in determining whether the results of the project could be applied to locations in the United States. Although the results of this project can be extended into the U.S. there is some question as to how far south the results can be applied. In the warmer regions of the U.S. construction practice may significantly differ from those considered in this project. Whereas air barriers are now generally mandated in the U.S., the practice of using vapour retarders and filling the cavities with insulation may differ in more southern locations. There was also interest in selecting locations of interest in the U.S. for future investigation.

The proposed wall configurations and the reference wall were designed for colder Canadian climates. The implications of this are:

1. The presence of insulation, usually filling the stud cavity unless insulation is externally applied
2. A warm side vapour retarder (i.e. towards the interior)
3. A warm side air barrier (i.e. towards the interior)

This suggested a possible limit to the zones in the U.S. where the experimental and simulation results might reasonably apply.

Thermal zoning

Consider that for almost all Canadian locations the number of degree-days above 18°C (HDD18) is 3000 or more. There are only 7 locations in the NBCC 2010 Table C-2 below 3000 HDD18, all in southern B.C. This provided a possible guide as to whether the results could be useful for more southerly climates. A current U.S. climate zoning scheme was developed by Briggs et al. and is shown in Figure 7 [10; 11]. The scheme is currently used in the International Energy Conserving Code, the International Building Code (IECC) [12], ANSI/ASHRAE Standard 90.1, and ANSI/ASHRAE Std. 169-2009 [13]. The main zones that are numbered are thermal by definition. Locations in IECC Zone 4 lie between 2000 and 3000 HDD18. Consequently it is recommended that the results of the project not be extended to zones warmer than the top half of IECC Zone 4; i.e. the results might be applicable in IECC Zones 5, 6, 7, 8, and the colder portions of IECC Zone 4. A list of U.S. locations and corresponding climate zones appears in ASHRAE Std. 169-2009 Table B-1 [13].

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[10] Briggs R. S. and Lucas R. G., "Climate Classification for Building Energy Codes and Standards Part 1- Development and Process. ASHRAE Transactions 2003, Vol. 109, Pt. 1.

[11] Briggs R. S. and Lucas R. G., "Climate Classification for Building Energy Codes and Standards Part 2- Zone Definitions, Maps, and Comparisons. ASHRAE Transactions 2003, Vol. 109, Pt. 1

[12] ICC (International Code Council), 2012 International Energy Conservation Code (IECC). Falls Church, VA: International code congress.

[13] ANSI/ASHRAE 169-2009, “Weather Data for Building Design Standards (ANSI Approved)”, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2009, 70 pages.

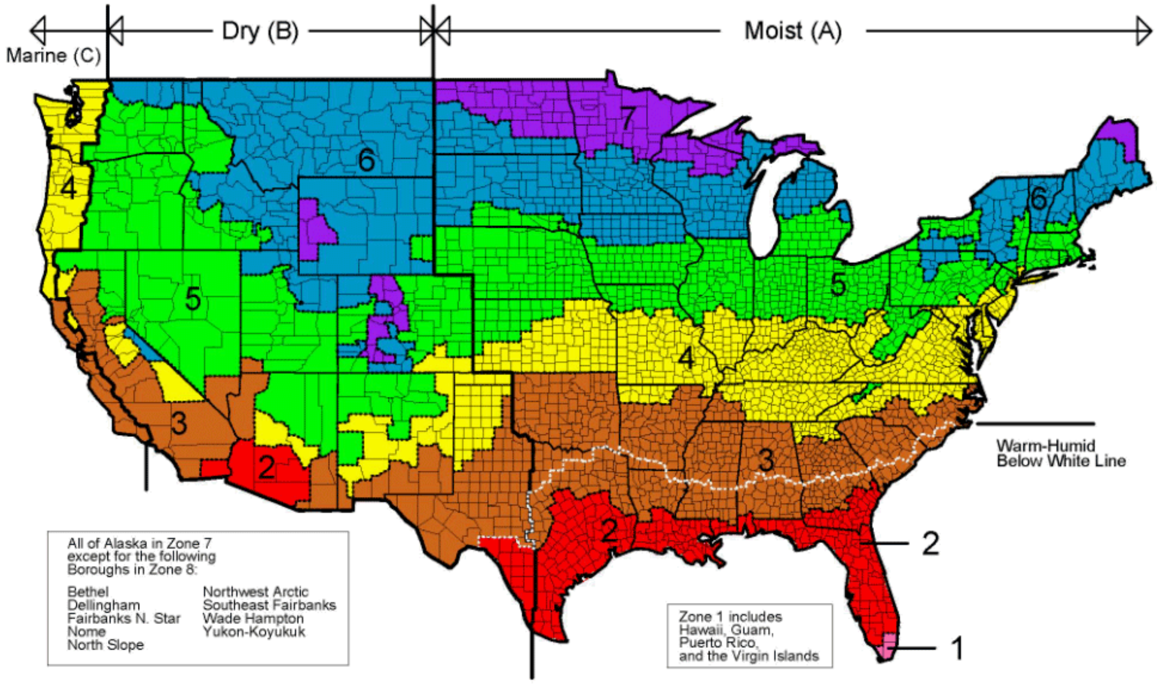


Figure 7 – IECC Climate zones in the United States – the main zoning is thermal [12]

Criteria for locations in the U.S.

The MI values in this project were derived from the NBCC, using normalizing factors particular to Canada [4]. A set of MI values for U.S. was created previously using a different normalizing scheme [14]. In order to directly compare the U.S. MI values produced previously with the Canadian MI values that appear in the NBCC the U.S. MI values were recalculated using the NBCC normalizing scheme.
Table 10 shows the locations in the U.S. in the top half of IECC Zone 4 or greater (HDD18 > 2500) where MI > 1 or MI > 0.9 and HDD18 < 2500. A list of U.S. locations meeting the criteria is given in Appendix 3. Using the methodology developed for selecting Canadian locations, the suggested locations in the United States are given in Table 10. There were no candidate locations in the U.S for the following ranges of MI: 1.4 to 1.5, 1.5 to 1.6, 1.8 to 1.9, and 1.9 to 2.0. Note that although Cold Bay, AK was the location with both highest MI and aDRI for the 1 to 1.1 band, Louisville, KY was also added. Louisville, KY has the same MI value as Cold Bay, AK but is the warmest location of all U.S. locations meeting the criteria and therefore of potential interest.

[14] Cornick, S. M., Dalgliesh, W. A., Said, N. M., Djebbar, R., Tariku, F., Kumaran, M. K., *Report from Task 4 of MEWS Project - Task 4 Environmental Conditions Final Report*, Research Report IRC-RR-113, Institute for Research in Construction, National Research Council of Canada, October 01, 2002.

Table 10 – United States locations

Station	MI	HDD18	Rainfall, mm	Wind, km/h	aDRI, m^2/s
Yakutat AK	3.43	5269	3349	11.68	10.9
Annette AK	2.57	3882	2501	16.64	11.6
Astoria OR	1.78	2866	1656	13.6	6.3
North Bend OR	1.71	2849	1607	14.24	6.4
Kodiak AK	1.65	4898	1519	17.6	7.4
Olympia WA	1.36	3142	1242	10.72	3.7
Eugene OR	1.31	2526	1238	12.16	4.2
Juneau AK	1.28	4943	1128	13.28	4.2
Islip NY	1.12	3137	1113	19.04	5.9
Cold Bay AK	1.09	5407	760	27.04	5.7
Louisville KY	1.09	2508	1085	13.28	4
Seattle WA	1.00	2727	935	14.08	3.7
Indianapolis IN	0.99	3119	955	15.36	4.1
Boston MA	0.95	3134	947	19.84	5.2

2.1.4 Database

A small database of hourly weather data for the project was created. The database comprises weather data in hygIRC format and WYEC2 format for all Canadian the locations selected and selected U.S. locations. The WYEC2 files contain complete data whereas the hygIRC formatted data only contains information relevant for hygrothermal modelling. The database also includes a selection of individual weather years and sequences for hygrothermal simulations (see Part 3: Weather Data for Hygrothermal Simulation). The weather data sets are stored in a relational database format for ease of use, whereas the individual hygrothermal years extracted from the database are in ASCII format.

2.2 Wind and Rain Loads for Wall Testing

Weather datasets were created to determine the wind-driven rain loads (WDR) and driving-rain wind pressures (DRWP) that could be expected on building facades. The objective was to determine the spray-rates, to simulate wind-driven rain loads, and the applied pressures, to simulate driving-rain wind pressures, that were used for the laboratory experiments.

2.2.1 Statistical Analysis

For each location in the dataset, a set of hourly values of WDR and DRWP was created. The calculation of WDR was performed using the method outlined in Cornick and Lacasse [15], as was the calculation of DRWP. A 2-parameter Weibull distribution was assumed for values of WDR and DRWP. In

[15] Cornick, S. M. and M. A. Lacasse (2009), An Investigation of Climate Loads on Building Facades for selected locations in the US, submitted to: ASTM E06 Symposium Up Against the Wall - An Examination of Building Envelope Interface Techniques and Systems, Journal of ASTM International (JAI) Volume 6, No. 2 (DOI 10.1520/JAI1011210)

Figure 9 the observed data and assumed distribution for Tofino BC are shown. The following values of interest were produced from statistical analysis of the data sets:

1. Mean WDR and DRWP: the arithmetic mean of the values in the set.
2. Median WDR and DRWP: the middle number of a group of numbers such that half the numbers have values that are greater than the median.
3. Standard deviation: Measure of dispersion in the set.
4. Maximum WDR and DRWP: Maximum calculated (WDR) and observed values (DRWP).
5. DWRP at maximum WDR and WDR at maximum DRWP.
6. 98% value WDR and DRWP: The value at which 98% of the values in the set are below or conversely the value at which only 2% of the values exceed.
7. Mean coincident X at 98% Y: The mean value of the set of values of X that occur at the 98-percentile of Y; mean DRWP at 98% value of WDR for e.g.
8. Mode: The most frequently occurring value in the data set; in the case of the distributions fitted the mode was zero.

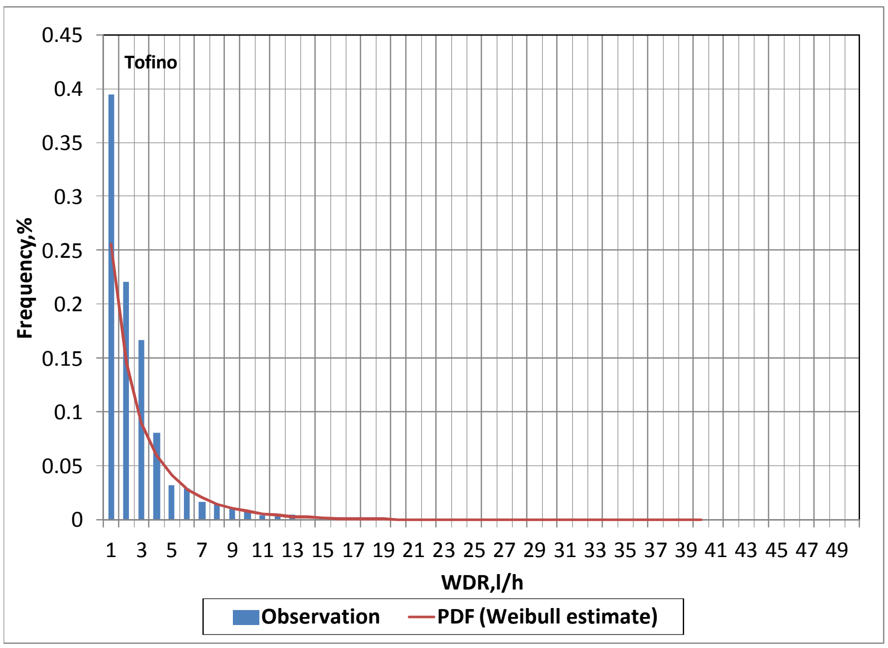


Figure 8 – Histogram and Probability Density Function (PDF) for wind-driven rain values in Tofino BC

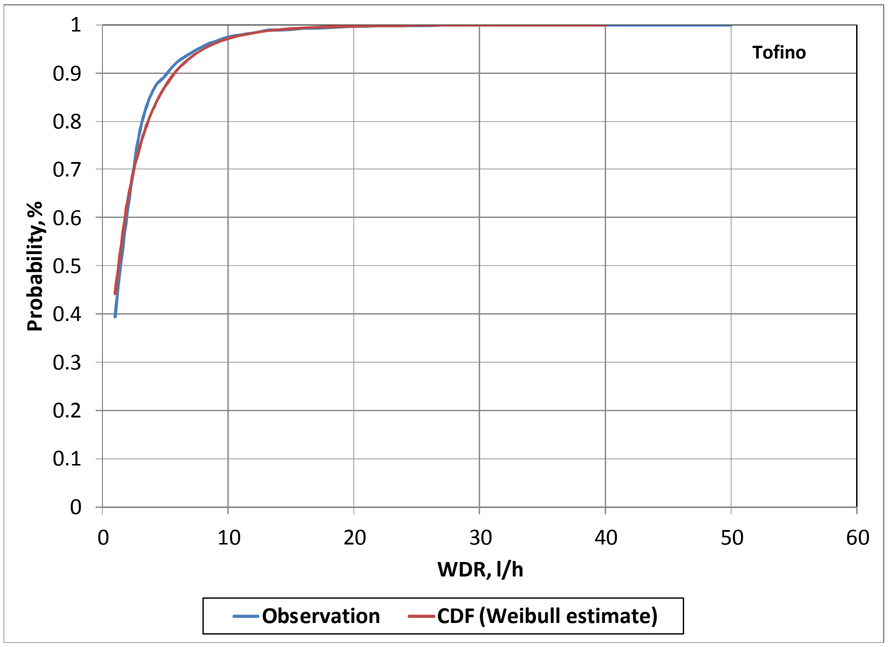


Figure 9 – Cumulative Distribution Function (CDF) for wind-driven rain values in Tofino, BC

Table 11 shows the WDR values of interest for the selected Canadian locations whereas Table 12 shows the DRWP values. The mean and median values of wind-driven rain for all locations are low, ranging from 0.54 l/h (0.01 l/min) to 2.5 l/h (0.04 l/min) per square meter of wall surface. The 98-perecentile rate of water deposition ranges from 5.6 l/h (0.09 l/min) to 13.2 l/hr (0.22 l/min). Maximum calculated water deposition rates were significantly higher, ranging from 21.7 l/hr (0.36 /min) to 56.7 l/hr (0.95 l/min). Locations on the east coast of Canada showed consistently higher values of maximum WDR. Graphical representations of Table 11 and Table 12 are given in Appendix 4.

With respect to DRWP the mean and median values were low on west coast, ranging from 9 to 28 Pa. Mean and median driving-rain wind pressures were more elevated on the east coast, ranging from 10 to 59 Pa. The same west-coast, east-coast pattern was apparent for the 98-percentile values of DRWP; 59 to 114 Pa and 103 to 214 Pa respectively. There was not an apparent east-coast, west-coast split for the maximum observed DRWP; the range was 184 to 512 Pa.

In summary, a water deposition rate of 1.41 l/hr (0.02 l/min) is sufficient to cover the median WDR for all locations, 2.5 l/hr (0.04 l/min) to cover the mean value, 13.2 l/hr (0.22 l/min) to cover the 98-precentile value, and 56.7 l/hr (0.95 l/min) to cover the maximum calculated value. For driving-rain wind pressures, 46, 59, 214, and 512 Pa cover the median, mean, 98-percentile, and maximum values respectively. Generally, for similar values of aDRI one would expect more rainfall but lower wind speeds on the west-coast as opposed to higher wind speeds but lower rainfall totals on the east coast. However at the extremes for the range of WDR and DRWP values, the spray rates and pressure differentials are similar on both coasts.

Table 11 – Wind-driven rain values in (a) litres per hour and (b) litres per minute per square meter of wall surface.

(a)

Location	Prov.	Mean WDR, l/h	Median WDR, l/h	Std dev, l/h	Max WDR, l/h[1]	DWRP @ max WDR, Pa[2]	98% WDR, l/h[3]	MC DRWP, Pa[4]
Abbotsford	BC	1.36	0.69	1.16	21.7	64	5.62	54
Port Hardy	BC	2.25	1.41	2.04	29.3	116	9.22	59
Terrace	BC	1.52	0.54	1.59	38.2	197	7.42	59
Tofino	BC	2.18	1.25	2.89	40.9	226	11.25	52
Vancouver	BC	1.37	0.62	1.33	24.7	82	6.16	24
Saint John	NB	2.31	1.16	3.00	52.1	366	12.20	91
Bonavista	NL	2.21	0.88	2.52	54.4	399	11.62	87
St John's	NL	2.09	0.85	3.03	46.8	296	12.09	102
Stephenville	NL	2.25	1.13	2.22	39.2	208	10.17	132
Halifax	NS	2.28	1.09	3.09	49.8	334	12.49	117
Sydney	NS	2.50	1.22	3.26	56.7	434	13.20	115
Summerside	PE	2.31	1.27	2.42	42.2	240	10.95	75

(b)

Location	Prov.	Mean WDR, l/min	Median WDR, l/min	Std dev, l/min	Max WDR, l/min[1]	DWRP @ max WDR, Pa[4]	98% WDR, l/min[5]	MC DRWP, Pa[6]
Abbotsford	BC	0.02	0.01	0.02	0.36	64	0.09	54
Port Hardy	BC	0.04	0.02	0.03	0.49	116	0.15	59
Terrace	BC	0.03	0.01	0.03	0.64	197	0.12	59
Tofino	BC	0.04	0.02	0.05	0.68	226	0.19	52
Vancouver	BC	0.02	0.01	0.02	0.41	82	0.10	24
Saint John	NB	0.04	0.02	0.05	0.87	366	0.20	91
Bonavista	NL	0.04	0.01	0.04	0.91	399	0.19	87
St John's	NL	0.03	0.01	0.05	0.78	296	0.20	102
Stephenville	NL	0.04	0.02	0.04	0.65	208	0.17	132
Halifax	NS	0.04	0.02	0.05	0.83	334	0.21	117
Sydney	NS	0.04	0.02	0.05	0.95	434	0.22	115
Summerside	PE	0.04	0.02	0.04	0.70	240	0.18	75

1. Max WDR is the maximum calculated; 2. DWRP @ max WDR is the DRWP occurring during the maximum calculated WDR; 3. 98% WDR is the 98-percentile value of WDR; 4. MC DWRP is the mean coincident DRWP at the 98% value of WDR.

Table 12 – Driving-rain wind pressure values in Pa

Location	Prov.	Mean DRWP, Pa	Median, DRWP Pa	Std Dev, Pa	Max DRWP, Pa[1]	WDR @ max DRWP, l/h (l/min)[2]	98% DRWP, Pa[3]	MC WDR, l/h (l/min)[4]
Abbotsford	BC	10	15	16	366	9.2 (0.15)	59	4.0 (0.07)
Port Hardy	BC	27	17	33	320	8.6 (0.14)	114	5.7 (0.10)
Terrace	BC	19	11	23	296	21 (0.36)	89	4.7 (0.08)
Tofino	BC	17	9	23	464	27 (0.45)	89	8.2 (0.14)
Vancouver	BC	14	9	14	184	4.8 (0.08)	59	3.4 (0.06)
Saint John	NB	28	19	27	366	52 (0.87)	115	10 (0.17)
Bonavista	NL	59	46	52	512	8.0 (0.13)	214	6.5 (0.11)
St John's	NL	38	26	38	434	11 (0.18)	159	7.3 (0.12)
Stephenville	NL	21	10	24	384	24 (0.41)	104	6.9 (0.11)
Halifax	NS	28	18	28	366	12 (0.19)	117	9.3 (0.15)
Sydney	NS	34	23	35	434	57 (0.95)	147	9.1 (0.15)
Summerside	PE	38	25	38	434	10 (0.17)	160	6.8 (0.11)

1. Max DRWP is the maximum observed; 2. WDR @ max DRWP is the WDR occurring during the maximum observed DRWP; 3. 98% DRWP is the 98-percentile value of DRWP; 4. MC WDR is the mean coincident WDR at the 98% value of DRWP.

2.2.2 Extreme Value Analysis

Extreme value analysis (EVA) is a special kind of statistical analysis. Given a time-series sequence of data, a subset of maximum values for a given period can be constructed. Rank order statistics can be performed on the set of maximum values. Sets of maximum yearly WDR and DRWP were constructed for all the locations selected. The data were fitted to a Type-I Generalized Extreme Value distribution (GEV), examples of which are shown in Figure 10 and Figure 11. The x-axis represents the return period in a standardized form. The return period can be calculated from the standard extremal variate, x, by using Equation 1. The y-axis gives the expected value for a given return period. The dashed lines represent the 95% confidence limits and the solid line represents the data fit. Using the GEV distribution, extreme values were calculated for various return periods, including a fifty-year, or one in fifty, return period. The 50-year values are given in Table 13. The mean and standard deviations for the Canadian locations used to calculate the return periods are given in Table 14. A fifty-year return was selected as to be compatible with the NBCC. The structural portion of the Code, Part 4, prescribes the use of the 1 in 50-year reference wind velocity for the design of façade components; see Clause 4.1.7.1.(4) which says that the reference velocity wind pressure, q, shall be based on 1 in 50 year value of wind pressure.

$$\frac{1}{R} = 1 - e^{-e^{-x}}$$ Where R is the return period Equation 1

2.2.2.a Spray rates

Table 13 gives the expected 1 in 50-year value for WDR for each location. Comparing the extreme values with maximum observed values given in Table 11, the values are similar (See Appendix 5). A spray rate of 1l/min would adequately cover both maximum calculated spray rate and the expected 1 in 50-year value. With respect to the selection of a coincident DRWP the most conservative assumption was to assume that the 1 in 50-year DRWP occurs coincidently with the 1 in 50-year WDR [15].

Table 13 – Extreme values for a fifty-year return period, 1 in 50, for WDR and DRWP

Location	Prov.	1/50 WDR, l/h	1/50 WDR, l/min	1/50 DRWP, Pa
Abbotsford	BC	21.1	0.35	278
Port Hardy	BC	29.9	0.50	324
Terrace	BC	31.6	0.53	298
Tofino	BC	38.2	0.64	418
Vancouver	BC	24.7	0.41	183
Saint John	NB	46.4	0.77	354
Bonavista	NL	55.8	0.90	515
St John's	NL	55.7	0.93	438
Stephenville	NL	36.7	0.61	340
Halifax	NS	48.8	0.81	362
Sydney	NS	50.7	0.84	422
Summerside	PI	43.1	0.72	442

Table 14 – Mean and standard deviation for extreme values used to calculate returns

	Wind-driven rain		Driving-rain wind pressure	
Location	Mean	Standard deviation	Mean	Standard deviation
Abbotsford	10.8	3.9	119	61
Bonavista	27.1	11.1	345	73
Halifax	28.6	7.8	203	61
Port Hardy	17.1	5.0	193	50
Saint John	27.1	7.4	192	63
St John's	30.0	9.9	259	69
Stephenville	15.3	8.3	157	71
Summerside	22.8	7.8	235	80
Sydney	30.6	7.7	229	75
Terrace	14.9	6.5	148	58
Tofino	25.7	4.8	212	79
Vancouver	14.2	4.1	109	28

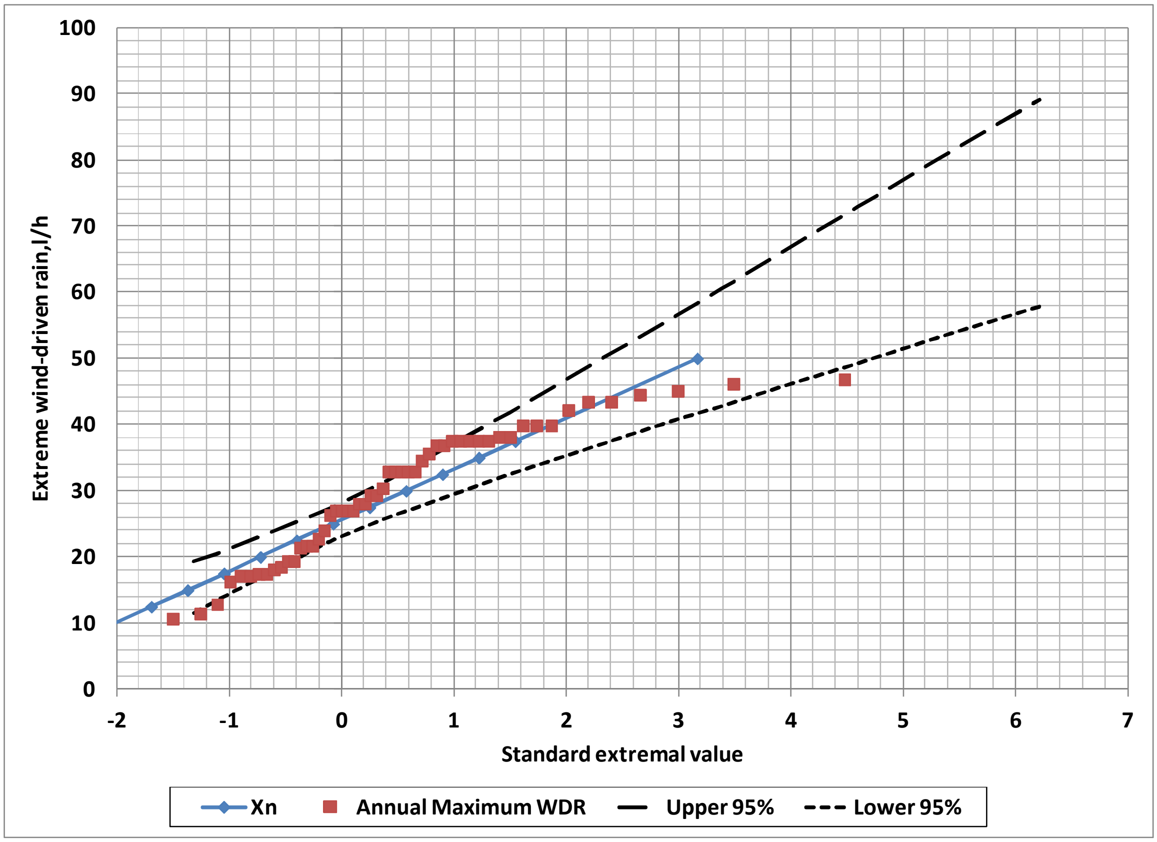


Figure 10 – GEV plot of annual maximum values of WDR for St. John's NL. 1 in 50 corresponds to a value of 3.9 on the x-axis

2.2.2.b Driving-rain wind pressure

Table 13 gives the expected 1 in 50 value for DRWP for each location. Comparing the extreme values with maximum observed values given in Table 12, the values are similar (See Appendix 5). A differential pressure of 500 Pa would adequately cover both maximum observed DRWP and the expected 1 in 50 year value. With respect to the selection of a coincident WDR the most conservative assumption would be to assume that the 1 in 50 WDR occurs coincidently with the 1 in 50 DRWP [15].

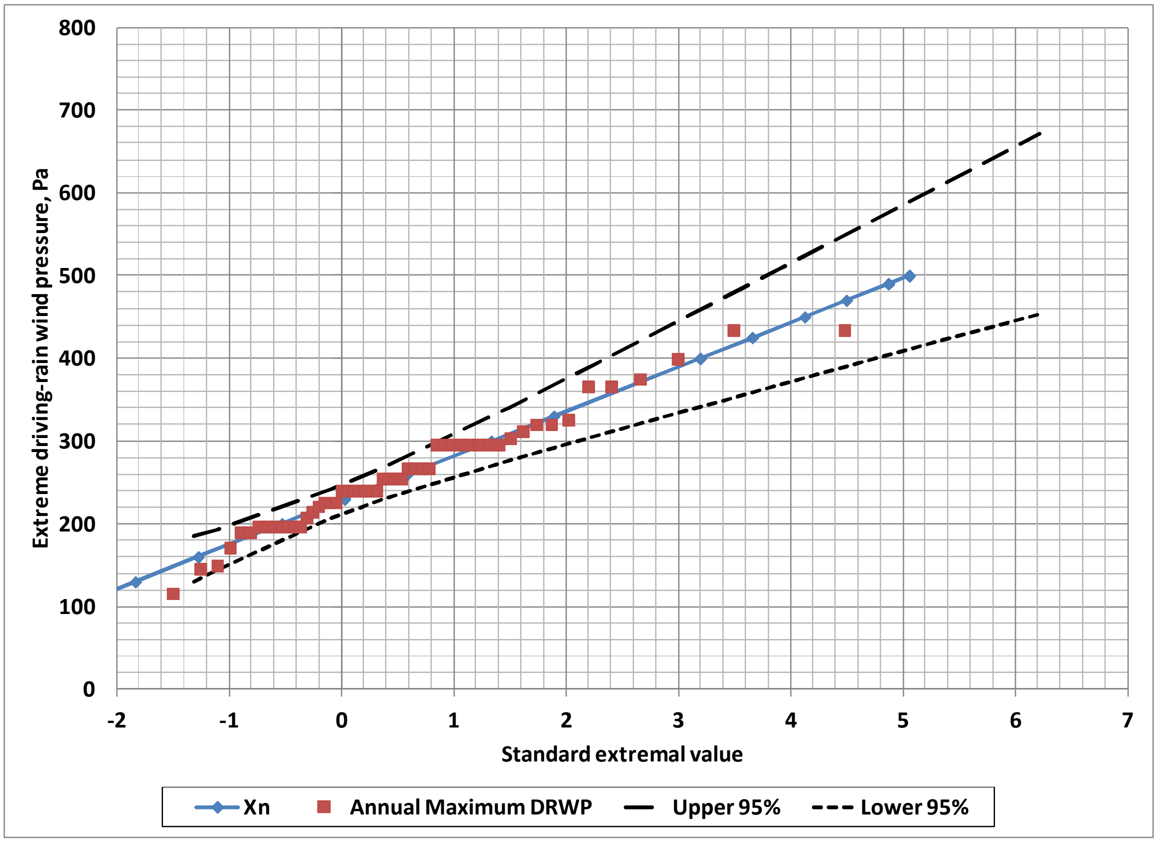


Figure 11 – GEV plot of annual maximum values of DRWP for St. John's NL. 1 in 50 corresponds to a value of 3.9 on the x-axis

2.3 Summary

All the Canadian locations having a value of MI of greater than one and with at least 8 years of hourly climate data were identified. Eleven MI bands between MI >1 and MI ≥ 2 were defined and representative locations within each band were identified. Two criteria were used to select the locations within a band; the greatest MI value within the band and the highest annual Driving Rain Index. If the two highest values did not correspond to a single location then two locations were selected; the location with highest MI and the location with the most wind-driven rain.

To extend the results of the project to the U.S. or to pick U.S. locations appropriate for the NBCC reference wall, the following criteria were used:

1. Degree-days above 18°C > 2500; i.e. upper half IECC climate zone 4
2. MI values defined by the NBCC > 0.9 or 1 according to NBCC 9.27.2.2.5 (a) or (b) modifying (a) to >2500 Degree-days above 18°C.

A database of hourly climate values for each location identified was produced. Statistical analysis of the datasets produced the following values for WDR and DRWP respectively:

1. Mean.
2. Median.
3. Standard deviation.
4. Maximum observed and coincident WDR or DRWP.
5. 98-percentile value and coincident mean WDR or DRWP.
6. 1 in 50-year return period value.

For all the locations a spray of 1 l/min-m^2 (or 60 l/hr-m^2) was sufficient to cover all locations and conditions for WDR. Similarly a 500 Pa differential pressure was sufficient to cover all value of DRWP. NOTE that the threshold values are limited to a height of 10m or less and time averages of 1-hour. For shorter time-averages or greater heights the methods documented by Cornick and Lacasse to modify the values can be applied [15].

3 Weather Data for Hygrothermal Simulation

The final part of environmental load task was to select appropriate weather data for moisture modelling. Specifically, the task was to select from the climate database years that could be used as input for the hygrothermal simulation exercise. Four methods of selecting Moisture Design Reference Years (MDRY's) were investigated. A summary of each method is given in Appendix 5. The methods were:

1. MEWS MI Method [16]
2. 10% Hot/Cold Method (ASHRAE 160-2009) [17]
3. ASHRAE 1325-RP Method [18]
4. 10-year run (ASHRAE 160-2009) [17]

3.1 MEWS Method

The MEWS method was developed as part of the MEWS project [19] and was fully documented by Cornick et al. [16]. Briefly, the method calculates the Moisture Index (MI) value for each year in the period of record in climate database for a particular location. The wetting and drying portions of the index are normalized to the maximum and minimum values within the dataset as opposed to the NBCC 2010 [4] which uses a geographical normalization scheme. The MI MEWS method specifies that for

[16] Cornick SM, Djebbar R, Dalgliesh WA., Selecting moisture reference years using a moisture index approach. Building and Environment 2003; 38(12): 1367-1379.

[17] ANSI/ASHRAE 160-2009 Standard 160-2009 "Criteria for Moisture-Control Design Analysis in Buildings (ANSI/ASHRAE Approved)", American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2009, 16 pages.

[18] Salonvaara Mikael, RP-1325 "Environmental Weather Loads for Hygrothermal Analysis and Design of Buildings", American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2011, 96 pages.

[19] Beaulieu, P.; Bomberg, M.; Cornick, S.; Dalgliesh, A.; Desmarais, G.; Djebbar, R.; Kumaran, K.; Lacasse, M.; Lackey, J.; Maref, W.; Mukhopadhyaya, P.; Nofal, M.; Normandin, N.; Nicholls, M.; O'Connor, T.; Quirt, J.; Rousseau, M.; Said, M.; Swinton, M.; Tariku, F.; van Reenen, D., Final Report from Task 8 of MEWS Project (T8-03) - Hygrothermal Response of Exterior Wall Systems to Climate Loading: Methodology and Interpretation of Results for Stucco, EIFS, Masonry and Siding Clad Wood-Frame Walls, Research Report IRC-RR-118, Institute for Research in Construction, National Research Council of Canada, Nov. 1, 2002.

calculating the amount of WDR the wall should be oriented in the orientation of the predominant driving-rain. The year with maximum value of MI was deemed to be the MEWS *wet* year. The year with the minimum MI was deemed to be the MEWS *dry* year. The year with the MI value closest to the mean value of yearly MI's was selected as the MEWS *average* year. All years having MI values within one standard deviation, σ, of the mean value for MI are considered to be average years. Years that fall outside of plus or minus 1 σ are considered to be wet or dry years respectively. Table 15 shows the MI Mews years for Abbotsford BC. The 90-pecentile year is the year closest to the 90-pecentile value; the value below which 90% of the values fall. Note that since the assumed distribution for MI values is normal, the values for median, mean and mode are identical. Hygrothermal year selections for all Canadian and U.S. locations are given in Appendix 5. The MEWS method specifies a sequence of three years, specifically the *wet* year, repeated twice, followed by the *average* year. The first year is considered to be a conditioning year and is ignored when analysing the results.

Table 15 – Hygrothermal year selections for Abbotsford BC.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1953	2004	1966
90%	1955	1997	1961
Median	1983	1963	1983
10%	1996	1975	2004
Min	2004	1955	1985
10-year run	1996-2005		

3.2 10% Hot/Cold Method

ASHRAE Standard 160-2009 specifies two methods for moisture design reference years [17]. The first method, a ten-year run, is discussed below. The second method, a single year method, specifies that for each year in the climate record the mean annual temperature be calculated. The years are then ranked according to the value of the mean annual temperature. The standard specifies that two simulation runs should be performed, one using the 90-percentile year, a *hot* year, and a second using the 10-percentile year, a *cold* year. Table 15 shows the *hot* and *cold* years for Abbotsford BC. The 90-pecentile year is the year closest to the 90-percentile value; the value below which 90% of the values fall. Note that since the assumed distribution of mean annual temperatures is normal, the values for the median and mean are identical. Hygrothermal year selections for all Canadian and U.S. locations are given in Appendix 5. No wall orientation is stipulated by the method.

3.3 ASHRAE 1325-RP Method

The 1325-RP method was developed as part of an ASHRAE sponsored research project [18]. The project was initiated to provide a method for selecting MDRYs for ASHRAE Standard 160 [17]. The method estimates the annual value of a damage function based on mean annual climate parameters such as dry bulb temperature, relative humidity, and solar insolation. The damage function was similar to the RHT index developed as part of MEWS [19]. In this case, instead of using RHT(80) as the estimate of risk of moisture damage, a more conservative index, RHT(70), was used. Table 15 shows the selection of 1325-RP years for Abbotsford BC. The 90-pecentile year is the year closest to the 90-percentile value; the value below which 90% of the values fall. Note that the since the assumed distribution for the accumulated RHT(70) index is normal, the values for median and mean are identical. Hygrothermal year selections for all Canadian and U.S. locations are given in Appendix 5. In report 1325-RP [18] it is specified that the direction of the wall, for simulation purposes, should be the low solar side; i.e. north for buildings in northern hemisphere (positive latitudes).

3.4 10-year run

ASHRAE Standard 160-2009 specifies that, ideally, for design purposes a 10-year sequence of weather years should be used for simulation runs to evaluate a proposed wall design [17]. Hygrothermal year sequences for all Canadian and U.S. locations are given in Appendix 5. No orientation is specified for this method.

3.5 Recommended Method

Running 10-year sequences was deemed impractical for this project. Standard 160 [17] initially assumes 1-dimensional hygrothermal analysis tools will be used. Whereas 10-year sequences are practical for 1-dimensional analysis 10-year sequences are not currently practical for 2- and 3-dimnesional analysis. A test was performed to determine which of the remaining methods was appropriate for the project. A simple 1-dimensional model of a direct applied stucco wall was created in hygIRC 1-D [20]. One percent of the wind-driven rain striking the surface of the wall was inserted onto the exterior side of the weather resistive barrier. The location of interest was the exterior most node in the sheathing layer, in this case Oriented Strand Board (OSB). The location was Vancouver International Airport (YVR). Initial conditions for all cases were determined by running a single year for the north and east orientation. The north orientation is specified by the 1325-RP method [18]. The MEWS MI [16] method specifies that the orientation should be that of the predominant direction of the driving-rain, in this case east. The year 1979 was selected as representing an average or close to the average year for all single year methods. For each test run the initial conditions were set to the final conditions at the end of the 1979 year run. Single year runs were performed using the 90-perecentile year for each method. In total 7 scenarios where examined:

1. MI MEWS (East)
2. 1325-RP (North)
3. 1325-RP (East)
4. 10% Cold (East)
5. 10% Cold (North)
6. 10% Hot (East)
7. 10% Hot (North)

The amount of water striking the wall is shown in Figure 12. Dashed lines represent the north orientations. The difference in the total amount of WDR striking the wall is apparent; more water is

[20] Maref, W., Cornick, S.M., Abdulghani, K., van Reenen, D., "An Advanced hygrothermal design tool "I-D hygIRC"" eSim 2004 Conference (Vancouver, B.C., June 09, 2004), pp. 190-195, June 01, 2004 (NRCC-46902) ; URL: http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc46902/nrcc46902.pdf

available on the east façade. The RHT(80) accumulated at the first exterior node of the sheathing board shows a direct relation between the RHT(80) and water striking the wall. This is shown in Figure 13. Figure 14 shows a significantly wetter pattern on the east facing facades. A conclusion of this small study was that the predominant rain orientation is more severe in terms of potential moisture accumulation than the 1325-RP conclusion that low solar orientation was the most severe. Note that a complete study comparing the two methods, MI MEWS and 1325-RP, was not within the scope of this project.

Figure 13 and Figure 14 show that there is little differentiation between the years selected by the different methods for east facing walls. The performance in all cases was considered to be unacceptable. The lack of differentiation can be explained by the relatively constant nature of the climate in Vancouver. The climate is moderate in all respects and there appears to be little inter-year variation among the main climate parameters; in other words the range is narrow. A 10-year simulation using the same wall used for the small study shows a consistent pattern of response. Water entry was not considered for the 10-year run. The result also shows the difference in response between the north façade and the east façade, Recall that the east façade is subjected to the most WDR.

The MI MEWS method was recommended for selected MDRY for this project. It was selected because:

1. The specified direction, direction of most WDR, subjects the wall to the most water on the surface and the most water penetration
2. The simulations undertaken demonstrated more significant wetting than the 1325-RP specified north facing walls.
3. The method has been successfully used in the past and compares well with other proposed methods [18]

A more in depth investigation into the selection of MDRY is in order but unfortunately beyond the scope of the project.

3.6 Summary

After reviewing several methods of selecting weather years for hygrothermal simulation, MDRYs, and a small comparison study it was concluded that the MI MEWS method was appropriate to use for this project. MI MEWS rankings were produced for all the years in the climate record for each Canadian and U.S. location selected. Three MI MEWS years, *wet*, *average*, and *dry*, were generated and converted to an acceptable format for hygrothermal analysis. As a by-product hygrothermal years using the other methods were also produced as was a 10-year sequence of the most recent years for each location. A typical table of the information generated for one location is shown in Table 15. This information forms part of the climate database generated for the project.

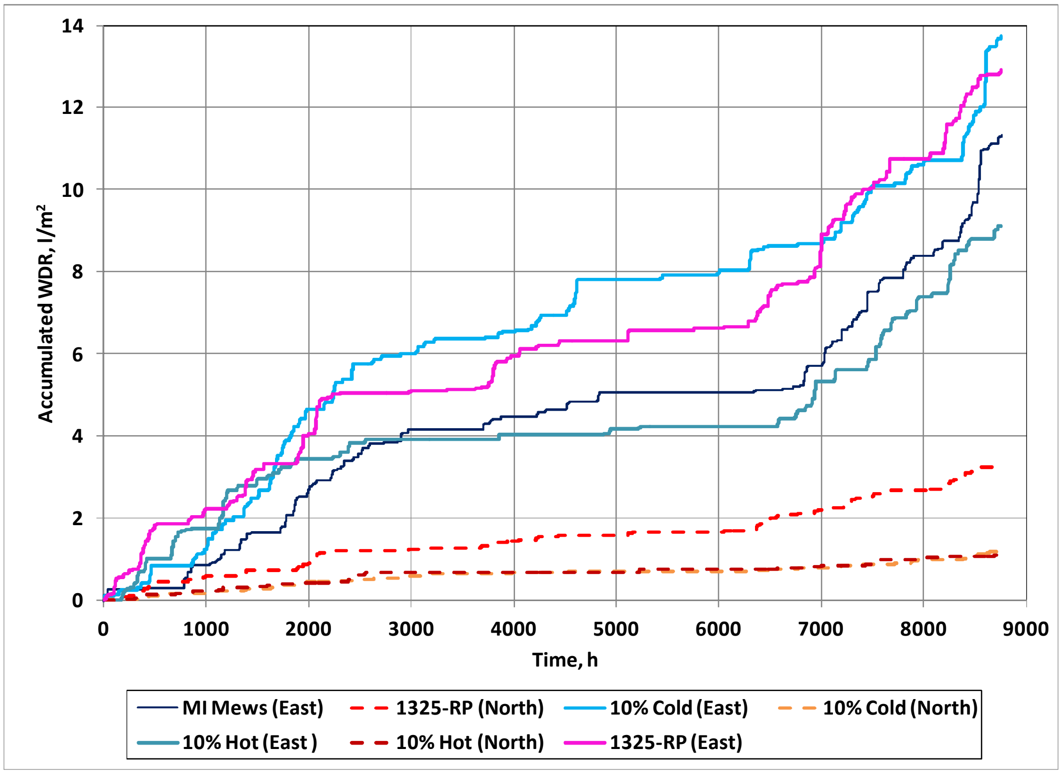


Figure 12 – Accumulated wind-driven rain striking the wall surface for various MDRY's for YVR

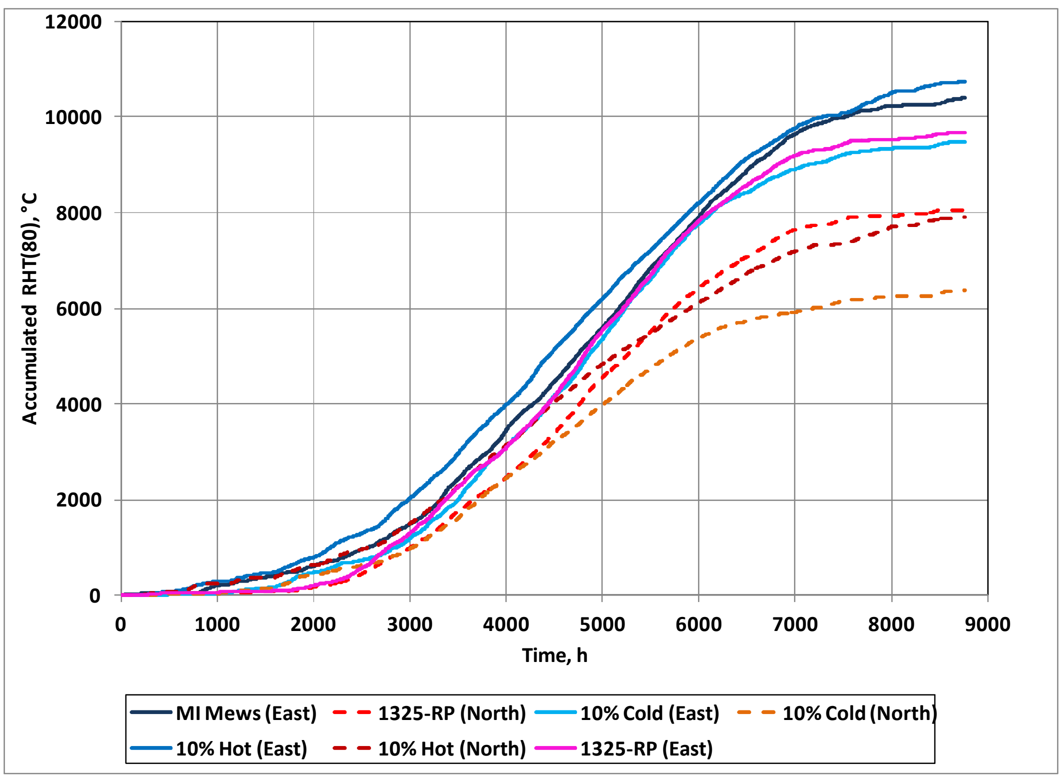


Figure 13 – Accumulated RHT(80) at the first node toward the exterior in the sheathing board for various MDRY's for YVR

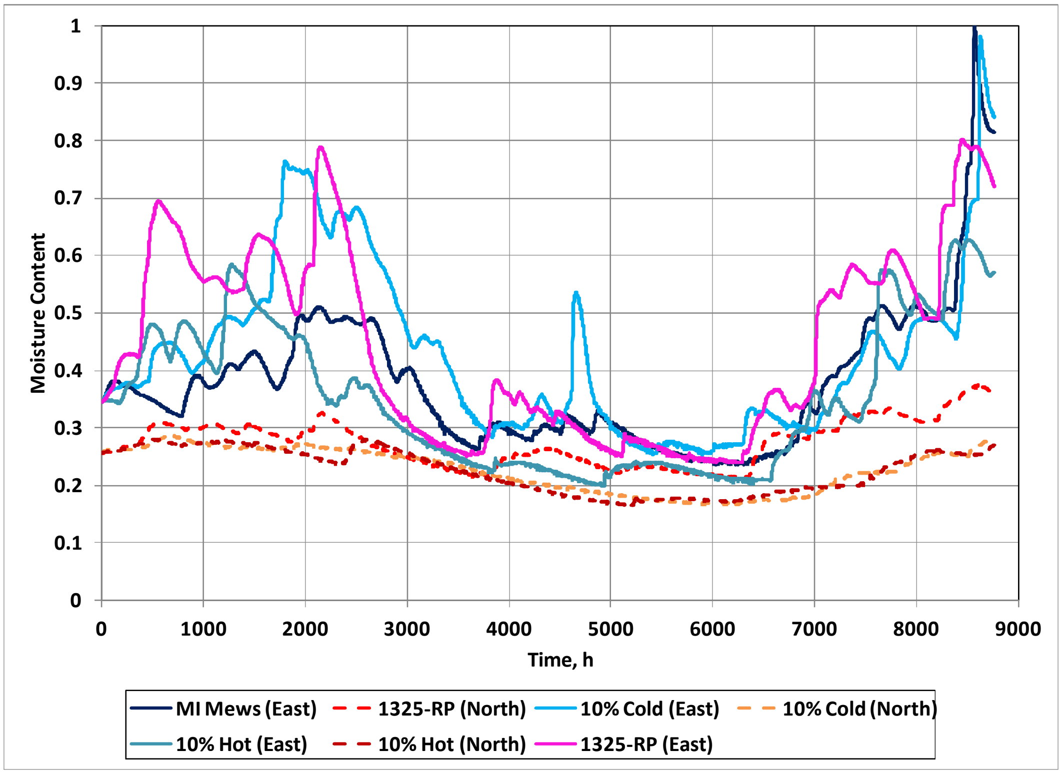


Figure 14 – Moisture content at for the first node toward the exterior in the sheathing board for various MDRY's for YVR

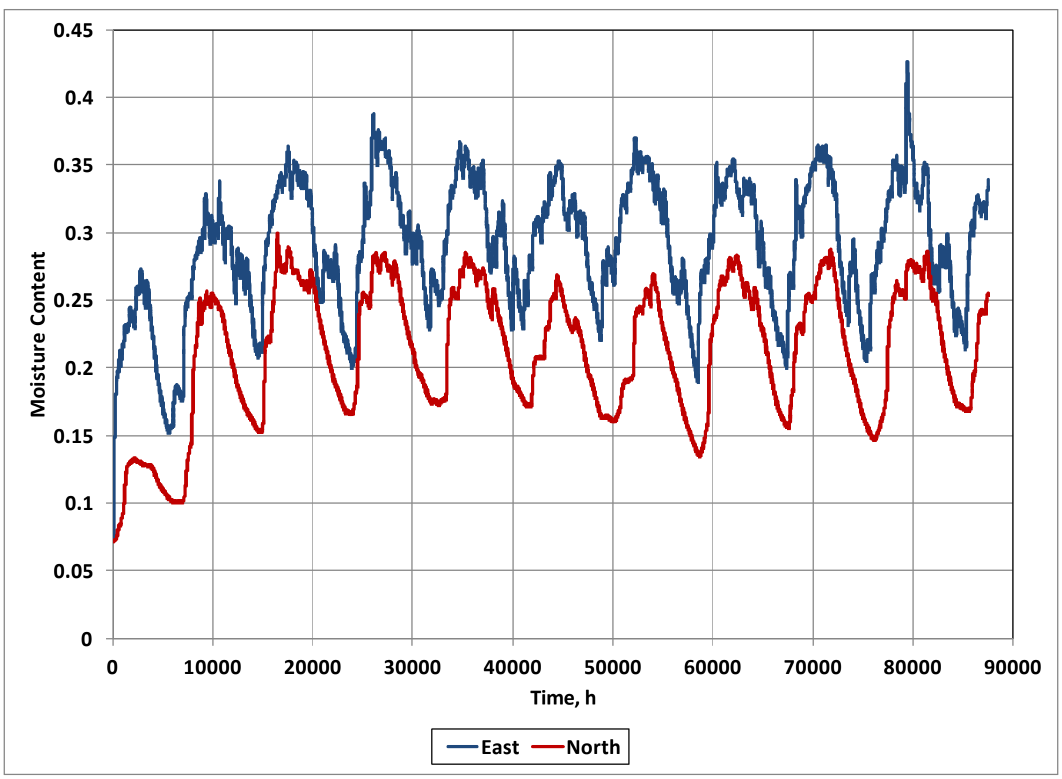


Figure 15 – 10-year simulation of a stucco wall without rain penetration from 1996 to 2005 in YVR showing moisture content of the first outboard node in the sheathing layer

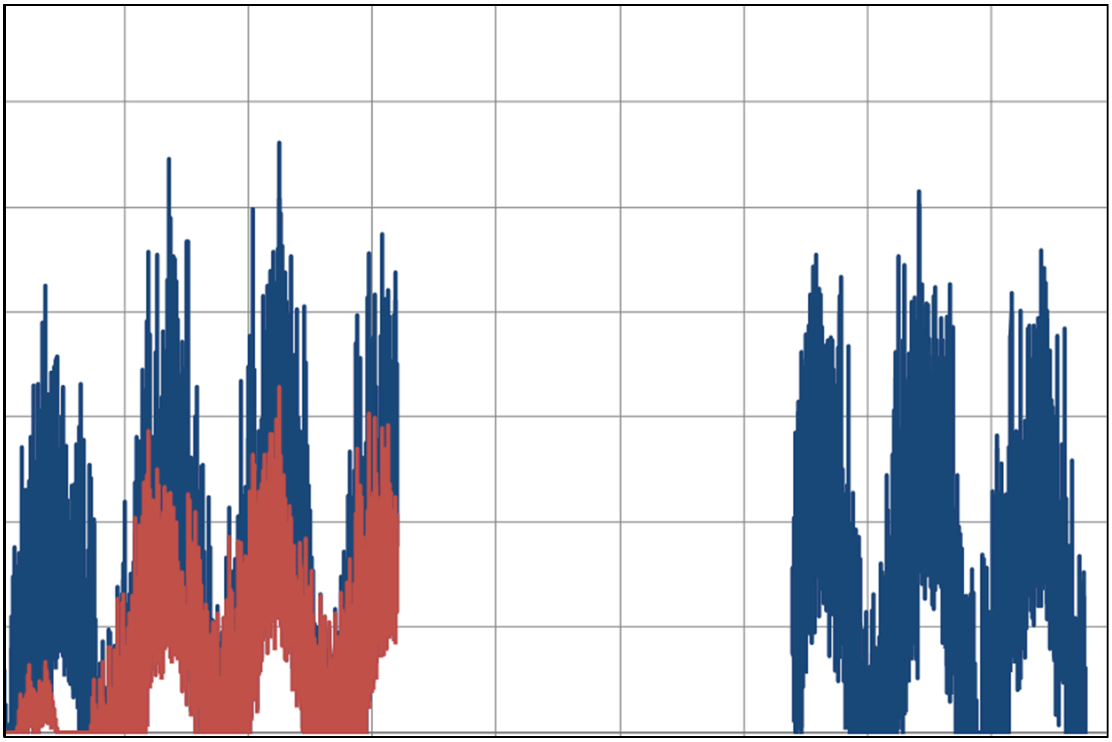


Figure 16 – 10-year simulation of a stucco wall without rain penetration from 1996 to 2005 in YVR showing RHT(80) of the first outboard node in the sheathing layer.

Appendix 1

EXCERPTS FROM THE 2005 CWEEDS USER'S MANUAL

CANADIAN WEATHER ENERGY AND ENGINEERING DATA SETS (CWEEDS FILES) and
CANADIAN WEATHER FOR ENERGY CALCULATIONS (CWEC FILES)
Revised on October 23, 2008

The background of the CWEEDS files
Climatic information related to solar irradiance for building and solar energy systems was provided by the 1985 Environment Canada publication Solar Radiation Data Analyses for Canada 1967-1976 (Volumes 1-6, Environment Canada, 1985). The increasing power, storage capacity, and cost-effectiveness of personal computers, accompanied by the sophistication of software used for building and energy system design has led to the requirement for ready access to long term hourly weather data sets. Environment Canada consulted with the user community in making decisions about the format and media used and obtained funding support from the Government of Canada Federal Panel on Energy Research and Development (PERD) to produce the CWEEDS files.

The format used for the CWEEDS files
The WYEC2 data format and units, described in Appendix A, was adopted for the CWEEDS files. WYEC2 (Weather Year for Energy Calculation, Version 2) has been devised by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) for providing WYEC2 data files for 76 cities including 5 in Canada (scheduled for release in June 1993). ASHRAE adapted the WYEC2 format from the TMY (Typical Meteorological Year) file format developed by Sandia National Laboratories in the US in the late 1970's.
Hour "1" of the WYEC2 format is 1:00 AM and hour "24" is midnight, local standard time, including solar irradiance and minutes of sunshine. (In the AES format, the hours for a day range from midnight to 23:00 [11 PM]. The hours for all the AES elements are local standard time except for hourly solar irradiance amounts and minutes of sunshine which are referenced to local apparent [solar] time.)

WYEC2 Format
Weather files in WYEC2 format consist of 8760 identical fixed format records (8784 records for leap years), one for each hour of each day of the year. Each record is 116 characters in length and is organized according to the table below. The flags associated with the data are described in the next section of the document.
All WYEC2 values are for Local Standard Time. Irradiance and illuminance fields contain data integrated over the hour, meteorological fields contain observations made at the end of the hour. For example, hour 12 contains irradiance/illuminance integrated from 11-12 and meteorological observations made at 12.

A file containing statistics about the radiation data is assembled. For this file the year is divided into four periods centered around March 21 ("spring"), June 21 ("summer"), September 21 ("autumn") and December 21 ("winter"). For each trimester the max and mean of global irradiance, diffuse irradiance and direct irradiance are computed for each hour of the day. The file contains a summary with five columns: element, trimester, hour, max value and min value.

Field Data Flag Data element and description
Number Positions Position Comments and warnings

001 001-005 -- WBAN station identification number

Unique alpha-numerical five-character string to identify each station.

002 006-006 -- File source code

A= AES Digital Archive of Canadian Climatological Data identified by element.

B= Canadian Reference Year for Energy Calculations (CWEC) file derived from a compilation of the above.

003 007-016 -- Time, Yr Mo Day Hr (Yr 4 chars, Mo Day Hr 2 chars each)

Mo is 1 to 12. Day is 1 to month length (28, 29, 30 or 31). Hr is 1 to 24.
1984051203 = 12 May 1984, 3 o'clock.

102 021-024 025-026 Global horizontal irradiance, kJ/m2

Total of direct and diffuse radiant energy received on a horizontal surface by a pyranometer during the hour ending at the time indicated in field 003. The values given in this field have been interpolated from Local Apparent Time to Local Standard Time but this is not reflected in the flags ("observed" values with a flag equal to blank are actually interpolated values).

103 027-030 031-032 Direct normal irradiance, kJ/m2

Portion of the radiant energy received by a pyranometer directly from the sun during the hour ending at the time indicated in field 003.

104 033-036 037-038 Diffuse horizontal irradiance, kJ/m2

Portion of the radiant energy received on a horizontal surface by a pyranometer indirectly from the sky during the hour ending at the time indicated in field 003. The values given in this field have been interpolated from Local Apparent Time to Local Standard Time but this is not reflected in the flags ("observed" values with a flag equal to blank are actually interpolated values).

204 077-084 085 Weather

Eight single digit codes as explained below.

204b 078 Occurrence of rain, rain showers or freezing rain

0 = None
1 = Light rain
2 = Moderate rain
3 = Heavy rain
4 = Light rain showers
5 = Moderate rain showers
6 = Heavy rain showers
7 = Light freezing rain
8 = Moderate or heavy freezing rain

If several phenomena occur simultaneously, the highest WYEC2 value is reported.

204c 079 Occurrence of drizzle, freezing drizzle

0 = None
1 = Light drizzle
2 = Moderate drizzle
3 = Heavy drizzle
4 = Light freezing drizzle
5 = Moderate freezing drizzle
6 = Heavy freezing drizzle

If several phenomena occur simultaneously, the highest WYEC2 value is reported.

205 086-090 091 Station pressure, 10 Pa
Pressure at station level 10150 = 101.5 kPa

206 092-095 096 Dry bulb temperature, 0.1°C
-152 = -15.2°C

207 097-100 101 Dew point temperature, 0.1°C
-152 = -15.2°C

208 102-104 105 Wind direction, 0-359 degrees
0 = north

209 106-109 110 Wind speed, 0.1 m/s
Wind speed and wind direction both 0 indicates calm.
350 = 35.0 m/s

210 111-112 113 Total sky cover, 0-10 in tenths
Amount of celestial dome in tenths covered by clouds or obscuring phenomena.

Flags
Flag characters indicate if the associated value is missing, was estimated or modelled or actually observed. Some fields have no flag, others have 1 or 2character flags as follows:

Field Flag type / comment
102-104 2 character (irradiance values)
105-212 1 character (all remaining fields)

1. One character flags. The following flags are used: blank Value was observed (that is, not derived with a model and not altered). Exception: irradiance and minutes of sunshine flags are written as blank though they are interpolated to change the time base from local apparent to local standard time.

A Value has been algorithmically adjusted (e.g. some values in Canadian Reference Years are smoothed at the beginning and end of months).

E Value was missing and has been replaced by a hand estimate.
I Value was missing and has been replaced with one derived by interpolation from neighbouring observations.
M Value was missing and has been replaced with one derived with a model (model used depends on element).
Q Value is derived from other values (e.g. illuminance data which are not observed).
9 Value is missing; data positions contain 9s as well.

2. Two character flags for radiation values (on WYEC2 irradiance fields 102,103 and 104), are a 1 character flag (as defined above) followed by a blank.

<u>List of locations provided on the AES CWEEDS CD-ROM's.</u>
STATION – is the name of the AES station corresponding to the RAD.CSN.

RAD.CSN – is the Canadian Station Number, an identification number assigned and used by AES, of the site where solar radiation is observed (it is not always the same site as where the other hourly observations are taken).
WX.CSN – is the Canadian Station Number, an identification number assigned and used by AES, of the site where the hourly observations other that solar irradiance and minutes of sunshine are taken.
LAT – is the latitude (°) of the site corresponding to RAD.CSN.
LONG – is the longitude (°) of the site corresponding to RAD.CSN.
MLONG – is the prime meridian (°) upon which the time zone is based. The difference in hours between Local Standard Time (LST) and Coordinated Universal Time (CUT) can obtained by the calculation LST = CUT - MLONG/15. For instance, if MLONG is 75°, and CUT is 11:00 then LST is 06:00.
SUN – indicates the source of the minutes of sunshine, if available. W indicates that the observations are from the site corresponding to WX.CSN. R indicates RAD.CSN. A blank means no observations of minutes of bright sunshine are available.
RAD – indicates by an R whether solar irradiance observations are available. A blank indicates no observations and all the irradiance fields are modelled.
FY – is the last two digits of the first year provided on the CWEEDS CD-ROM (i.e. 53 means 1953).
LY – is the last two digits of the last year on the CD-ROM.

STATION	WBAN	RAD.CSN	WX.CSN	LAT	LONG	MLONG	SUN	RAD	FY	LY	N
ALBERTA											
CALGARY INT'L. A	25110	3031093	3031093	51.1	114.02	105	W		53	5	53
COLD LAKE A	25129	3081680	3081680	54.42	110.28	105	W		54	5	52
CORONATION	25113	3011880	3011880	52.1	111.45	105	W		53	94	42
COWLEY A	CAN43	3031920	3031920	49.63	114.08	105			53	59	7
EDMONTON INT'L. A	25142	3012205	3012205	53.32	113.58	105	W		61	5	45
EDMONTON MUNICIPAL A	CAN98	3012208	3012208	53.57	113.52	105	W		53	4	52
EDMONTON NAMAO	CANA6	3012210	3012210	53.67	113.47	105			56	94	39
EDMONTON STONY PLAIN	25145	301222F	3012205	53.55	114.1	105	W	R	61	5	45
EDSON	CAN46	3062241	3062241	53.58	116.42	105	W		60	69	10
EDSON A	CAN47	3062244	3062244	53.58	116.47	105	W		71	90	20
FORT CHIPEWYAN A	CAN52	3072658	3072658	55.35	114.98	105			68	78	11
FORT MCMURRAY A	25105	3062693	3062693	56.65	111.22	105	W		53	5	53
GRANDE PRAIRIE A	25115	3072920	3072920	55.18	118.88	105	W		53	5	53
HIGH LEVEL A	CAN53	3073146	3073146	58.62	117.16	105	W		71	5	35
LAC LA BICHE	CAN48	3063680	3063680	54.77	111.97	105			53	57	5
LAC LA BICHE AUT	CAN49	3063685	3063685	54.77	112.02	105			59	70	12
LETHBRIDGE A	94108	3033880	3033880	49.63	112.8	105	W		53	5	53
LLOYDMINSTER	CAN42	3013961	3013961	53.31	110.07	105			83	5	23
MEDICINE HAT A	25118	3034480	3034480	50.02	110.72	105	W		53	5	53
PEACE RIVER A	25101	3075040	3075040	56.23	117.43	105			59	5	47
PINCHER CREEK	CAN44	3035201	3035201	49.5	113.95	105			61	73	13
RED DEER A	25119	3025480	3025480	52.18	113.9	105			53	5	53
ROCKY MTN. HOUSE	CAN05	3015520	3015520	52.38	114.92	105			53	77	25
SLAVE LAKE	CAN50	3066001	3066001	55.3	114.78	105			72	91	20
SPRINGBANK A	CAN45	303F0PP	303FOPP	51.1	114.37	105			89	1	13
VERMILION A	CAN04	3016800	3016800	53.35	110.83	105			53	81	29
WAGNER	CAN51	3066920	3066920	55.35	114.98	105			53	69	17
WHITECOURT	CAN03	3067370	3067370	54.13	115.67	105			53	77	25
BRITISH COLUMBIA											
ABBOTSFORD A	24288	1100030	1100030	49.02	122.37	120	W		53	5	53
BEATTON RIVER A	CAN26	1180750	1180750	57.38	121.28	120			53	66	14
CAPE ST. JAMES	25342	1051350	1051350	51.93	131.02	120	R	R	57	91	35
CASTLEGAR A	94110	1141455	1141455	49.3	117.63	120	W		54	5	52
COMOX A	24292	1021830	1021830	49.72	124.9	120	W		53	5	53
CRANBROOK A	94157	1152102	1152102	49.6	115.78	120	W		70	5	36
FORT NELSON A	25218	1192940	1192940	58.83	122.58	120	R	R	53	5	53
FORT ST. JOHN A	25231	1183000	1183000	56.23	120.73	120	W		53	5	53
KAMLOOPS A	25220	1163780	1163780	50.7	120.45	120	W		53	5	53
KELOWNA A	CAN22	1123970	1123970	49.96	119.38	120	W		70	76	7
KIMBERLEY A	CAN25	1154200	1154200	49.73	115.78	120			53	68	16

LYTTON	CAN21	1114740	1114740	50.23	121.5	120	W		53	69	17
NANAIMO A	CAN20	1025370	1025370	49.05	123.87	120	W		54	67	14
OLD GLORY MOUNTAIN	CAN97	1145730	1145730	49.15	117.92	120			55	67	13
PENTICTON A	94116	1126150	1126150	49.47	119.6	120	W		53	5	53
PORT HARDY A	25223	1026270	1026270	50.68	127.37	120	R	R	53	5	53
PRINCE GEORGE A	25206	1096450	1096450	53.88	122.67	120	R	R	53	5	53
PRINCE RUPERT A	25353	1066481	1066481	54.3	130.43	120	W		61	5	45
PRINCETON A	CAN23	1126510	1126510	49.47	120.51	120	W		53	68	16
QUESNEL A	25224	1096630	1096630	53.03	122.52	120			53	5	53
SANDSPIT A	25346	1057050	1057050	53.25	131.82	120	R	R	53	5	53
SMITHERS A	25225	1077500	1077500	54.82	127.18	120	W		53	5	53
SMITH RIVER A	CAN27	1197530	1197530	59.9	126.43	120			53	68	16
SPRING ISLAND	CAN09	1037650	1037650	50	127.42	120			53	79	27
SUMMERLAND CDA	94152	1127800	1126150	49.57	119.65	120	R	R	53	5	53
TERRACE A	25229	1068130	1068130	54.47	128.58	120	W		55	5	51
TOFINO A	94234	1038205	1038205	49.08	125.77	120	W		60	5	46
VANCOUVER INT'L.	24287	1108447	1108447	49.25	123.25	120	W		53	5	53
VANCOUVER UBC	94238	1108487	1108447	49.25	123.25	120	R	R	53	5	53
VICTORIA GONZALES HTS	CAN18	1018610	1018610	48.42	123.32	120	W		53	67	15
VICTORIA INT'L. A	24297	1018620	1018620	48.65	123.43	120	W		53	5	53
VICTORIA MARINE	CAN19	1018642	1018642	48.65	123.43	120			70	83	14
WILLIAMS LAKE A	25247	1098940	1098940	52.18	122.07	120	W		61	5	45
MANITOBA											
BRANDON A	14997	5010480	5010480	49.92	99.95	90	W		59	5	47
CHURCHILL A	15901	5060600	5060600	58.75	94.07	90	R	R	53	5	53
DAUPHIN A	25009	5040680	5040680	51.1	100.05	90	W		55	5	51
GIMLI	CAN96	5031038	5031038	50.63	97.02	90	W		72	90	19
GIMLI A	CAN63	5031040	5031040	50.63	97.05	90			53	71	19
ISLAND LAKE	CAN60	5061376	5061376	53.85	94.65	90			87	5	19
LYNN LAKE	CAN61	5061646	5061646	53.86	101.08	90	W		70	4	35
NORWAY HOUSE	CAN62	506B047	506B047	53.95	97.85	90			75	4	30
PORTAGE LA PRAIRIE A	94912	5012320	5012320	49.9	98.27	90			53	5	53
RIVERS	CAN59	5012440	5012440	50.02	100.32	90	W		53	69	17
THE PAS A	25004	5052880	5052880	53.97	101.1	90	R	R	53	5	53
THOMPSON A	15919	5062922	5062922	55.8	97.87	90	W		68	5	38
WINNIPEG INT'L. A	14996	5023222	5023222	49.9	97.23	90	R	R	53	5	53
NEW BRUNSWICK											
CAMPBELLTON	CAN76	8100700	8100700	48	66.67	60	W		53	66	14
CHARLO A	14683	8100880	8100880	48	66.33	60	W		67	90	24
FREDERICTON CDA	14670	8101600	8101500	45.92	66.62	60	R	R	53	5	53
MIRAMICHI A	14631	8101000	8101000	47.02	65.45	60	W		53	5	53
MONCTON A	14625	8103200	8103200	46.12	64.68	60	W		53	5	53
SAINT JOHN A	14643	8104900	8104900	45.32	65.88	60	W		53	5	53
ST LEONARD	CAN78	8104928	8104928	47.16	67.83	60	W		86	94	9
NEWFOUNDLAND											
ARGENTIA A	CAN85	8400100	8400100	47.3	54	60			53	69	17
BATTLE HARBOUR	CAN06	8500398	8500398	52.25	55.6	60			57	83	27
BONAVISTA	14522	8400600	8400600	48.7	53.08	60			60	94	35
BUCHANS A	CAN87	8400700	8400700	48.85	56.83	60			53	64	12
BURGEO	CAN88	8400798	8400798	47.62	57.62	60	W		67	90	24
CAPE HARRISON	CAN95	8500900	8500900	54.77	58.45	60			53	59	7
CARTWRIGHT	15503	8501100	8501100	53.7	57.03	60	W		64	5	42
CHURCHILL FALLS A	CAN83	8501132	8501132	53.55	64.1	60	W		69	92	24
COMFORT COVE	CAN89	8400798	8400798	49.27	54.88	60			67	82	16
DANIELS HARBOUR	15504	8401400	8401400	50.23	57.58	60	W		66	87	22
DEER LAKE A	14523	8401501	8401501	49.22	57.4	60			66	5	40
GANDER INT'L. A	14509	8401700	8401700	48.95	54.57	60	W		53	5	53
GOOSE UA	15601	8501910	8501900	53.32	60.37	60	W	R	53	5	53
HOPEDALE	15642	8502400	8502400	55.45	60.23	60			64	83	20
PORT AUX BASQUES	CAN90	8402975	8402975	47.57	59.15	60			67	91	25
ST. ANDREWS	CAN91	8403300	8403300	47.77	59.33	60			53	65	13
ST. ANTHONY	CAN92	8403400	8403400	51.37	55.58	60			53	65	13
ST. JOHN'S A	14506	8403506	8403506	47.62	52.75	60	W		53	5	53
ST. JOHN'S WEST CDA	14521	8403600	8403506	47.52	52.78	60	R	R	53	5	53
STEPHENVILLE A	14503	8403800	8403800	48.53	58.55	60	W		54	5	52
TWILLINGATE	CAN94	8404000	8404000	49.67	54.82	60			54	66	13
WABUSH LAKE A	15628	8504175	8504175	52.93	66.87	60	W		61	5	45
NWT											
CAPE PARRY A	27202	2200675	2200675	70.17	124.68	105			57	5	49
FORT RELIANCE	CAN32	2201900	2201900	62.72	109.17	105			69	90	22

FORT RESOLUTION A	CAN33	2202000	2202000	61.28	113.69	105			60	69	10
FORT SIMPSON	CAN34	2202100	2202100	61.87	121.35	120	W		56	62	7
FORT SIMPSON A	CAN35	2202101	2202101	61.76	121.24	120	W		64	5	42
FORT SMITH A	26102	2202200	2202200	60.02	111.97	105	W		53	5	53
HAY RIVER A	CAN36	2202400	2202400	60.84	115.78	105			53	5	53
INUVIK UA	22258	2202582	2202570	68.32	133.53	105	R	R	58	5	48
NORMAN WELLS A	26202	2202800	2202800	65.28	126.8	105	R	R	56	5	50
SACHS HARBOUR A	CAN41	2503650	2503650	72	125.27	105			71	76	6
YELLOWKNIFE A	26110	2204100	2204100	62.47	114.45	105	W		53	5	53
NOVA SCOTIA											
COPPER LAKE	CAN79	8201100	8201100	45.38	61.97	60	W		53	61	9
DEBERT	CAN80	8201400	8201400	45.42	63.45	60			53	60	8
EDDY POINT	CAN81	8201716	8201716	45.52	61.25	60	W		72	84	13
GREENWOOD A	14636	8202000	8202000	44.98	64.92	60			53	5	53
HALIFAX	CAN82	8202200	8202200	44.65	63.57	60	W		53	62	10
HALIFAX INT'L. A	14673	8202250	8202250	44.88	63.52	60			61	5	45
SABLE ISLAND	14642	8204700	8204700	43.93	60.02	60	R	R	56	91	36
SHEARWATER A	14633	8205090	8205090	44.63	63.5	60	W		53	5	53
SHELBURNE	CAN84	8205126	8205126	43.72	65.25	60	W		82	86	5
SYDNEY A	14646	8205700	8205700	46.17	60.05	60	W		53	5	53
TRURO	14675	8205990	8205990	45.37	63.27	60	W		61	76	16
YARMOUTH A	14647	8206500	8206500	43.83	66.08	60	W		53	5	53
NUNAVUT											
ALERT	CANA4	2400300	2400300	82.5	62.33	60			64	5	42
BAKER LAKE	16903	2300500	2300500	64.3	96	90	R	R	63	5	43
CAMBRIDGE BAY A	26005	2400600	2400600	69.1	105.12	105	R	R	56	5	50
CAPE DYER	CAN39	2400654	2400654	66.58	61.62	60			60	89	30
CHESTERFIELD	16914	2300700	2300700	63.33	90.72	90			63	67	5
CLYDE	CAN93	2400800	2400800	70.49	68.52	75			85	93	9
COPPERMINE	CAN69	2300900	2300900	67.83	115.14	105	W		70	77	8
CORAL HARBOUR A	16801	2301000	2301000	64.2	83.37	75	R	R	56	5	50
ENNADAI	CAN37	2301100	2301100	61.13	100.9	90			56	69	14
EUREKA	CANA5	2401200	2401200	80	85.93	75	W	R	82	5	24
HALL BEACH A	16895	2402350	2402350	68.78	81.25	75		R	59	5	47
ISACHSEN	CANA7	2402600	2402600	78.78	103.53	105			70	78	9
IQALUIT A	16603	2402590	2402590	63.75	68.55	75	W		53	5	53
KUGLUKTUK A	CAN86	2300902	2300902	67.82	115.14	105	W		80	5	26
RANKIN INLET A	CAN38	2303401	2303401	62.82	92.1	90			81	5	25
REA POINT	CAN40	2403450	2403450	75.37	105.72	105			72	76	5
RESOLUTE	17901	2403500	2403500	74.72	94.98	90	R	R	63	5	43
ONTARIO											
ARMSTRONG A	CAN08	6040325	6040325	50.28	88.9	75	W		53	67	15
ATIKOKAN	94932	6020379	6020379	48.75	91.62	75	W		67	88	22
BIG TROUT LAKE	15806	6010738	6010738	53.83	89.87	90	R	R	67	90	24
BUTTONVILLE	CAN17	615HMAK	615HMAK	43.87	79.37	75			87	5	19
CHAPLEAU	CAN67	6061358	6061358	47.83	83.43	75			66	75	10
EARLTON A	94797	6072225	6072225	47.7	79.85	75			53	5	53
GERALDTON	CAN10	6042715	6042715	49.7	86.95	75			68	76	9
GORE BAY A	94803	6092925	6092925	45.88	82.57	75			55	5	51
GRAHAM A	CAN64	6042975	6042975	49.27	90.58	75			53	66	14
HAMILTON A	4797	6153194	6153194	43.25	79.93	75			70	5	36
KAPUSKASING A	14899	6073975	6073975	49.42	82.47	75		R	53	5	53
KENORA A	14999	6034075	6034075	49.8	94.37	90			53	5	53
KINGSTON A	CAN15	6104146	6404146	44.22	76.6	75	W		70	94	25
KILLALOE	CAN68	6104125	6104215	45.57	77.42	75			53	71	19
LONDON A	94805	6144475	6144475	43.03	81.15	75	W		55	5	51
MOOSONEE	CANA1	6075425	6075425	51.27	80.65	75	W		57	93	37
MOUNT FOREST	94857	6145503	6145503	43.98	80.75	75	W		62	86	25
MUSKOKA A	4704	6115525	6115525	44.97	79.3	75			55	5	51
NAKINA A	CAN65	6045550	6045550	50.18	86.7	75			53	66	14
NORTH BAY A	4705	6085700	6085700	46.37	79.42	75	W		53	5	53
OTTAWA CDA	CAN14	6105976	6106000	45.38	75.72	75	R	R	53	5	53
OTTAWA NRC	4772	6106090	6106000	45.45	75.62	75	W	R	53	5	53
PETAWAWA A	CAN70	6106398	6106398	45.95	77.32	75			72	92	21
PETERBOROUGH A	CAN99	6166418	6166418	44.23	78.35	75			96	4	9
SAULT STE. MARIE A	94842	6057592	6057592	46.48	84.5	75	W		62	5	44
SIMCOE	94858	6137730	6137730	42.85	80.27	75			62	76	15
SIOUX LOOKOUT A	15909	6037775	6037775	50.12	91.9	90			53	5	53
ST. CATHERINES A	CAN16	6137287	6137287	43.2	79.17	75			72	5	34
STIRLING	CAN71	6158050	6158050	44.32	77.63	75			53	68	16

SUDBURY A	94828	6068150	6068150	46.62	80.8	75	W		54	5	52
THUNDER BAY A	94804	6048261	6048261	48.37	89.32	75	W		53	5	53
TIMMINS A	94831	6078285	6078285	48.57	81.37	75			55	5	51
TORONTO	4714	6158350	6158733	43.67	79.38	75	R	R	55	5	51
TORONTO DOWNSVIEW A	CAN72	6158443	6158443	43.75	79.48	75			58	64	7
TORONTO ISLAND A	CANA2	6158665	6158665	43.63	79.4	75			61	5	45
TORONTO MET RES STN	4795	6158740	6158733	43.8	79.55	75	R	R	53	5	53
TORONTO PEARSON INT'L	94791	6158733	6158733	43.67	79.63	75			53	5	53
TRENTON A	4715	6158875	6158875	44.12	77.53	75			53	5	53
WHITE RIVER	CAN66	6059475	6059475	48.6	85.28	75	W		53	75	23
WIARTON A	94809	6119500	6119500	44.75	81.1	75	W		53	5	53
WINDSOR A	94810	6139525	6139525	42.27	82.97	75			53	5	53
PEI											
CHARLOTTETOWN CDA	14688	8300400	8300300	46.25	63.13	60	R	R	53	5	53
SUMMERSIDE A	14645	8300700	8300700	46.43	63.83	60	W		53	90	38
QUEBEC											
BAGOTVILLE A	94795	7060400	7060400	48.33	71	75			53	5	53
BAIE COMEAU A	14627	7040440	7040440	49.13	68.2	75	W		65	4	40
CHIBOUGAMAU A	CAN74	7091401	7091401	49.82	74.42	75	W		72	81	10
CHIBOUGAMAU CHAPAIS	CAN75	7091404	7091404	49.77	74.53	75	W		83	91	9
GASPE A	CAN73	7052605	7052605	48.78	64.48	60	W		77	5	29
GRINDSTONE ISLAND	CAN13	7052960	7052960	47.38	61.87	60	W		69	82	14
KUUJJUARAPIK A	15701	7103536	7103536	55.28	77.77	75	W		53	5	53
KUUJUAQ A	15605	7113534	7113534	58.1	68.42	75	R	R	55	5	51
LA GRANDE IV A	CANA8	7093GJ3	7093GJ3	53.75	73.67	75	W		86	91	6
LA GRANDE RIVIERE A	73715	7093715	7093715	53.63	77.7	75	W		76	5	30
LAKE EON A	CAN07	7043740	7043740	51.87	63.28	75			56	76	21
MONT JOLI A	14639	7055120	7055120	48.6	68.2	75	W		53	5	53
MONTREAL INT'L. A	94792	7025250	7025250	45.47	73.75	75	R	R	53	5	53
MONTREAL JEAN BREBEUF	4770	7025260	7025250	45.5	73.62	75	R/W	R	53	5	53
MONTREAL MIRABEL A	75290	7035290	7035290	45.68	74.03	75	W		76	5	30
NITCHEQUON	15703	7095480	7095480	53.2	70.9	75	R	R	59	85	27
QUEBEC A	4708	7016294	7016294	46.8	71.38	75	W		53	5	53
RIVIERE DU LOUP	CAN12	7056615	7056615	47.8	69.55	75			66	79	14
ROBERVAL A	4752	7066685	7066685	48.52	72.27	75	W		58	5	48
SCHEFFERVILLE A	15619	7117825	7117825	54.8	66.82	75	R	R	62	93	32
SEPT-ILES UA	77912	7047912	7047910	50.22	66.25	75	R	R	53	5	53
SHERBROOKE A	4785	7028124	7028124	45.43	71.68	75	W		63	94	32
ST. HUBERT A	4712	7027320	7027320	45.52	73.42	75			53	5	53
STE. AGATHE DES MONTS	4790	7036762	7036762	46.05	74.28	75	W		67	91	25
VAL D'OR A	4730	7098600	7098600	48.05	77.78	75	W		55	5	51
SASKATCHEWAN											
BROADVIEW	25030	4010879	4010879	50.38	102.55	90	W		65	5	41
COLLINS BAY	CANA3	4061630	4061630	58.17	103.7	105			72	90	19
ESTEVAN A	24092	4012400	4012400	49.07	103	90	W		53	5	53
HUDSON BAY	CAN57	4083320	4083320	52.87	102.4	90			54	73	20
KINDERSLEY	CAN54	4043900	4043900	51.52	109.48	90	W		86	5	20
LA RONGE	CAN55	4064150	4064150	55.15	105.27	90			77	5	29
MOOSE JAW A	25018	4015320	4015320	50.33	105.55	90	W		54	5	52
NORTH BATTLEFORD A	25012	4045600	4045600	52.77	108.25	90	W		53	5	53
PRINCE ALBERT A	25013	4056240	4056240	53.22	105.68	90	W		53	5	53
REGINA A	25005	4016560	4016560	50.43	104.67	90	W		53	5	53
SASKATOON	25015	4057120	4057120	52.17	106.68	90			53	5	53
STONY RAPIDS A	CAN56	4067PR5	4067PR5	59.25	105.83	90			87	5	19
SWIFT CURRENT CDA	25028	4028060	4028040	50.27	107.73	105	W/R	R	55	5	51
URANIUM CITY A	CAN02	4068340	4068340	59.57	108.48	105			63	82	20
WYNYARD	25029	4019035	4019035	51.77	104.2	90	W		65	88	24
YORKTON A	25017	4019080	4019080	51.27	102.47	90	W		53	5	53
YUKON TERRITORY											
BURWASH A	26325	2100182	2100182	61.37	140.05	120			67	86	20
DAWSON	CAN58	2100400	2100400	64.05	139.43	120			60	75	16
DAWSON A	CAN24	2100402	2100402	64.04	139.13	120			76	87	12
MAYO	CAN28	2100700	2100700	63.62	135.87	120			74	5	32
SNAG A	CAN29	2101000	2101000	62.37	140.4	120			53	65	13
TESLIN A	CAN30	2101100	2101100	60.17	132.74	120			55	5	51
WATSON LAKE	CAN31	2101200	2101200	60.12	128.82	120	W		53	92	40
WHITEHORSE A	26316	2101300	2101300	60.72	135.07	120	R	R	53	5	53

Appendix 2

PREPARATION AND QUALITY CONTROL OF CLIMATE DATA

Interpolation and Filling of Missing Data

Although some weather data sets claim to be fully populated, i.e. they do not contain any blanks, nevertheless, there can be missing values, usually entered as a series of 9's coupled with an alphanumeric code "9" in the element flag position. The number of missing elements is usually recorded in the metadata file for a given location.

The first pass for quality control consisted of filling in missing data in the data sets. If all the missing data gaps are filled then the data were sent through a second pass which checked for out of range parameters or outliers. In some instances however there were gaps which were considered too large to be filled using automated techniques. Every year which has more than 168 consecutive hours of missing data for dry bulb, dew point, wind speed, was flagged and dealt with manually. This presumes that years with large amounts of missing data have already been excluded. If a data gap was too large then the year was excluded. The criteria for rejecting years were based on two tests; an absolute threshold and the longest streak of missing values. If more than 5800 records from a given year were missing then the year was rejected; this equivalent to having a reading once every 3 hours. Finally if more than 744 records were missing in sequence from a year the year was rejected; this represents a month of missing data. The key parameters checked were wind speed and direction, dry bulb temperature, and the present weather condition. Occasionally there was a gap in solar irradiance. Generally small gaps in solar data can be handled by linear interpolation while large gaps can be filled in using a solar model. The solar model used however was dependent on other climate parameters, such as cloud cover, which could not be missing in order to run the solar model. Consequently a final pass was used to fill in missing solar data. Finally the data were converted into simulation/load input files appropriate for the project. Most of the data filling methods outlined below were taken from three sources: Huang [5] and, Baltazar and Claridge D [6; 7]

<u>Dry Bulb and Dew Point Temperatures</u>
To interpolate for missing dry-bulb and dew point temperatures linear interpolation was used if the gap was less than 8 hours. If the gap was greater than 8 hours, they it was filled by repeating the temperatures at the same hours the previous day, but with the beginning and end hours of the gap linearly interpolated to match the observed value. If more than 168 consecutive hours of missing data the data was flagged and dealt with manually, usually by copying sequences of data from other portions of the weather record.

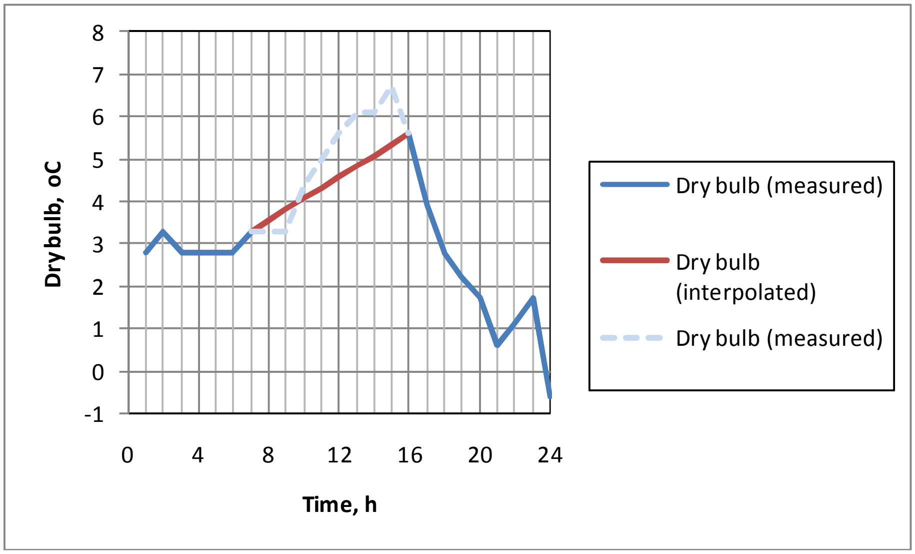


Figure A2.2 Linear interpolation for small gaps in dry bulb and dew point temperatures.

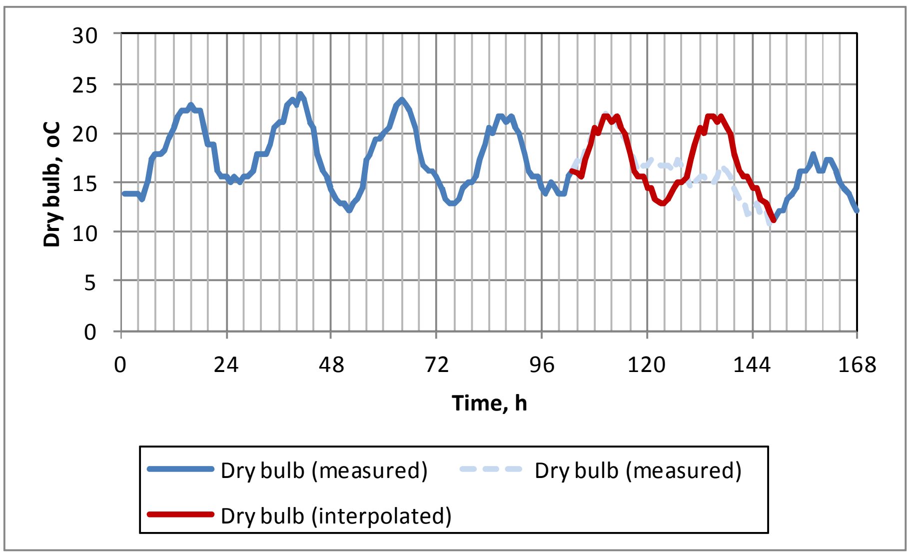


Figure A2.3 Data filling for medium gaps in dry bulb and dew point temperatures.

Pressure

The CWEEDS and ISH databases report station pressure or sea level pressure for a location. To fill in missing pressure readings linear interpolation was used if the gap is less than 24 hours. If the gap was greater than 24 hours, they were filled by repeating the pressure at the same hours the previous day, but with the beginning and end hours of the gap linearly interpolated to match the observed value. If weather files contain no or very infrequent recordings of pressure then a constant mean sea level pressure of 1013.25 millibars was used, interpolating between the first and last filled values and first and last measured values. If the sea level pressure was reported the station pressure was calculated using the following equation [21]:

$$station\ pressure = sea\ level\ pressure\ e^{-elevation/(29.263\ temp)}$$

Where: *station Pressure* = barometric pressure in millibars (1 mbar = 1 hPa = 100 Pa)
sea level Pressure = reported pressure at sea level in millibars
elevation = station elevation in meters (available from station metadata)
temp = current temperature in Kelvin (0 K = -273.15°C)

Note that CWEEDS data set reports station pressure.

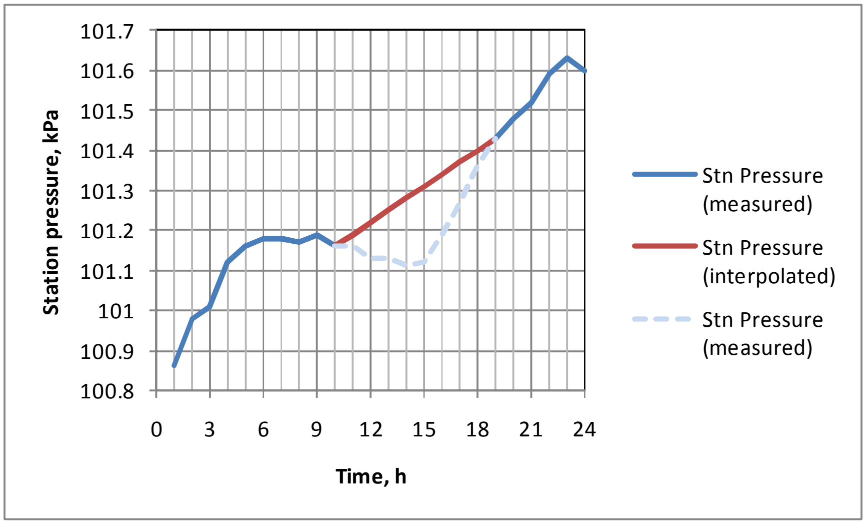


Figure A2.4 Linear interpolation for small gaps in station pressure.

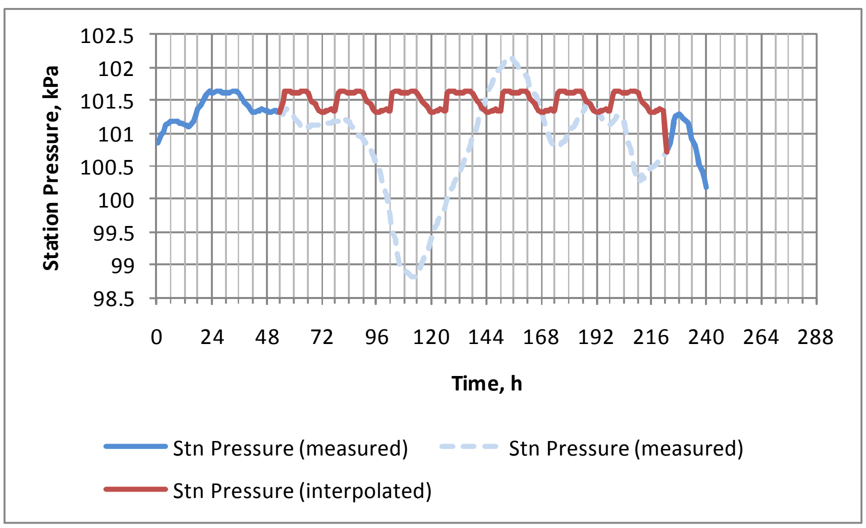


Figure A2.5 Data filling by copying for medium gaps in station pressure.

[21] Sandhurst 2009. Sandhurst Weather Royal County of Berkshire UK Web site http://www.sandhurstweather.org.uk/barometric.pdf

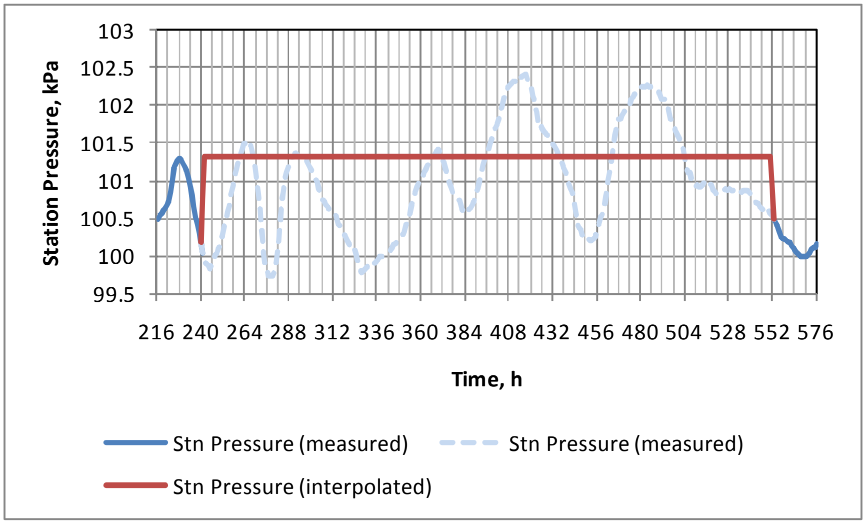


Figure A2.6 Constant filling for large gaps in station pressure.

Wind Speed

To interpolate for missing wind speed linear interpolation was used if the gap was less than or equal to 24 hours. If the gap is greater than 24 hours, they were filled by repeating the wind speed at the same hours the previous day, but with the beginning and end hours of the gap linearly interpolated to match the observed value. If more than 168 consecutive hours of missing data the data was flagged and dealt with manually. The method will be outlined below.

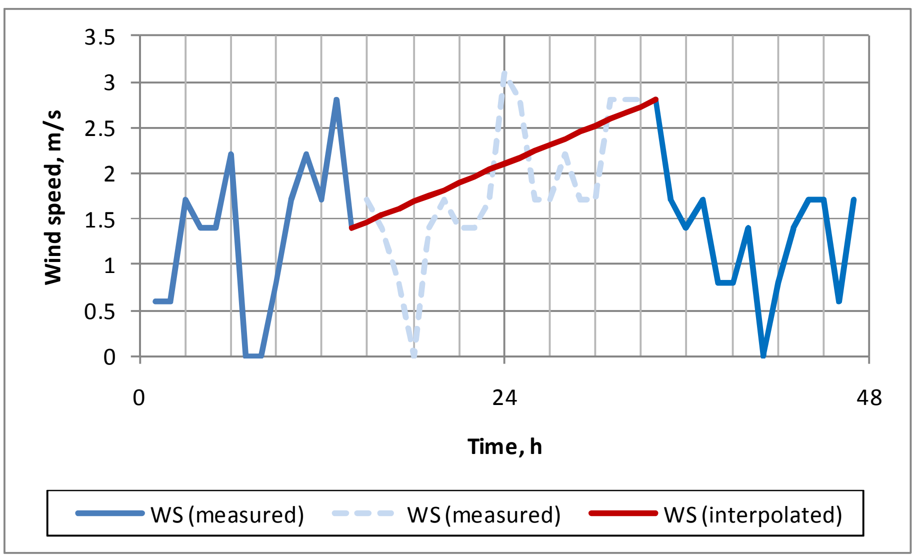


Figure A2.7 Linear interpolation for small gaps in wind speed.

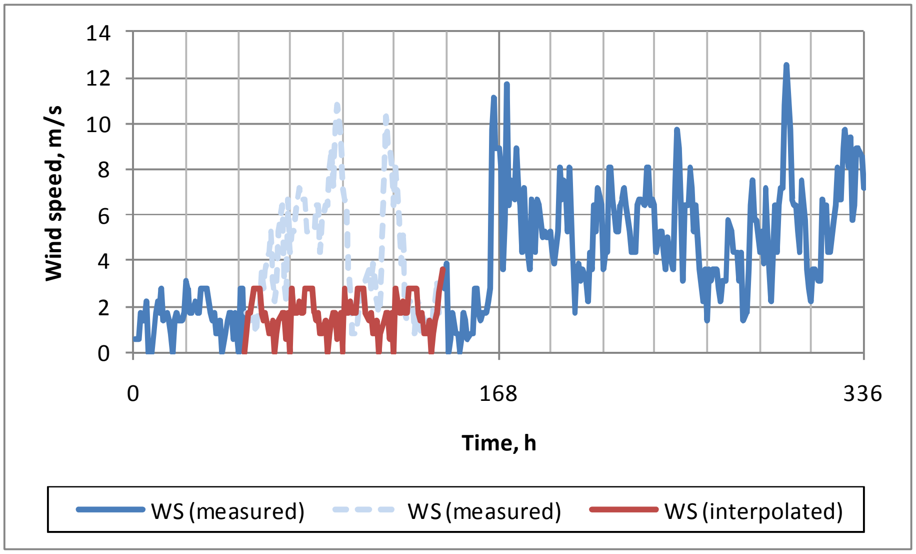


Figure A2.8 Data filling by copying for medium gaps in wind speed.

Dealing with large tracts of missing wind data

The method for dealing with large amounts of missing wind speed data was to generate random numbers that correspond to the long-term wind speed distribution. The distribution fitted to the wind data was a two-parameter Weibull distribution, defined below:

$$f(x) = \frac{\gamma}{\alpha^{\gamma}}(x)^{(\gamma-1)}\,e^{-(x/\alpha)^{\gamma}}$$

γ is the shape parameter and α is the scale parameter. The parameters were solved directly or estimated by linearizing the cumulative distribution function and performing a rank regression on the Y parameter. Once the distribution parameters have been estimated random wind speeds were generated by calculating the percentage point function for a random number, p, with a uniform distribution between 0 and 1. The percentage point function is defined below:

$$G(p) = \alpha(-\ln(1-p))^{1/\gamma}$$

There is an issue with this approach. The method does not duplicate runs of wind speed but merely generates random values according to the distribution parameters.

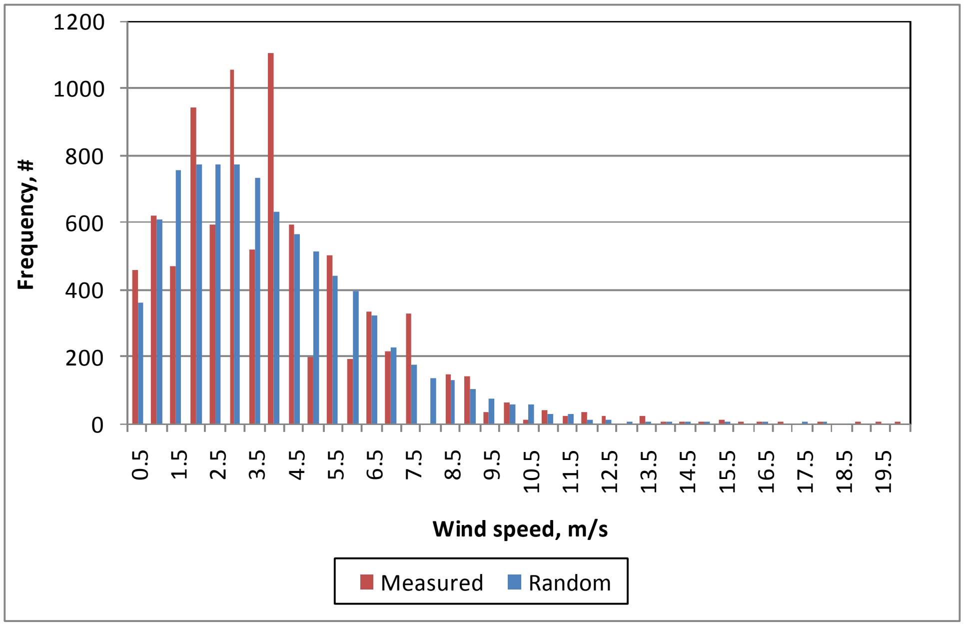


Figure A2.9 Measured data fitted to a 2-parameter Weibull distribution.

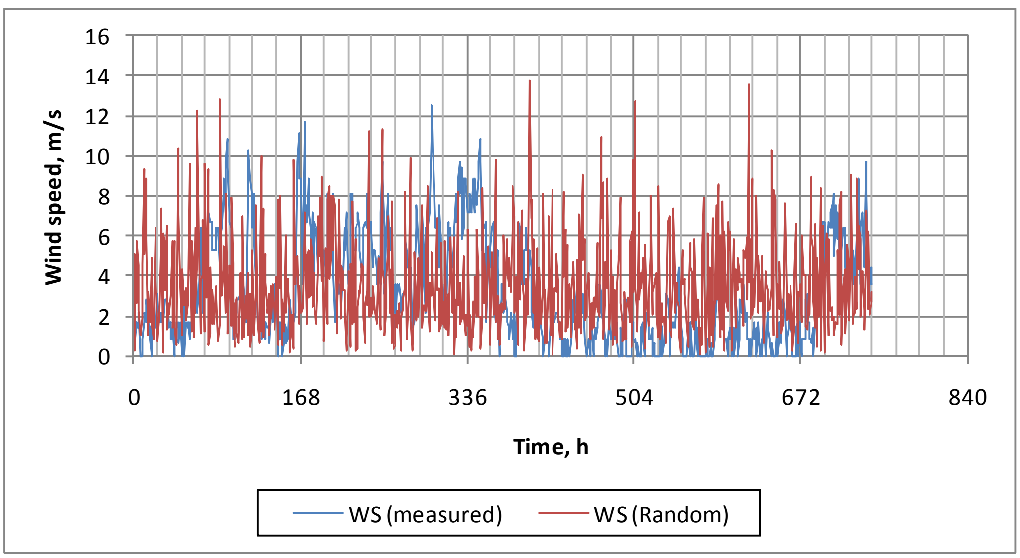


Figure A2.10 Stochastic method for filling large gaps in wind speed.

Wind Direction

There was no reliable way to fill in missing wind direction values. Huang in the final report to 1477-RP used a step function method to fill in missing wind direction data. The last observed wind direction is repeated for the first half of the gap, and the next observed wind direction was repeated for the second half of the missing hours.

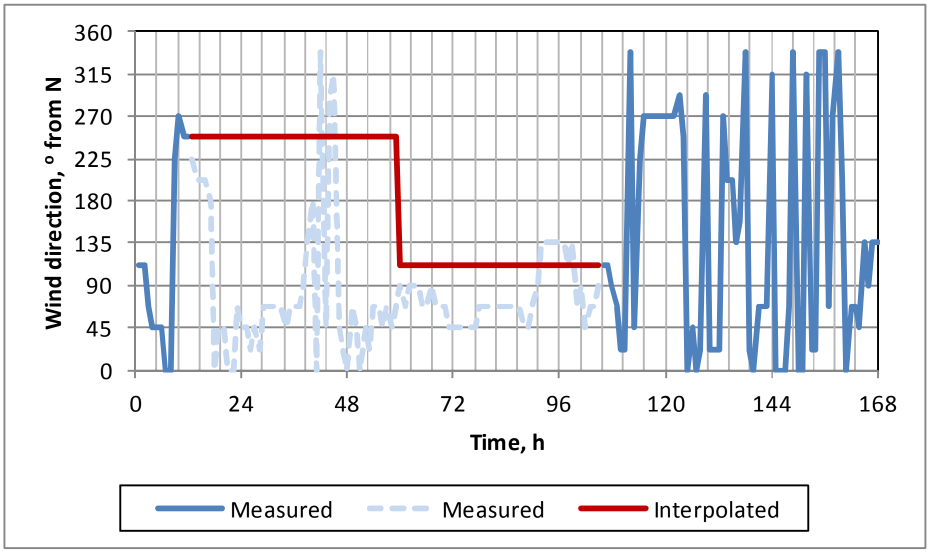


Figure A2.11 Step function method for filling small to medium gaps in wind direction.

If there were sufficient historical data regarding wind direction then a stochastic method biased towards the prevailing wind direction, during the occurrence of rain and during occurrence of no rain, was used to fill long gaps of 168 hours or more. Given the probability of occurrence for a specific direction it was possible to construct a look up table to model the cumulative distribution function. By matching uniformly generated random numbers to the corresponding cumulative distribution function and using the lookup table value it was possible to assign a wind direction to the number. If there was a significant difference between wind direction during rain and during dry periods then separate lookup tables were constructed. If there was information for the hour regarding the occurrence of rain then the table for wind direction during rain was used; otherwise the table for all events was used.

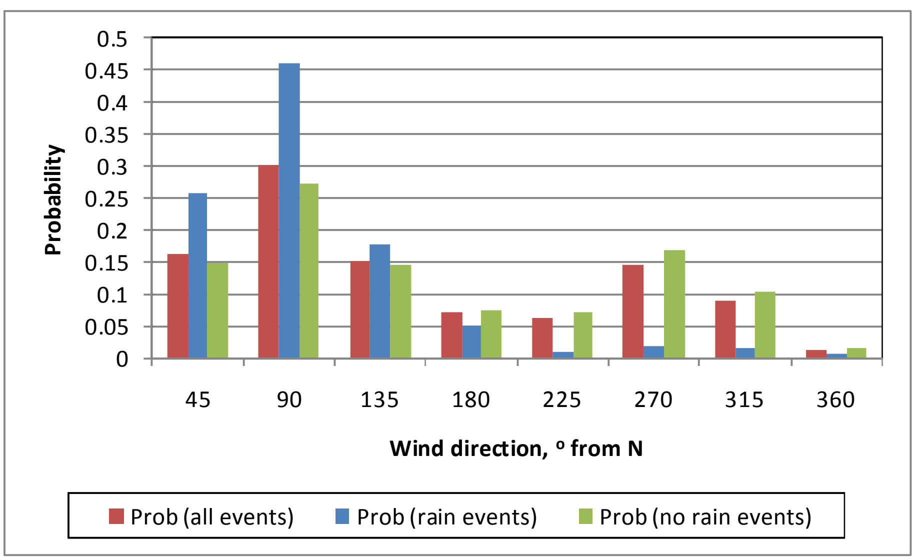


Figure A2.12 Distribution of wind direction during rain, during dry periods, and all hours.

Table A2.1 Example of a lookup table for all directions

Direction	Frequency	PDF (all hours)	CDF (all hours)
0	0	0	0
45	1366	0.16	0.16
90	2500	0.3	0.47
135	1258	0.15	0.62
180	589	0.07	0.69
225	517	0.06	0.75
270	1206	0.15	0.9
315	747	0.09	0.99
360	116	0.01	1

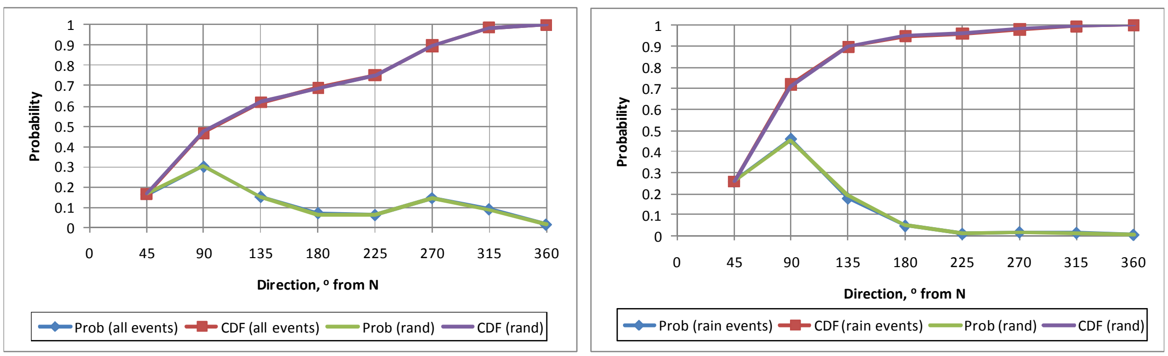


Figure A2.13 Distribution of wind direction during all hours and rain, observed vs. random.

There was a further possibility of relating the wind direction to the time of day and time of season by constructing monthly and hourly tables. The extra effort in obtaining a higher degree of verisimilitude was not justified in this instance given the uncertainty in other the weather parameters. The method does not duplicate runs of wind direction but merely generates random values according to the distribution parameters.

Total Sky Cover

Values for Total Sky Cover when missing were linearly approximated for short gaps, less than or equal 24 hours. For long gaps values were assigned by 1) tabulating the probability and CDF for each value of the cloud index using the same method as for wind direction, 2) generating a uniform random number between 0 and 1, and 3) assigning the corresponding Total Sky Cover using a lookup table method as for wind direction. The method does not duplicate long clear or cloudy periods but merely generates random values according to the distribution parameters.

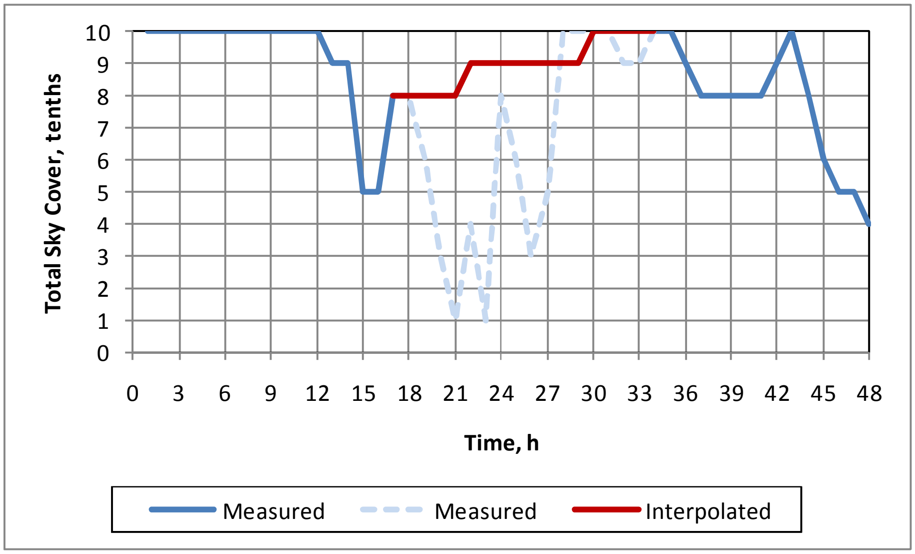


Figure A2.15 Linear interpolation method for filling small gaps in Total Sky Cover.

<u>Rain</u>

CWEEDS: Present weather – rain is derived from the CWEEDS file from the present weather codes; i.e there was no hourly perception total in the CWEEDS files (see section on generating rain data from CWEEDS files below). A step function where the last observed present weather was repeated for the first half of the missing hours, and the next observed present weather value was repeated for the second half of the missing hours was used for filling missing present weather values. This procedure was not used for a gap of more than 8 hours however. For gaps longer than 8 hours the missing data was filled in with zeros; i.e. no precipitation. The 8-hour limit was based on the assumption that the average length of system or rain event is approximately 8 hours.

ISD: The ISD weather data contains both present weather observations and hourly rainfall totals. A similar procedure was used for the ISD as the CWEEDS data, except that the hourly values in the ISD data sets record the total amount of precipitation at the end of a period of accumulation. The present weather codes must then be used to 1) distinguish between solid and liquid precipitation, and 2) spread the rainfall totals over the period of the event to recover the time-series rainfall event.

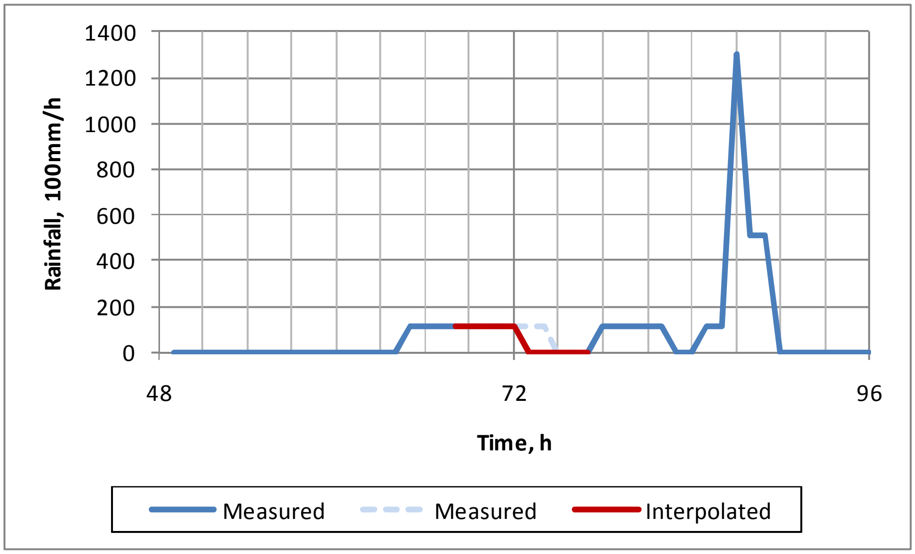


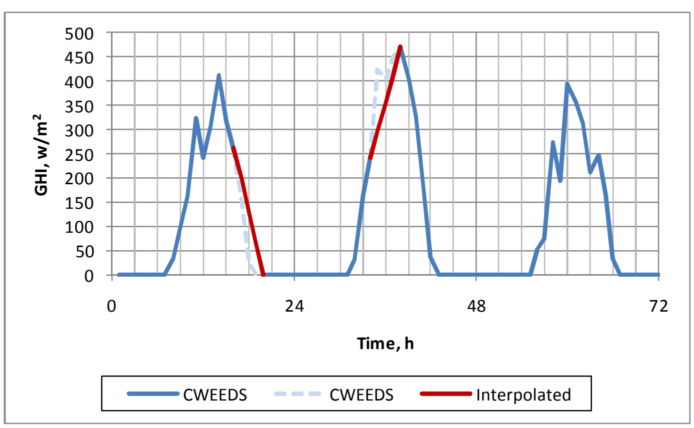
Figure A2.16 Step function method for filling small gaps in present weather and precipitation.

Solar

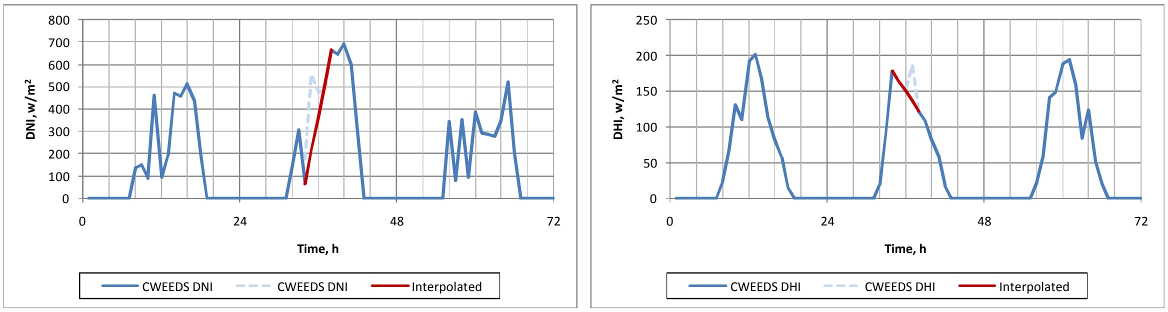
There are four types of radiation important for hygrothermal simulations; global horizontal irradiance (GHI), direct normal irradiance (DNI), diffuse horizontal irradiance (DHI), and reflected radiation. GHI, DNI, and DHI were all treated similarly. The fourth, reflected radiation will be dealt with first.

Reflected Solar

The value of reflected radiation, i.e. radiation reflected from the ground and other buildings, was currently set to 0 for all hours. Reflected radiation was calculated by the hygrothermal simulation tool for this project or can be easily calculated from the other solar radiation parameters using the equations found in the 2009 ASHRAE Handbook – Fundamentals Chapter 14.



(a)



(b) (c)

Figure A2.17 Linear interpolation for filling small gaps in solar radiation (a) Global Horizontal Irradiance, (b) Direct Normal Irradiance, and (c) Diffuse Horizontal Irradiance.

Global/Direct/Diffuse

For gaps of 3 hours or less linear interpolation was used (see figures above). Whereas for gaps of more than 3 hours, the following solar model for global horizontal irradiance (GHI) was used.

The GHI model was a modified version of the Zhang-Huang model first proposed in the 1477-RP Final Report. The model used coefficients optimized for particular climate zones instead of global coefficients and is given by:

$$I = I_o \sin h \{C_0 + C_1 (CC) + C_2 (CC)^2 + C_3 (T_n - T_{n-3}) + C_4 RH + C_5 V_w\} + D \qquad \text{when } 0.1\, I_o > I > 0.9\, I_o$$

$$I = 0.9\, I_o \text{ when } I > 0.9\, I_o;\ I = 0.1\, I_o \qquad \text{when } I < 0.1\, I_o$$

Where: I = predicted GHI, W/m^2

I_0 = solar constant, 1367.7 W/m^2

h =solar altitude, in degrees

CC = cloud cover in tenths, 0 to 1

RH = relative humidity, 0 to 100%

T_n, T_{n-3}= dry bulb temperature at time *n* and *n-3*, ^{o}C

V_w = wind speed in m/s

C_0, C_1, C_2, C_3, C_4, C_5, D = regression coefficients

The original global coefficients for the model published by Zhang et al. [22] are listed below.

C_0, = 0.6641, C_1 = 0.591, C_2 = -0.8021, C_3 = 0.03371, C_4 = -0.00376, C_5 = 0.0166, D = -21.178

Coefficients based on a Köppen-Geiger [23] climate zoning are published in the 1477-RP Final Report [5]. A subset of the table, containing only Canadian and United States Köppen climate zones, is given below.

[22] Zhang, Q.Y., Huang, Y.J., and Lang, S.W. 2002 "Development of typical year weather data for Chinese locations", LBNL-51436. ASHRAE Transactions, vol. 108, pt. 2, 2002 Annual Meeting, Honolulu HI.

[23] Peel, M.C., Finlayson, B.L. and McMahon, T.A. 2007. "Updated world map of the Köppen-Geiger climate classification", Hydrol. Earth Syst. Sci., 11, 1633-1644.

Table A2.2 Regional solar coefficients for Zhang-Huang Solar Model by Köppen-Geiger climate region from [5]

Zone	C0	C1	C2	C3	C4	C5	D
Aw	0.8089	0.07355	-0.40101	-0.00424	-0.00242	0.00342	-8.395
BSk	0.57692	-0.08062	-0.24399	0.0261	0.00054	0.00277	-1.21103
BWh	0.51315	0.1554	-0.42157	0.01427	-0.00035	0.00469	-9.55426
Cfa	0.67839	0.03646	-0.39075	0.01359	-0.00148	0.0073	-8.71373
Cfb	0.7437	-0.02988	-0.26353	0.02606	-0.00323	-0.00008	-1.97366
Csa	0.54698	0.21871	-0.42476	0.0233	-0.00038	0.00183	-9.83335
Csb	0.6425	0.06685	-0.35491	0.01935	-0.00111	0.00001	-5.40989
Dfa	0.73067	0.04956	-0.32687	0.01269	-0.00298	0.00581	0.30725
Dfb	0.69491	-0.10822	-0.22999	0.01232	-0.00091	0.0039	-3.46883
Dfc	0.73447	-0.03502	-0.18087	0.01923	-0.00225	-0.00443	-3.61457
Dsb	0.73447	-0.03502	-0.18087	0.01923	-0.00225	-0.00443	-3.61457
ET	0.77029	0.00687	-0.35561	0.01849	-0.00149	-0.00278	-6.41702
EF	0.77029	0.00687	-0.35561	0.01849	-0.00149	-0.00278	-6.41702

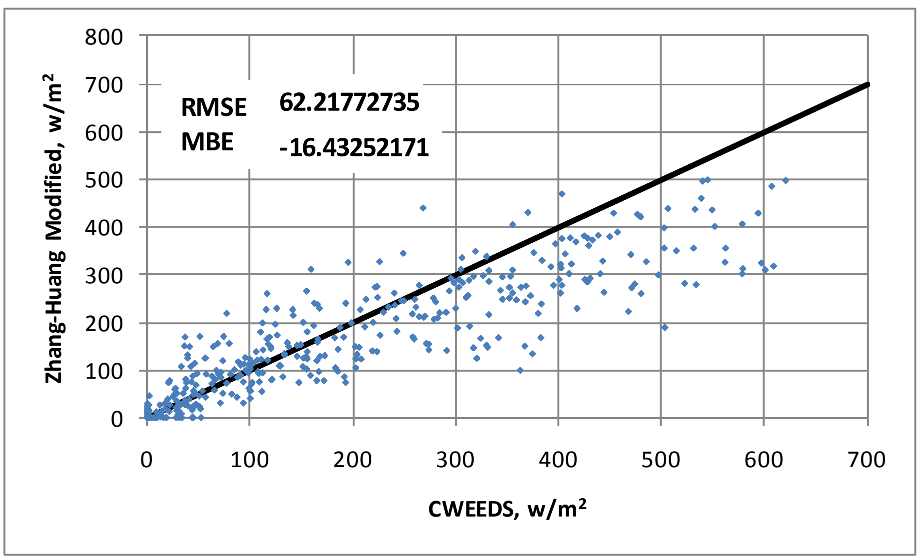


Figure A2.18 Prediction of daily average GHI using the modified Zhang-Huang model vs. CWEEDS modelled data.

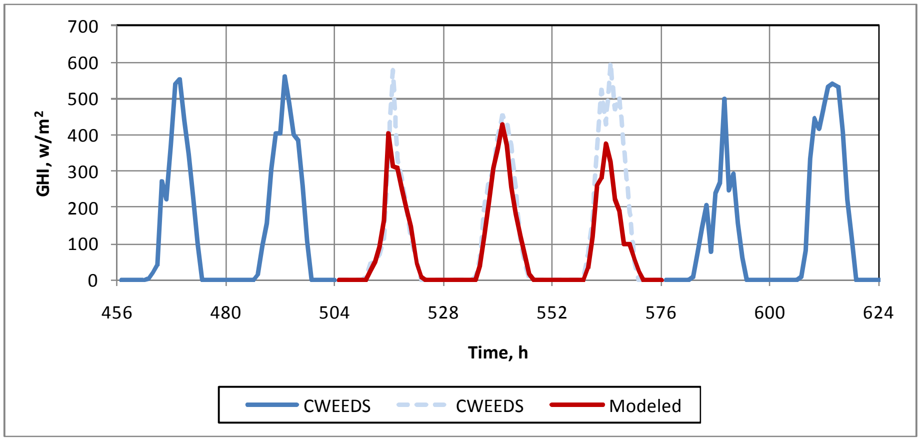


Figure A2.19 Interpolation of a medium size gap of GHI using the modified Zhang-Huang model vs. CWEEDS modelled data.

A split model was used to estimate the direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI); to split the global horizontal irradiance (I) into diffuse (I_d) and direct components (I_n) a relative simple model, based on the Gompertz function, was used to calculate the direct diffuse split [24].

Direct normal irradiance (DNI) = $I_n = K_n I_0$

Diffuse horizontal irradiance (DHI) = $I_d = I - I_n \sin h$

Where:

I = global horizontal irradiance (GHI)

I_0 = solar constant, 1367.7 W/m^2

I_n = direct normal irradiance DNI, W/m^2

I_d = diffuse horizontal irradiance DHI, W/m^2

K_n = direct beam transmittence

$$K_n = A_1 A_2^{-A_3 A_2^{-A_4 K_t}}$$

Where: $A_1 = -\,0.1556 \sin^2 h + 0.1028 \sin h + 1.3748$

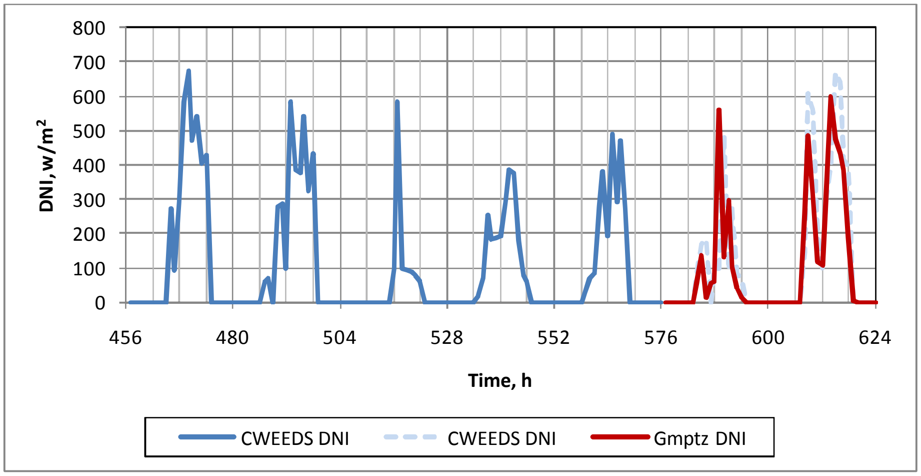
$A_2 = 0.7973 \sin^2 h + 0.1509 \sin h + 3.035$

$A_3 = 5.4307 \sin h + 7.2182$

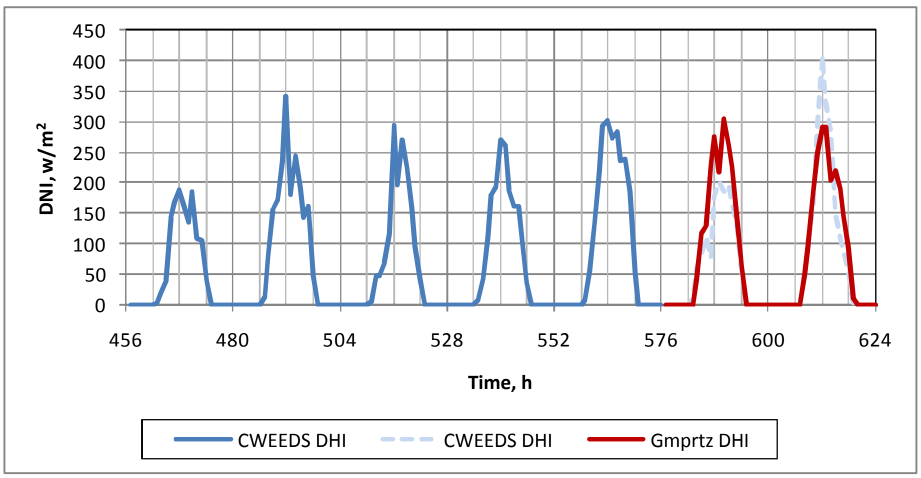
$A_4 = 2.990$

$K_t = I/(I_0 \sin h)$

[24] Zhang, Q.Y., Lou, C.Z., and Yang, H.X. 2004. “A new method to separate horizontal solar radiation into direct and diffuse components”, Proceedings, ISESAP 2004.



(a)



(b)

Figure A2.19 Interpolation of a medium size gap of DNI (a) and DHI (b) using Zhang et. al. Gompertz model [24] vs. CWEEDS modelled data.

Quality Control of Data

Dry Bulb and Dew Point Temperatures

Where possible, long term climate normal data were obtained and the extreme maximum and minimum set as the upper and lower bounds for temperature. In no cases was the dew point allowed to be greater than the dry-bulb temperature. The maximum dewpoint was not allowed to exceed maximum temperature; the minimum dewpoint was not allowed to be below the minimum drybulb at 15% RH. Swings in dry bulb or dew point 15°C were flagged for investigation. Steady runs of 12 hours or more of constant temperature were flagged and investigated.

Pressure

At no times was the station pressure allowed to exceed1080 millibars or to be lower than 850 millibars.

Wind Speed

Where possible long term climate normal data were obtained and the extreme maximum and minimum set as the upper and lower bounds for hourly wind speed. Steady runs of 24 hours or more were flagged and investigated.

Wind Direction

Steady runs of 24 hours or more were flagged and investigated. Values less than 0 or greater than 359 were flagged.

Total Sky Cover

Values for Total Opaque Sky Cover range from 0 to 10. Values outside the range were flagged.

Solar

No solar value was allowed to exceed the value for the solar constant 1367 W/m^2 (4921 MJ/m2) or be less than 0. In no cases did the diffuse horizontal irradiance exceed global horizontal irradiance. Constant non-zero runs longer than 6 hours were investigated.

Estimating Hourly Values from Weather data

CWEEDS data are stored in WYEC2 format which has no parameter for hourly precipitation [25]. The occurrence of precipitation is recorded in an eight character field called *present weather*. The second and third elements of the *present weather* field relate to precipitation, rain and drizzle. In CWEEDS field 204b represents the occurrence of rain, rain showers or freezing rain. Field 204c represents the occurrence of drizzle or freezing drizzle. Precipitation is recorded as one of nine single digit codes. The codes and the corresponding meanings are given in the table below. There are also guidelines for the observer as to the assignment of codes. These guidelines were published by Environment Canada [26, 27]. Solid forms of precipitation such as hail and snow, which are stored in other columns of the observations field, were not considered.

Table A2.3 Present weather codes for precipitation in the CWEEDS dataset.

Code	Filed204b, Rain	Field 204c, Drizzle
0	None	None
1	Light rain	Light drizzle
2	Moderate rain	Moderate drizzle
3	Heavy rain	Heavy drizzle
4	Light rain showers	Light freezing drizzle
5	Moderate rain showers	Moderate freezing drizzle
6	Heavy rain showers	Heavy freezing drizzle
7	Light freezing rain	n/a
8	Moderate or heavy freezing	n/a

[a]If several phenomena occur simultaneously, the highest WYEC2 value is reported.

Increasingly the recording of present weather and weather data is being automated. In some cases, depending on how the precipitation was measured (an observer, a tipping bucket, or radar gun) there might be real rain data for a CWEEDS site. However, Canadian automated stations, such as Automated Weather Observation System (AWOS) still report in the same WYEC2 format. Consequently quantitative rain data is reported in the CWEEDS files as an observer code but is stored separately where available. The difficulty with CWEEDS data is how to transform the present weather codes into quantitative hourly values. A simplification of the method outlined by Cornick and Dalgliesh [28] was used here. Since the bulk of observations and rainfall events, about 95%, occur in the light rain category the value assumed by the light rain category, L, has the most importance. The first step was to simply substitute the value for L from the table below, 1.8 mm/h for each occurrence of light rain. The values for moderate, heavy and drizzle intensities were assumed to take on the values in the table below. Next, the long-term annual rainfall was calculated using all the available years for a location. This value was compared with the

[25] Stoffel TL, Rymes MD. Production of the Weather Year for Energy Calculations Version 2 (WYEC2) Data Sets. ASHRAE Transactions 1998;104(2):487-497.

[26] Atmospheric Environment Services. Software Implementation for Climatological Ice Accretion Modelling Project. Internal Report to Energy and Industrial Applications Section. Canadian Climate Center. Toronto Canada, 1984, p. 157.

[27] Environment Canada. Manual of Service Weather Observations (MANOBS). Atmospheric Environment Service. Central Service Directorate. Toronto. Ontario. 1987.

[28] Cornick, S.M., Dalgliesh, A., "Adapting rain data for hygrothermal modeling," Building and Environment, Vol. 30, pp. 1-10, October 20.

long-term mean obtained from the current 1971–2000 climate normal data. The value of L was adjusted to minimize the difference between calculated value and the climate normal value. The value for L was constrained by the range recommended by the local meteorological service.

Table A2.4 Precipitation intensities and typical intensities as well as the divisions used to separate the intensities.

Reported precipitation intensity, mm/h	Rain	Showers	Drizzle	Range for Rain or Showers	Range for Drizzle
Light	1.8	1.8	0.1	1.1 to 2.5	less than 0.2
Moderate	5.1	5.1	0.3	2.6 to 7.5	0.2 to 0.4
Heavy	13	13	0.8	7.6 or greater	0.5 to 1.0

For ISD data a different method was used. The ISD has a field for hourly precipitation; the field records the total accumulation at the end of an event. Consequently it is possible to “reconstruct” the rain event by using a combination of the present weather code, to flag the occurrence and type of precipitation, and the accumulation, which is spread over the duration of the event. Huang [5] in the final report for ASHRAE RP-1477 describes the method and the varying degree of success.

The optimized values for L for each Canadian location and the error from the climate normal data are shown below.

Table A2.5 Optimized values for light rain precipitation intensity, L, and difference from long-term annual rainfall.

Station	**Mean annual rainfall, mm**	**Light rain intensity value, mm/h**	**Long-term estimate, mm**	**Diff. %**
Abbotsford A., BC	1508	1.6	1513	0.33
Bonavista A., NL	816	1.1	834	2.21
Halifax Int'l. A., NS	1239	2.1	1156	-6.70
Port Hardy A., BC	1808	1.6	1878	3.87
Saint John A., NB	1148	2.1	1082	-5.75
St. John's A., NL	1191	1.8	1221	2.52
Stephenville A., NL	985	2.5	905	-8.12
Summerside A., PI	806	1.6	823	2.11
Sydney A., NS	1213	2	1178	-2.89
Terrace A., BC	970	1.1	1186	22.27
Tofino A., BC	3257	1.8	3125	-4.05
Vancouver Int'l. A., BC	1155	1.1	1259	9.00

Appendix 3

UNITED STATES LOCATIONS

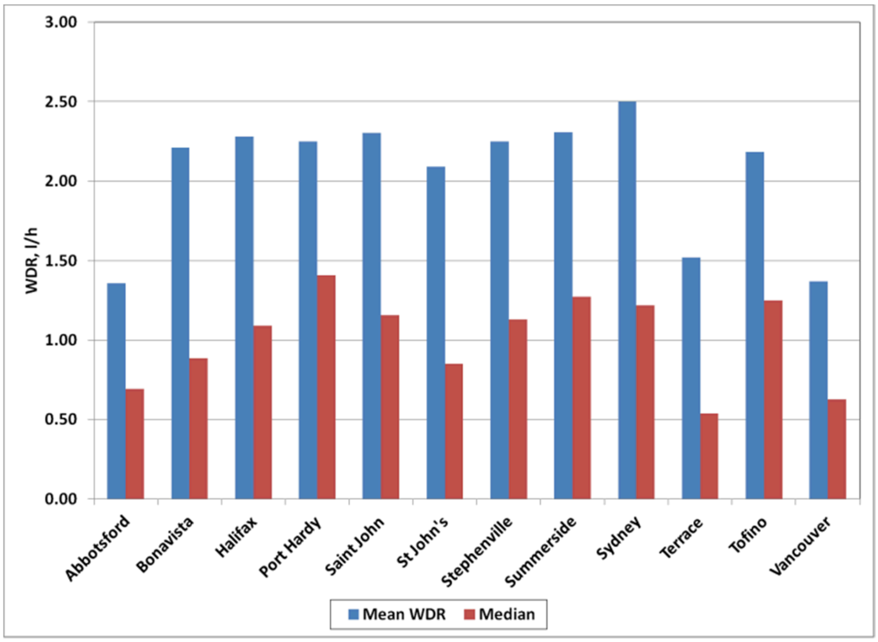
Table A.3 List of United States locations that meet the criteria;
HDD18 > 2500 and MI ≥ 1 or MI > 0.9 and HDD18 < 3400
(bolded location selected for analysis)

Station Name	State	MI	HDD18	Station Name	State	MI	HDD18
VALDEZ	AK	1.03	5529	KANSAS CITY	MO	0.92	2996
COLD BAY	**AK**	**1.09**	**5407**	MIDDLETOWN-HARRISBURG	PA	0.94	2971
YAKUTAT	**AK**	**3.43**	**5269**	HARRISBURG	PA	1.00	2970
JUNEAU	**AK**	**1.28**	**4943**	COVINGTON	KY	1.01	2915
KODIAK	**AK**	**1.65**	**4898**	COLUMBIA	MO	0.95	2896
WILKES-BARRE	PA	1.04	4183	**ASTORIA**	**OR**	**1.78**	**2866**
PORTLAND	ME	1.01	4099	**NORTH BEND**	**OR**	**1.71**	**2849**
ANNETTE	**AK**	**2.57**	**3882**	NEW YORK-JFK ARPT.	NY	1.00	2793
WORCHESTER	MA	1.07	3877	PHILADELPHIA	PA	1.00	2752
HARTFORD	CT	1.00	3417	WILMINGTON	DE	0.99	2743
ELKINS	WV	1.02	3400	SALEM	OR	1.05	2737
WILLIAMSPORT	PA	0.96	3382	NEW YORK-LGA ARPT.	NY	1.01	2728
PROVIDENCE	RI	1.07	3269	**SEATTLE**	**WA**	**1.00**	**2727**
QUILLAYUTE	WA	2.72	3254	NEWARK	NJ	1.05	2716
ALLENTOWN	PA	1.04	3214	LEXINGTON	KY	1.10	2657
COLUMBUS	OH	0.92	3171	ST. LOUIS	MO	0.91	2643
OLYMPIA	**WA**	**1.36**	**3142**	ATLANTIC CITY	NJ	1.00	2627
ISLIP	**NY**	**1.12**	**3137**	EVANSVILLE	IN	1.07	2616
BOSTON	**MA**	**0.95**	**3134**	BALTIMORE	MD	0.98	2615
INDIANAPOLIS	**IN**	**0.99**	**3119**	HUNTINGTON	WV	1.00	2592
BECKLEY	WV	0.95	3088	CHARLESTON	WV	1.00	2581
BRIDGEPORT	CT	1.00	3076	SPRINGFIELD	MO	1.06	2577
				EUGENE	**OR**	**1.31**	**2526**
				PORTLAND	OR	0.96	2512
				LOUISVILLE	**KY**	**1.09**	**2508**

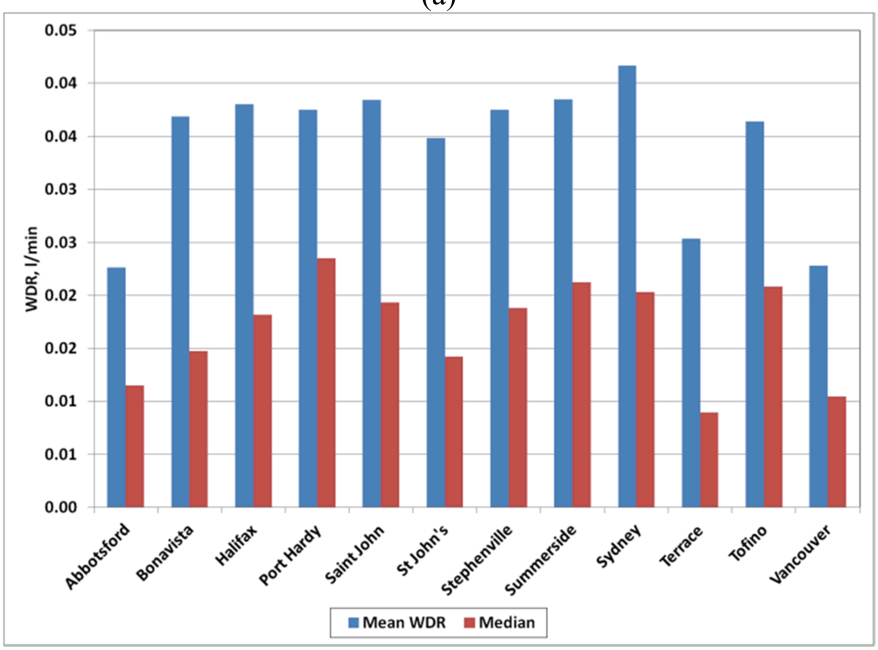
Appendix 4

WDR AND DRWP VALUES FOR CANADIAN AND U.S. LOCATIONS

The charts for Canadian in this appendix show graphically the contents of Table 11 and Table 12 in the main report. There are meant for visual comparison.

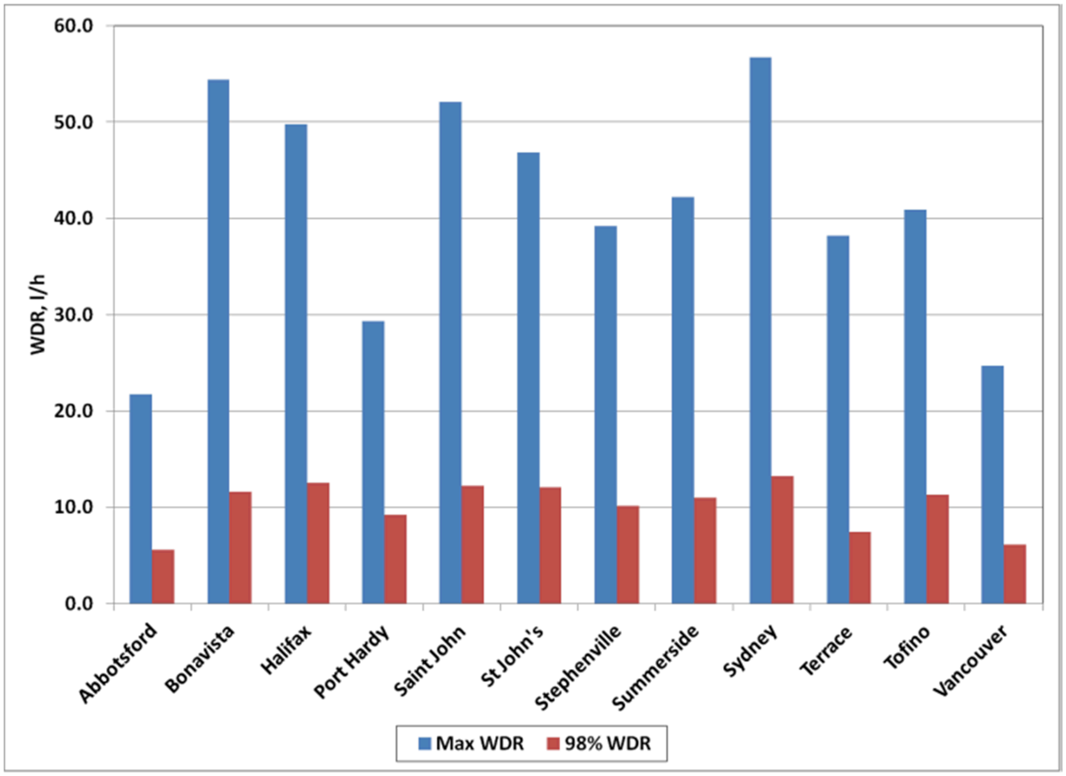


(a)

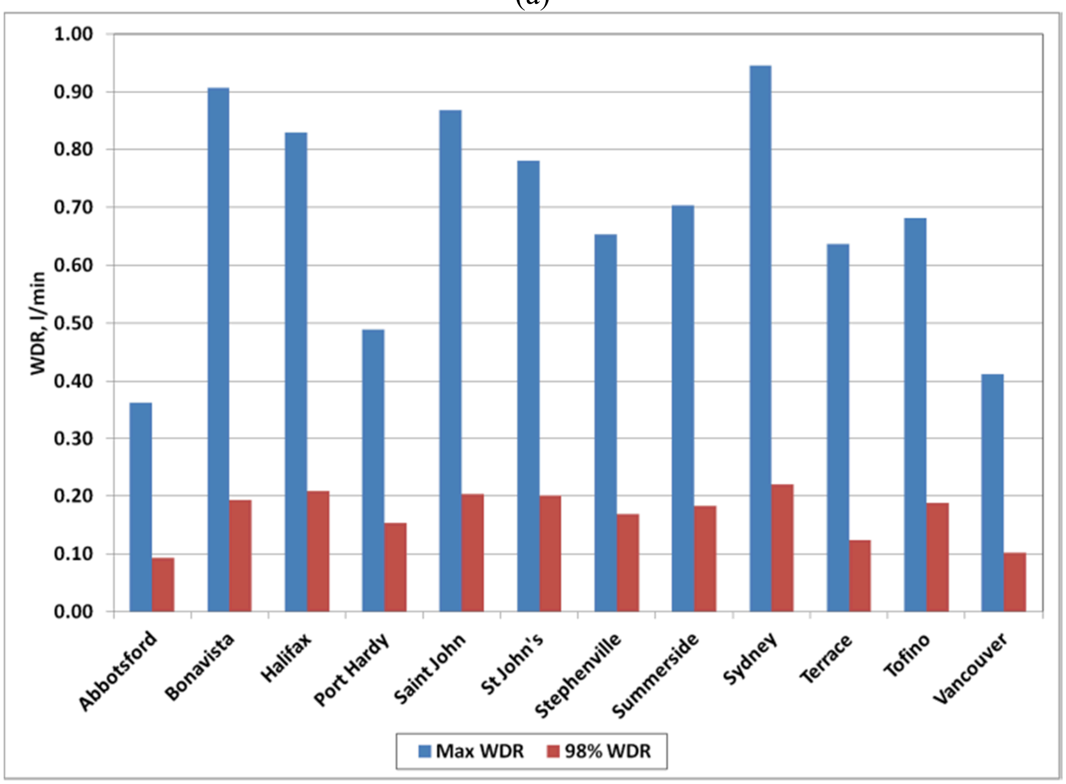


(b)

Figure A5.1 Mean and median WDR in l/h (a) and l/min (b) for Canadian locations.



(a)



(b)

Figure A5.2 Maximum and 98-percentile value WDR in l/h (a) and l/min (b) for Canadian locations.

NRC · CNRC

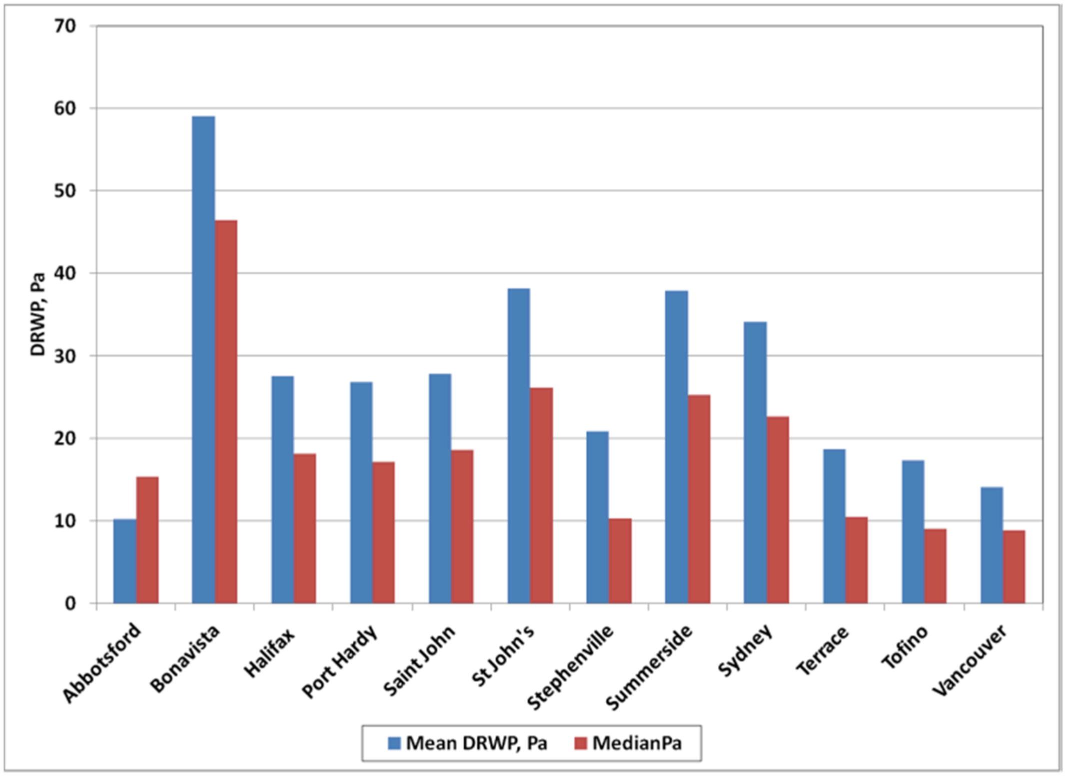


Figure A5.3 Mean and median DRWP in Pa for Canadian locations.

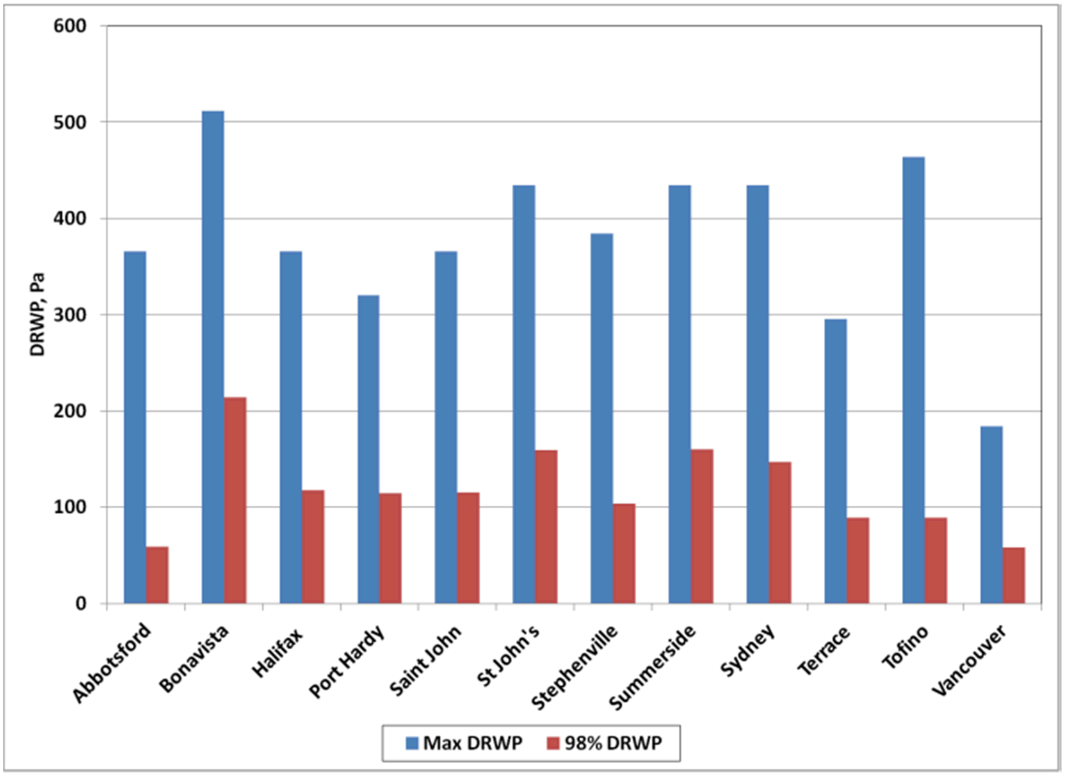
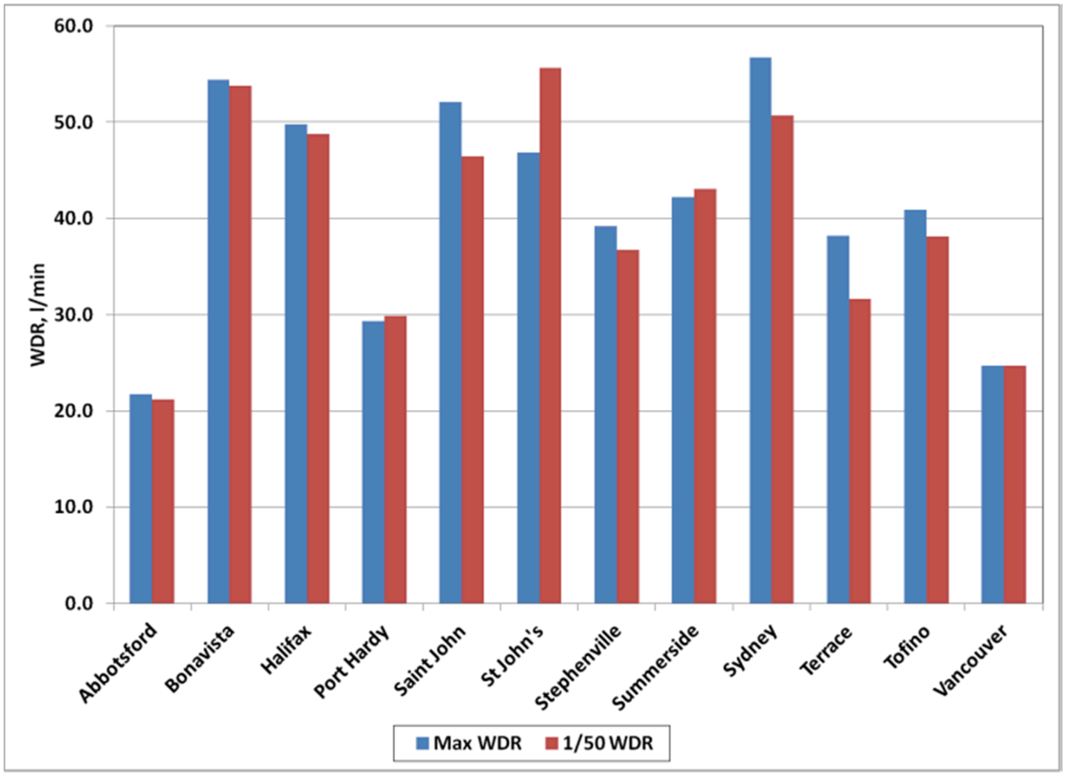
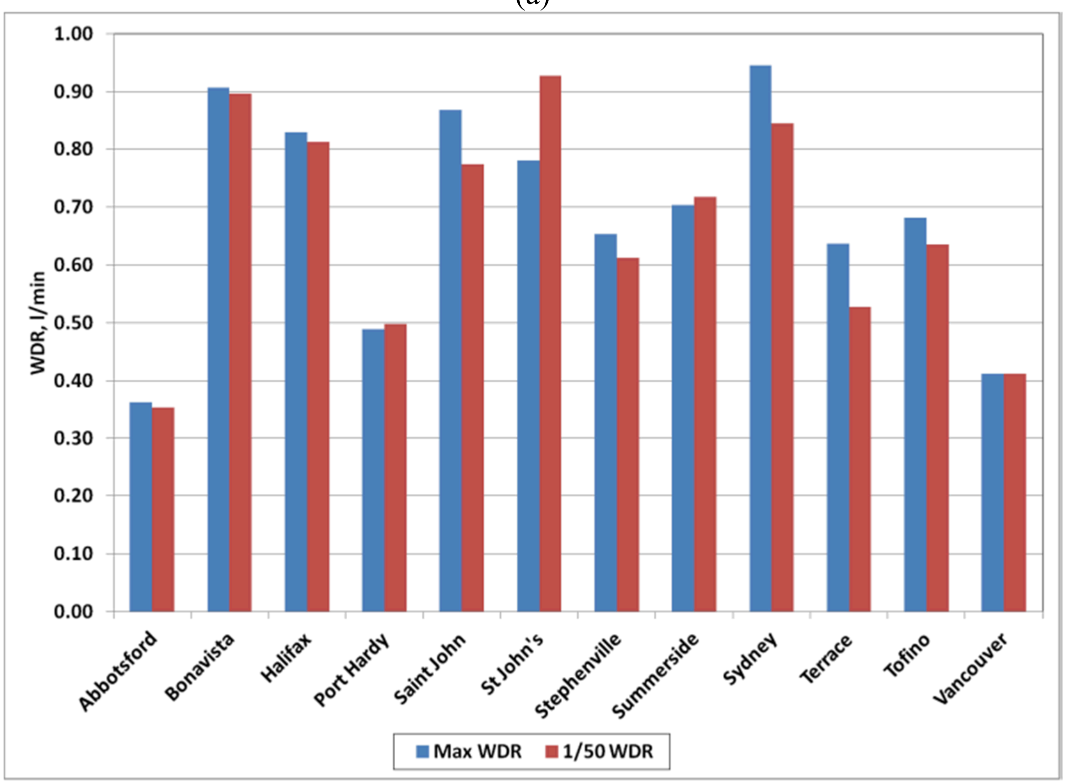


Figure A5.4 Maximum and 98-percentile value DRWP in Pa for Canadian locations.



(a)



(b)

Figure A5.5 Max and 50-year return WDR in l/h (a) and l/min (b) for Canadian locations.

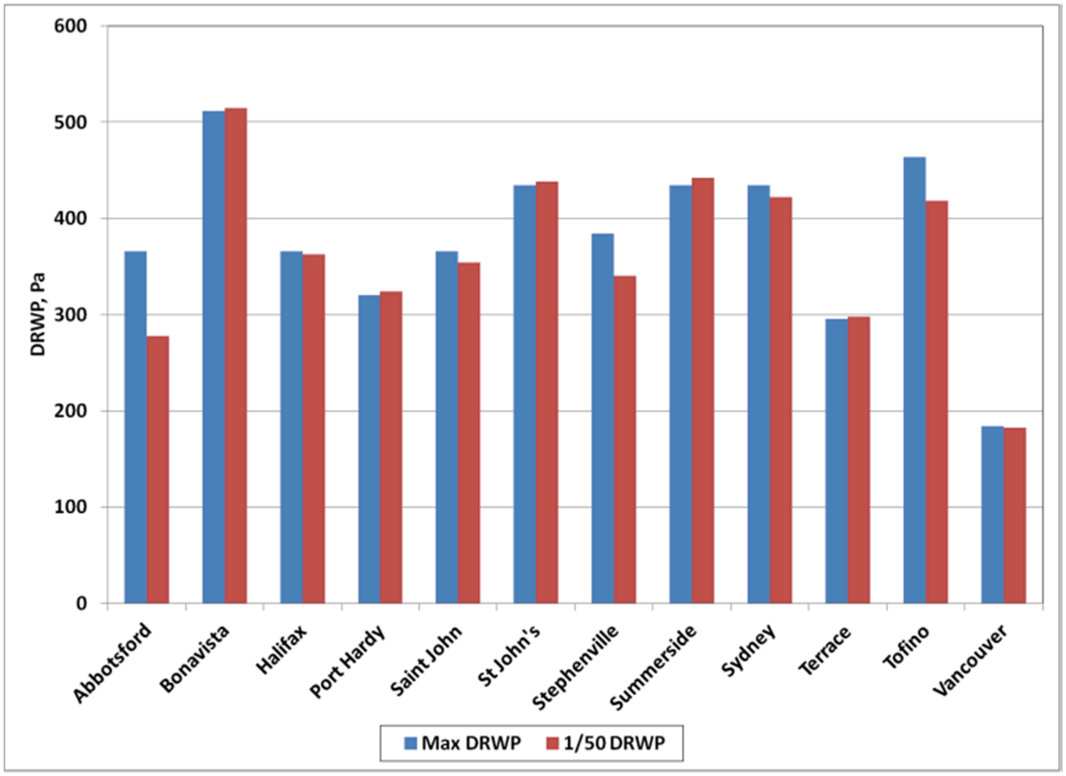
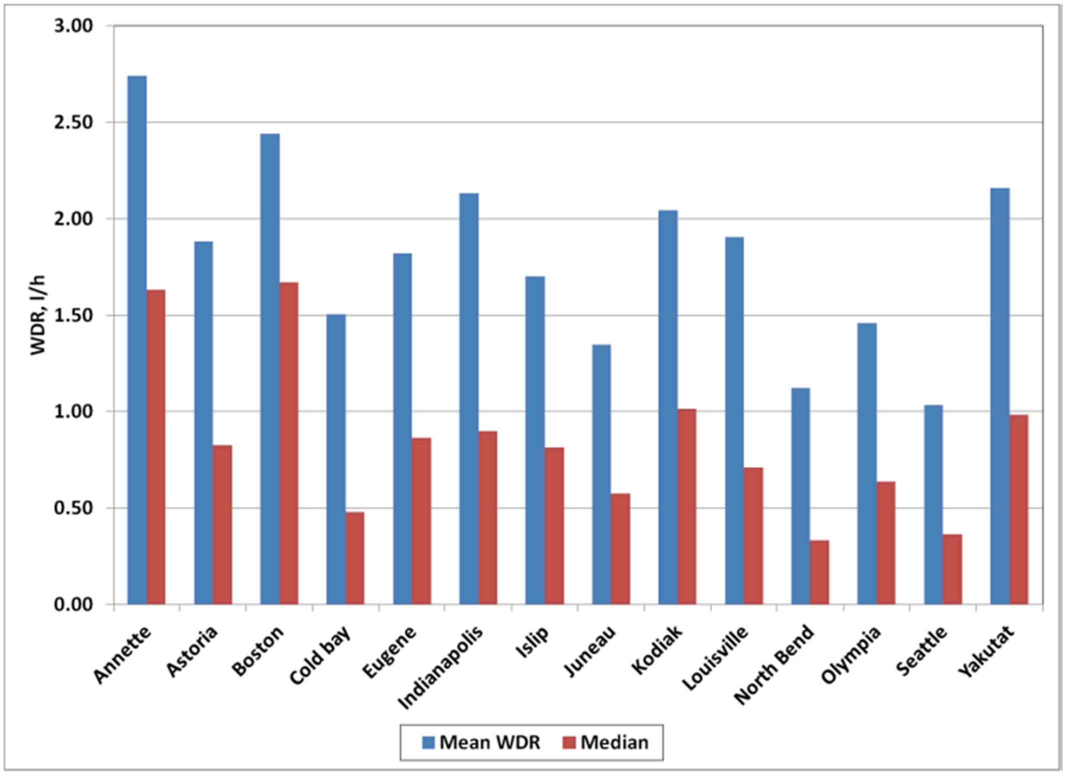
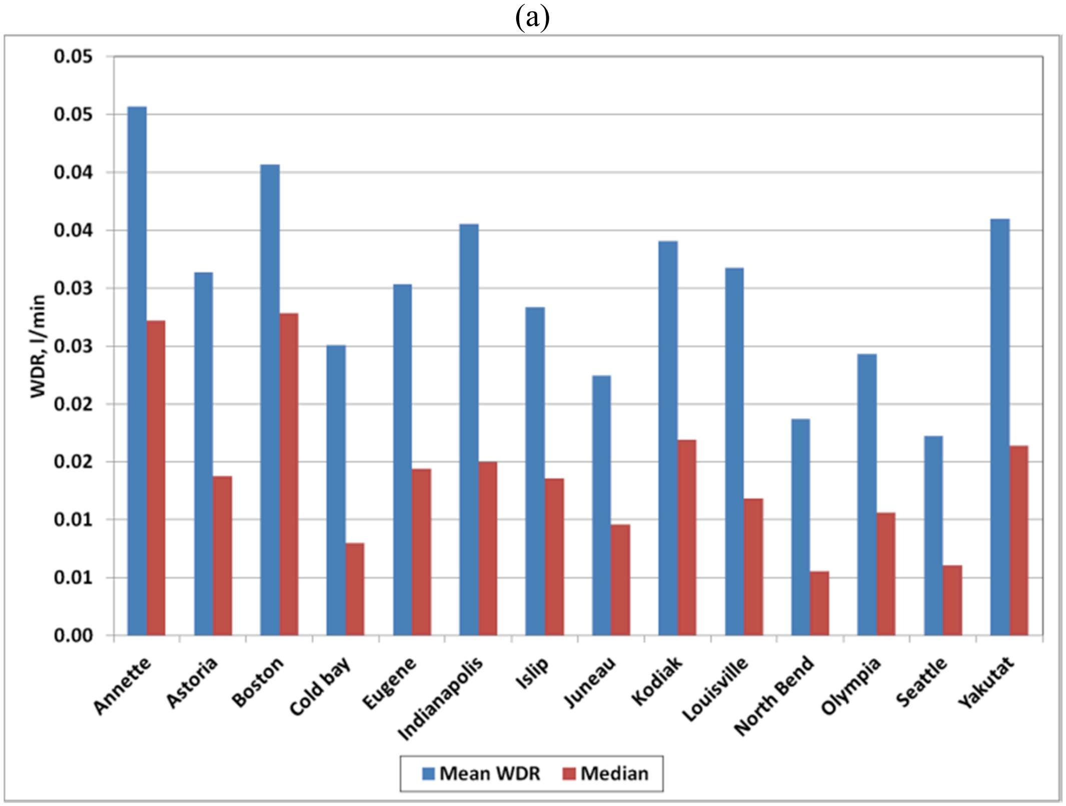


Figure A5.6 Max and 50-year return DRWP in Pa for Canadian locations.

Charts and Tables for U.S. locations are below.

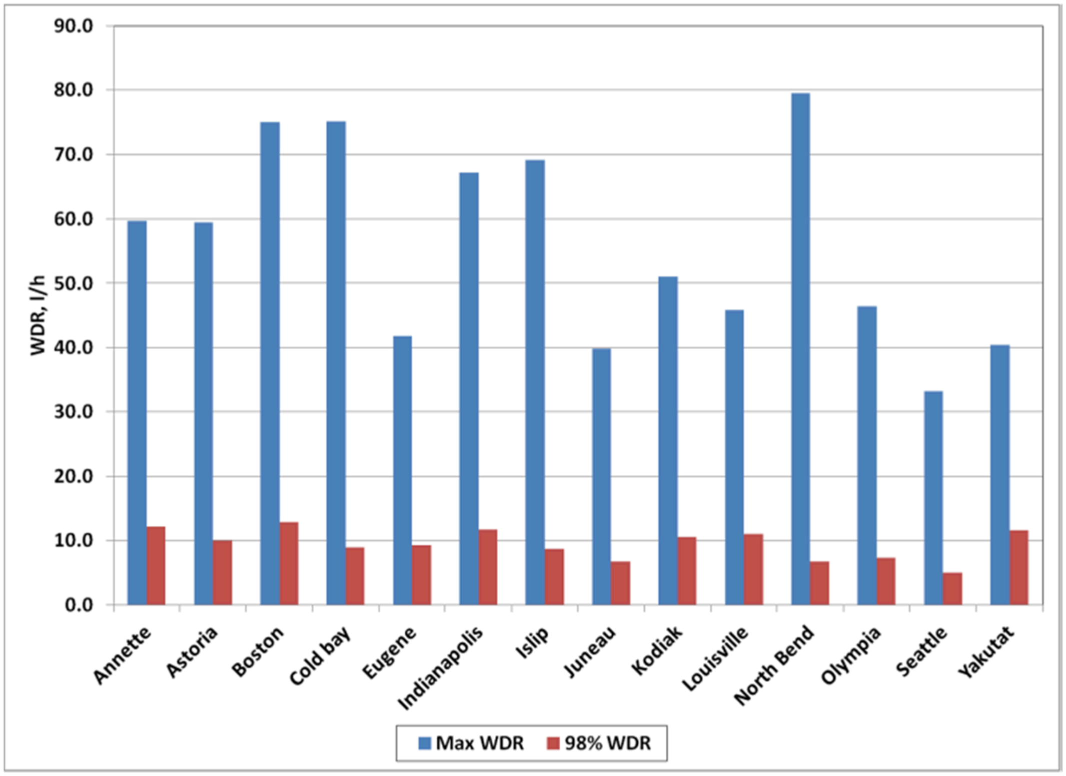


(a)

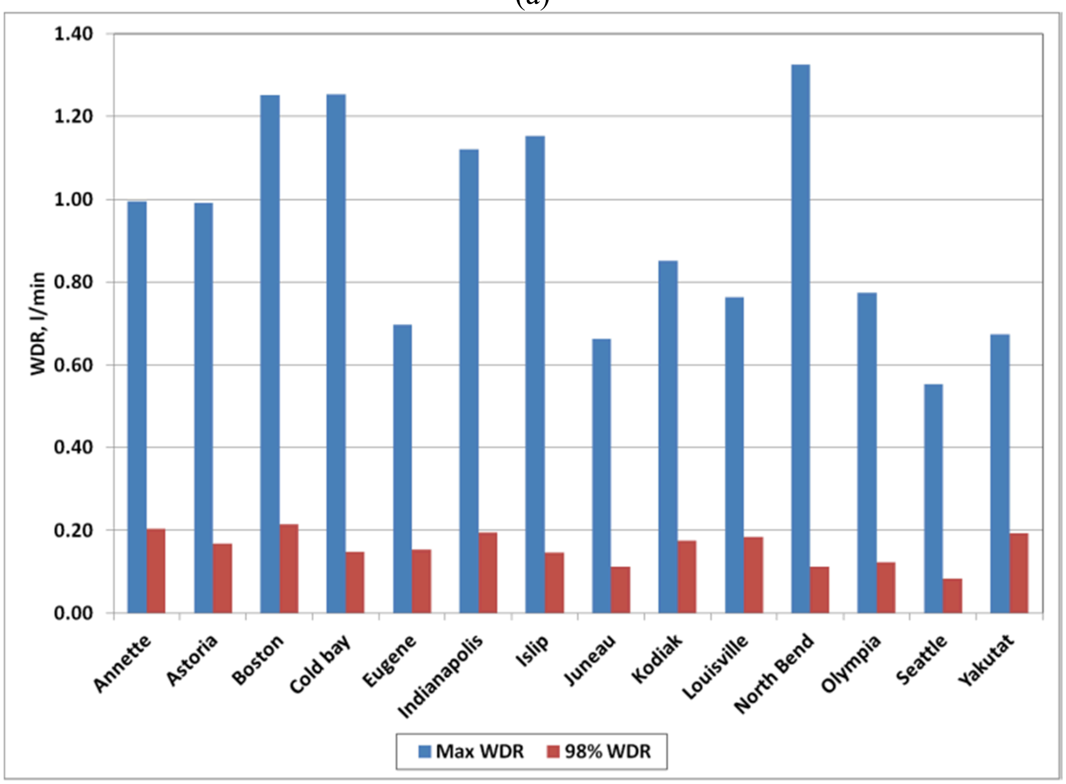


(b)

Figure A5.7 Mean and median WDR in l/h (a) and l/min (b) for U.S. locations.



(a)



(b)

Figure A5.8 Maximum and 98-percentile value WDR in l/h (a) and l/min (b) for U.S. locations.

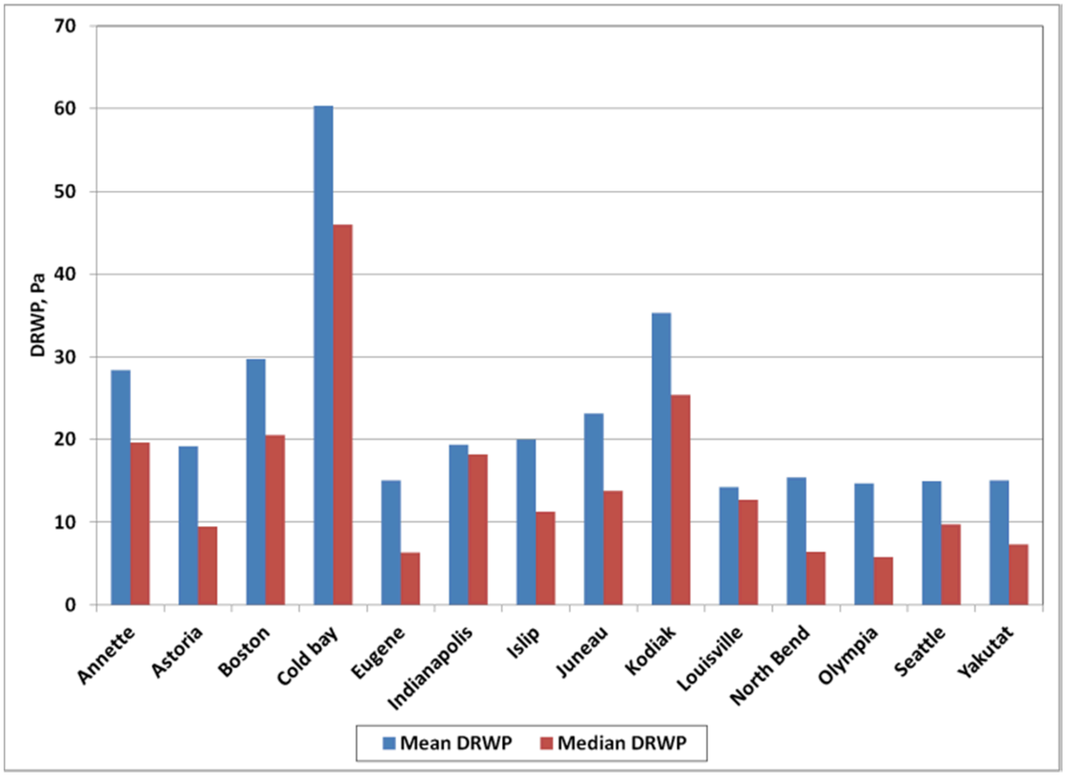


Figure A5.9 Mean and median DRWP in Pa for U.S. locations.

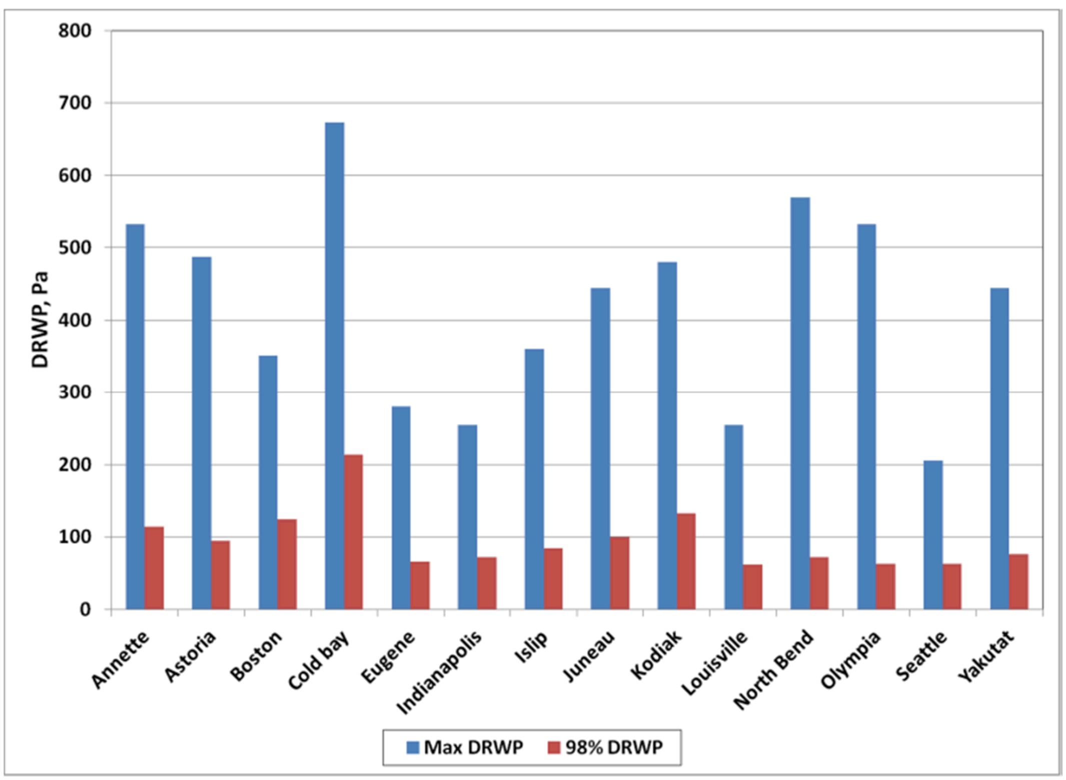
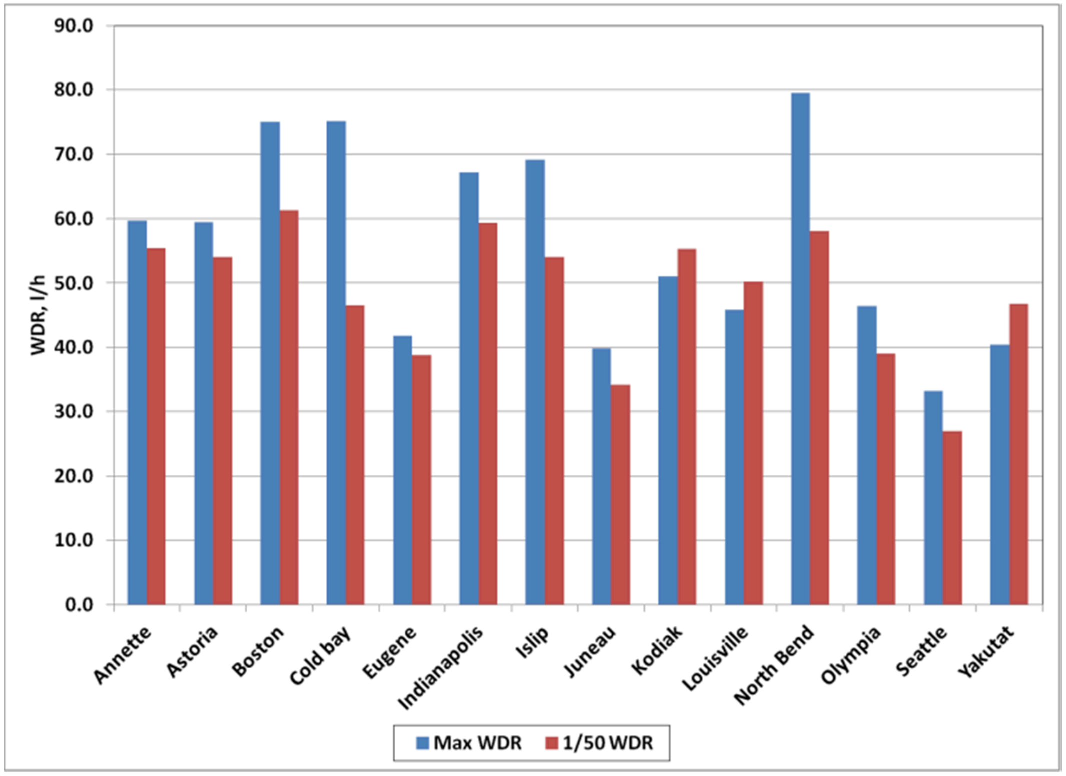
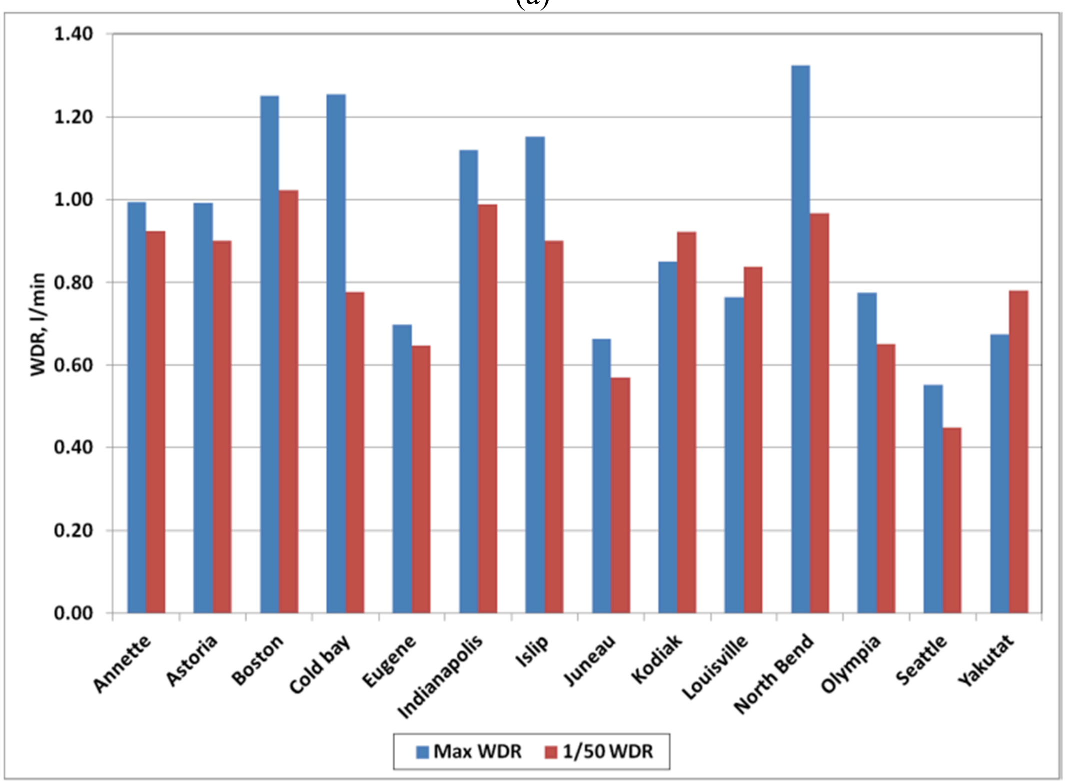


Figure A5.10 Maximum and 98-percentile value DRWP in Pa for U.S. locations.



(a)



(b)

Figure A5.11 Max and 50-year return WDR in l/h (a) and l/min (b) for U.S. locations.

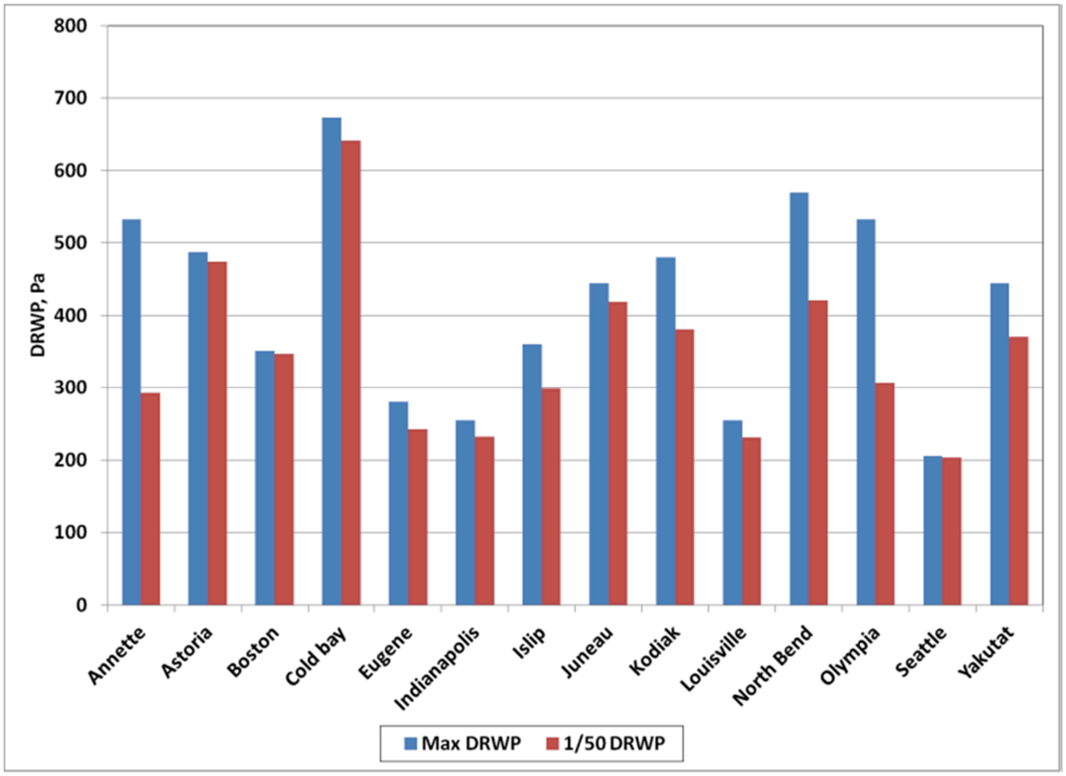


Figure A5.12 Max and 50-year return DRWP in Pa for U.S. locations.

Table A5.1 Wind-driven rain values in (a) litres per hour and (b) litres per minute per square meter of wall surface, U.S. Locations

(a)

Location	State	Mean WDR, l/h	Median, WDR l/h	Std dev, l/h	Max WDR, l/h	DWRP @ max WDR, Pa	98% WDR, l/h	MC DRWP, Pa
Annette	AK	2.74	1.63	3.15	59.7	184	12.21	8
Astoria	OR	1.88	0.83	2.58	59.5	184	10.01	67
Boston	MA	2.44	1.67	3.36	75.1	194	12.85	69
Cold bay	AK	1.51	0.48	2.37	75.2	165	8.91	138
Eugene	OR	1.82	0.86	2.28	41.8	137	9.23	39
Indianapolis	IN	2.13	0.90	3.09	67.2	64	11.65	32
Islip	NY	1.70	0.81	2.31	69.1	52	8.74	46
Juneau	AK	1.35	0.58	1.63	39.8	86	6.73	69
Kodiak	AK	2.05	1.01	2.76	51.1	100	10.49	92
Louisville	KY	1.90	0.71	2.89	45.8	36	11.06	11
North Bend	OR	1.12	0.33	1.80	79.5	84	6.75	42
Olympia	WA	1.46	0.64	1.82	46.5	34	7.33	39
Seattle	WA	1.03	0.36	1.19	33.2	403	5.01	34
Yakutat	AK	2.16	0.98	2.95	40.4	124	11.58	11

(b)

Location	State	Mean WDR, l/min	Median, WDR l/min	Std dev, l/min	Max WDR, l/min	DWRP @ max WDR, Pa	98% WDR, l/min	MC DRWP, Pa
Annette	AK	0.05	0.03	0.05	0.99	184	0.20	8
Astoria	OR	0.03	0.01	0.04	0.99	184	0.17	67
Boston	MA	0.04	0.03	0.06	1.25	194	0.21	69
Cold bay	AK	0.03	0.01	0.04	1.25	165	0.15	138
Eugene	OR	0.03	0.01	0.04	0.70	137	0.15	39
Indianapolis	IN	0.04	0.01	0.05	1.12	64	0.19	32
Islip	NY	0.03	0.01	0.04	1.15	52	0.15	46
Juneau	AK	0.02	0.01	0.03	0.66	86	0.11	69
Kodiak	AK	0.03	0.02	0.05	0.85	100	0.17	92
Louisville	KY	0.03	0.01	0.05	0.76	36	0.18	11
North Bend	OR	0.02	0.01	0.03	1.32	84	0.11	42
Olympia	WA	0.02	0.01	0.03	0.77	34	0.12	39
Seattle	WA	0.02	0.01	0.02	0.55	403	0.08	34
Yakutat	AK	0.04	0.02	0.05	0.67	124	0.19	11

Table A5.2 Driving-rain wind pressure values in Pa, U.S. Locations

Location	State	Mean DRWP, Pa	Median DRWP Pa	Std Dev, Pa	Max DRWP, Pa	WDR @ max DRWP, l/h (l/min)	98% DRWP, Pa	MC WDR, l/h (l/min)
Annette	AK	28	20	27	533	24.4 (0.41)	114	9.5 (0.16)
Astoria	OR	19	9	24	488	5.2 (0.09)	94	11.0 (0.18)
Boston	MA	30	20	30	351	37.1 (0.62)	124	7.5 (0.12)
Cold bay	AK	60	46	53	673	15.6 (0.26)	214	5.5 (0.09)
Eugene	OR	15	6	14	280	5.7 (0.09)	66	6.1 (0.10)
Indianapolis	IN	19	18	17	255	14.9 (0.25)	72	5.1 (0.09)
Islip	NY	20	11	18	360	8.9 (0.15)	84	5.5 (0.09)
Juneau	AK	23	14	24	445	2.5 (0.04)	100	5.4 (0.09)
Kodiak	AK	35	25	34	481	1.3 (0.02)	132	7.2 (0.12)
Louisville	KY	14	13	14	255	21.2 (0.35)	61	3.7 (0.06)
North Bend	OR	15	6	17	569	19.7 (0.33)	73	4.0 (0.07)
Olympia	WA	15	6	14	533	9.4 (0.16)	63	5.6 (0.09)
Seattle	WA	15	10	1	205	4.6 (0.08)	63	2.3 (0.04)
Yakutat	AK	15	7	18	444	8.6 (0.14)	76	8.8 (0.15)

Table A5.3 Extreme values for a fifty-year return period, 1 in 50, for WDR and DRWP, U.S. Locations.

Location	State	1/50 WDR, l/h	1/50 WDR, l/min	1/50 DRWP, Pa
Annette	AK	55.4	0.92	293
Astoria	OR	54.1	0.90	474
Boston	MA	61.3	1.02	347
Cold bay	AK	46.6	0.78	641
Eugene	OR	38.8	0.65	242
Indianapolis	IN	59.3	0.99	232
Islip	NY	54.1	0.90	299
Juneau	AK	34.2	0.57	418
Kodiak	AK	55.3	0.92	381
Louisville	KY	50.2	0.84	231
North Bend	OR	58.1	0.97	420
Olympia	WA	39.1	0.65	307
Seattle	WA	26.9	0.45	203
Yakutat	AK	46.8	0.78	370

Table A5.4 Mean and standard deviation for extreme values used to calculate returns, U.S. locations.

	Wind-driven rain		Driving-rain wind pressure	
Location	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Annette	29.0	10.2	174	46
Astoria	26.0	10.8	195	107
Boston	29.8	12.2	195	58
Cold bay	31.3	13.6	401	93
Eugene	22.7	6.2	119	48
Indianapolis	30.1	11.3	126	41
Islip	20.7	12.9	140	61
Juneau	14.9	7.5	199	85
Kodiak				
Louisville	28.6	8.2	113	45
North Bend	23.1	13.5	166	98
Olympia	17.7	8.2	109	76
Seattle	11.9	5.8	114	34
Yakutat	28.6	7.1	199	65

Appendix 5

HYGROTHERMAL YEAR SELECTIONS

Table A.5.1 Hygrothermal year selections for Abbotsford BC.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1953	2004	1966
90%	1955	1997	1961
Median	1983	1963	1983
10%	1996	1975	2004
Min	2004	1955	1985
10-year run	1996-2005		
Location	Abbotsford A. BC		
Lat	49°01'31.000" N		
Long	122°21'36.000" W		
Elevation	59.10 m		
TZ Long	120 W (-8)		

Table A.5.2 Hygrothermal year selections for Bonavista NL.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1993	1981	1981
90%	1980	1979	1992
Median	1978	1994	1988
10%	1979	1993	1986
Min	1961	1972	1989
10-year run	1985-1994		
Location	Bonavista A. NL		
Lat	48°40'02.000" N		
Long	53°06'51.000" W		
Elevation	25.60 m		
TZ Long	60 W (-4)		

Table A.5.3 Hygrothermal year selections for Halifax NS.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1972	1999	1988
90%	1979	1983	1971
Median	1966	1961	1976
10%	1984	1962	1991
Min	2001	1972	1978
10-year run	1996-2005		
Location	Halifax Int'l A. NS		
Lat	44°52'48.060" N		
Long	63°30'00.050" W		
Elevation	145.40 m		
TZ Long	60 W (-4)		

Table A.5.4 Hygrothermal year selections for Port Hardy BC.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1954	2004	1961
90%	1957	1992	1976
Median	1969	2001	1991
10%	1989	1973	1973
Min	1985	1955	1985
10-year run	1985-1994		
Location	Port Hardy A. BC		
Lat	50°40'49.000" N		
Long	127°21'58.000" W		
Elevation	21.60 m		
TZ Long	120 W (-8)		

Table A.5.5 Hygrothermal year selections for Saint John NB.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1957	1999	1953
90%	1953	1979	1958
Median	1992	1988	1984
10%	1985	1967	2001
Min	2001	1972	1997
10-year run	1996-2005		
Location	Saint John A. NB		
Lat	45°19'05.000" N		
Long	65°53'08.050" W		
Elevation	108.80 m		
TZ Long	60 W (-4)		

Table A.5.6 Hygrothermal year selections for St. John's NL.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1953	1999	1955
90%	1964	2005	1963
Median	1960	2002	1995
10%	1983	1993	1989
Min	2003	1992	1985
10-year run	1996-2005		
Location	St. John's A. NL		
Lat	47°37'20.000" N		
Long	52°44'34.000" W		
Elevation	140.5 m		
TZ Long	60 W (-4)		

Table A.5.7 Hygrothermal year selections for Stephenville NL.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	2000	1999	1996
90%	1972	1960	1967
Median	1955	1977	1977
10%	1980	1993	1985
Min	1979	1972	1978
10-year run	1996-2005		
Location	Stephenville A. NL		
Lat	48°32'00.000" N		
Long	58°33'00.000" W		
Elevation	24.7 m		
TZ Long	60 W (-4)		

Table A.5.8 Hygrothermal year selections for Summerside, PE.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1953	1953	1962
90%	1967	1966	1963
Median	1977	1975	1983
10%	1968	1965	1985
Min	1987	1972	1978
10-year run	1981-1990		
Location	Summerside A. PE		
Lat	46°26'20.000 N"		
Long	63°49'54.000 W"		
Elevation	19.50 m		
TZ Long	60 W (-4)		

Table A.5.9 Hygrothermal year selections for Sydney NS.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1953	1999	1955
90%	1954	2001	1968
Median	1961	1994	1980
10%	1991	1992	2002
Min	2001	1974	2001
10-year run	1996-2005		
Location	Sydney A. NS		
Lat	46°10'00.000" N		
Long	60°02'53.300" W		
Elevation	61.90 m		
TZ Long	60 W (-4)		

Table A.5.10 Hygrothermal year selections for Terrace BC

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1964	1981	2005
90%	1957	1987	1976
Median	1985	1978	1972
10%	1989	1975	1971
Min	1982	1972	1978
10-year run	1996-2005		
Location	Terrace A. BC		
Lat	54°27'59.000" N		
Long	128°34'39.000" W		
Elevation	217 m		
TZ Long	120 W (-8)		

Table A.5.11 Hygrothermal year selections for Tofino BC.

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1961	1963	1961
90%	1962	1967	1962
Median	1965	1969	1966
10%	1977	1971	1972
Min	1970	1975	1977
10-year run	1968-1977		
Location	Tofino A. BC		
Lat	49°04'47.000" N		
Long	125°45'59.020" W		
Elevation	24.50 m		
TZ Long	120 W (-8)		

Table A.5.12 Hygrothermal year selections for Vancouver BC

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1953	1958	1961
90%	1966	2003	1956
Median	1984	1963	1969
10%	1985	1975	1973
Min	1996	1955	1996
10-year run	1996-2005		
Location	Vancouver Int'l A. BC		
Lat	49°11'42.000" N		
Long	123°10'55.000" W		
Elevation	4.30 m		
TZ Long	120 W (-8)		

Table A.5.13 Hygrothermal year selections for Annette AK

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1964	1993	1988
90%	1963	2005	2003
Median	1966	1980	1989
10%	2003	1965	1973
Min	2004	1975	1968
10-year run	1986-1995		
Location	Annette A. AK		
Lat	55° 3' 0" N		
Long	131° 34' 0" W		
Elevation	33 m		
TZ Long	135 W (-9)		

Table A.5.14 Hygrothermal year selections for Astoria OR

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1975	1981	2001
90%	1974	2000	2000
Median	1981	2002	1977
10%	1992	1993	1975
Min	2000	1985	1982
10-year run	1985-1994		
Location	Astoria A. OR		
Lat	46° 9' 00"N		
Long	123° 52' 48"W		
Elevation	2 m		
TZ Long	120 W (-8)		

Table A.5.15 Hygrothermal year selections for Boston MA

	Method		
Criteria	MEWS MI	Std 160-2009	1325-RP
Max	1963	2010	1969
90%	1970	1975	1972
Median	2006	1984	1971
10%	1974	1992	1976
Min	2003	1962	2002
10-year run	1986-1995		
Location	Boston Logan A. MA		
Lat	42° 21'36"N		
Long	71° 1' 48"W		
Elevation	6 m		
TZ Long	75 W (-5)		

Table A.5.16 Hygrothermal year selections for Cold Bay AK

	Method		
Criteria	MEWS MI	Std 160-2009	1325-RP
Max	1976	1979	1990
90%	1973	2005	1973
Median	1996	1984	1989
10%	2004	1982	2000
Min	2003	1976	2001
10-year run	1989-1998		
Location	Cold Bay A. AK		
Lat	55° 12' 0" N		
Long	162° 43' 0" W		
Elevation	29 m		
TZ Long	135 W (-9)		

Table A.5.17 Hygrothermal year selections for Eugene OR

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1982	1992	1986
90%	1983	1995	1975
Median	1975	1991	1980
10%	1992	1993	1976
Min	1995	1985	1977
10-year run	1986-1995		
Location	Eugene A. OR		
Lat	44° 7' 1.2" N		
Long	123° 46' 59" W		
Elevation	4 m		
TZ Long	120 W (-8)		

Table A.5.18 Hygrothermal year selections for Indianapolis IN

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1979	2007	1975
90%	1976	2006	1974
Median	2003	1975	1973
10%	1987	1980	2010
Min	2002	1979	2001
10-year run	1986-1995		
Location	Indianapolis Int'l. IN		
Lat	39° 43'48"N		
Long	86° 15' 36"W		
Elevation	241 m		
TZ Long	75 W (-5)		

Table A.5.19 Hygrothermal year selections for Islip NY

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1978	1998	1978
90%	1983	2006	1975
Median	1986	2005	1990
10%	2006	1992	1981
Min	1991	1978	1992
10-year run	1985-1994		
Location	Islip A. NY		
Lat	40° 46' 59" N		
Long	73° 54' 0" W		
Elevation	26 m		
TZ Long	75 W (-5)		

Table A.5.20 Hygrothermal year selections for Juneau AK

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1974	2004	1983
90%	1973	1981	2006
Median	1978	1978	2002
10%	2003	1982	1979
Min	2004	1973	1978
10-year run	1978-1987		
Location	Juneau A. AK		
Lat	58° 21' 0" N		
Long	134° 34' 59" W		
Elevation	4 m		
TZ Long	135 W (-9)		

Table A.5.21 Hygrothermal year selections for Kodiak AK

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1975	1983	1995
90%	1988	1979	1975
Median	1974	1987	1981
10%	2001	1974	1980
Min	2003	1975	2001
10-year run	1987-1996		
Location	Kodiak A. AK		
Lat	57° 45' 0" N		
Long	152° 04' 0" W		
Elevation	5 m		
TZ Long	135 W (-9)		

Table A.5.22 Hygrothermal year selections for Louisville KY

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1974	2007	1979
90%	1982	2002	1989
Median	1988	2009	1983
10%	1991	1976	2000
Min	2010	1979	1981
10-year run	1984-1993		
Location	Louisville A. KY		
Lat	38° 10' 48"N		
Long	85° 43' 48"W		
Elevation	147 m		
TZ Long	75 W (-5)		

Table A.5.23 Hygrothermal year selections for North Bend OR

	Method		
Criteria	MEWS MI	Std 160-2009	1325-RP
Max	2006	1983	2002
90%	1999	1992	2003
Median	1980	2005	2006
10%	2004	1999	1994
Min	1995	1985	1999
10-year run	1997-2006		
Location	North Bend A. OR		
Lat	43° 25' 1.2" N		
Long	125° 15' 0" W		
Elevation	5 m		
TZ Long	120 W (-8)		

Table A.5.24 Hygrothermal year selections for Olympia WA

	Method		
Criteria	MEWS MI	Std 160-2009	1325-RP
Max	1975	1992	1989
90%	1976	2006	1995
Median	2001	1991	1973
10%	1992	1976	2008
Min	2004	1975	1985
10-year run	1986-1995		
Location	Olympia A. WA		
Lat	47° 6' 0" N		
Long	122° 54' 0" W		
Elevation	21 m		
TZ Long	120 W (-8)		

Table A.5.25 Hygrothermal year selections for Seattle WA

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1964	1995	1990
90%	1960	1987	1963
Median	1969	1974	2000
10%	1987	1975	1973
Min	2004	1964	1977
10-year run	1987-1996		
Location	Seattle A. WA		
Lat	47° 28' 0" N		
Long	125° 19' 0" W		
Elevation	122 m		
TZ Long	120 W (-8)		

Table A.5.26 Hygrothermal year selections for Yakutat AK

	Method		
Criteria	**MEWS MI**	**Std 160-2009**	**1325-RP**
Max	1992	1981	1988
90%	1988	1980	1987
Median	1989	1992	1992
10%	1993	1982	1995
Min	2006	1975	1996
10-year run	1988-1997		
Location	Yakutat A. AK		
Lat	59° 31' 0" N		
Long	139° 38' 0" W		
Elevation	9 m		
TZ Long	135W (-9)		