Heating/Cooling Degree-day Seasonality in British Columbia

BC Hydro Customer Information Management—Load Analysis
BC Hydro, Burnaby, British Columbia

January 2010

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Introduction

Had composer Antonio Vivaldi been a load research analyst at BC Hydro he may have titled one of his most famous works *The Three Seasons* instead of the usual four. Classification of months into seasons having meaningful, stable relationships to electrical load demand was required to pursue weather sensitivity analyses of BC Hydro's account rate classes and site types. Three seasons were recognized from cluster analyses of heating/cooling degree day (HDD/CDD) data: summer, winter, and "shoulder". Summer always included June–August. Winter included November-March; April and October were always shoulder or transition months. May and September were sometimes shoulder and sometimes summer months. In addition to classifying the months in the context of BC's climate, the analyses revealed intriguing cycles and trends that were investigated in a separate research project for their predictive benefits (Wahlgren, 2010).

Data sources

The assessment used the following data sources: Canadian Weather for Energy Calculations (CWEC; 12 stations shown in Figure A-1-1; Meteorological Service of Canada, 2007) and a weather database from 1953-2008 (4 stations shown in Figure A-2-1) supplied to BC Hydro by Environment Canada.

The CWEC files were prepared under the direction of the Meteorological Service of Canada (MSC) and the National Research Council of Canada (NRC). Twelve CWEC files were available for BC stations (Table 1). The User's Manual (MSC, 2007) stated[1]:

> The CWEC files are created by concatenating twelve Typical Meteorological Months selected from a database of, in most cases, 30 years of WYEC2 data. The method is similar to TMY procedure developed in the eighties by Sandia Laboratories. The months are chosen by statistically comparing individual monthly with long-term monthly means for daily total global radiation, mean, minimum and maximum dry bulb temperature, mean, minimum and maximum dew point temperature, and mean and maximum wind speed.

Table 1: Twelve stations with CWEC files tabulated according to BC Hydro's four administrative (sales) regions. Stations in bold were representative weather stations for their region according to Yu (2007).

Lower Mainland	Vancouver Island	Northern Region	Interior Region
Abbotsford	Comox	Fort St John	**Kamloops**
Vancouver	Port Hardy	**Prince George**	Summerland
	Victoria	Prince Rupert	
		Sandspit	
		Smithers	

CWEC files had always 8760 records representing each hour of the year. February had always 28 days in the CWEC files.

[1] WYEC2 data refers to Weather Year for Energy Calculation, Version 2, devised by the American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. (ASHRAE).

Methods

CWEC data sets HDD and CDD

Monthly heating degree days, HDD, [kelvin·days], based on an 18°C balance temperature and hourly dry bulb temperature, t_{db}, observations were calculated in SAS software in three steps, namely

Step 1: Calculate daily mean air temperature (dry bulb, °C)

$$\bar{t}_{db} = \frac{\sum_{i=1}^{24} t_{db_i}}{24} \tag{1}$$

Step 2: Calculate daily heating degree days (kelvin·days)

$$Daily\_HDD = \sum_{j=1}^{24} \left(18 - \bar{t}_{db}\right)_j \tag{2}$$

Step 3: Calculate monthly heating degree days (kelvin·days)

$$Monthly\_HDD = \sum_{k=1}^{N} Daily\_HDD_k \tag{3}$$

where N = number of days in month (February always has 28 days).

Similarly, cooling degree days based on a 20°C balance temperature were calculated as

Step 1: Equation (1)

Step 2: Calculate daily cooling degree days (kelvin·days)

$$Daily\_CDD = \sum_{j=1}^{24} \left(\bar{t}_{db} - 20\right)_j \tag{4}$$

Step 3: Calculate monthly heating degree days (kelvin·days)

$$Monthly\_CDD = \sum_{k=1}^{N} Daily\_CDD_k \tag{5}$$

For both HDD and CDD, only positive values were counted.

HDD and CDD from Environment Canada data sets

Because the Environment Canada (EC) data sets represented real observations in contrast to the CWEC synthesized Typical Meteorological Year, HDD and CDD formulas used in processing the EC data were adjusted to give full weight to quadri-annual instances of a 29-day February. Monthly HDD/CDD values were normalized by the average number of days in a month (30.5 days).

$$\text{Normalized HDD} = (\mathit{Monthly\_HDD} / \text{N}) \times 30.5 \tag{6}$$

$$\text{Normalized CDD} = (\mathit{Monthly\_CDD} / \text{N}) \times 30.5 \tag{7}$$

where N = number of days in month (February has 28 days but 29 days in leap-years).

Cluster analyses for allocating months to seasons

The data was subjected to cluster analyses using the SAS statistical analysis software procedures PROC CLUSTER (Ward's minimum variance method) and PROC TREE. SAS software made available a choice of eleven different clustering methods. Four of these clustering methods (Ward, average, complete, and single linkage) were tested on the CWEC data for Vancouver Airport —all gave the same result.

The SAS 9.2 User's Guide stated:

Many simulation studies comparing various methods of cluster analysis have been performed. In these studies, artificial data sets containing known clusters are produced using pseudo-random-number generators. The data sets are analyzed by a variety of clustering methods, and the degree to which each clustering method recovers the known cluster is evaluated…In most of these studies, the clustering method with the best overall performance has been either average linkage or Ward's minimum variance method.

On this basis, classification of months into seasons used Ward's method as the standard.

Regression analyses for HDD/CDD relationships between Vancouver and other BC stations

The strength of HDD and CDD relationships between Vancouver and each of Victoria, Prince George, and Kelowna was examined using regression analyses. This was done to determine if it would be appropriate to use Vancouver's HDD/CDD and seasons as a proxy for these three parameters in the rest of BC.

Temporal stability analyses of HDD and CDD regimes

Possible cycles and trends were noticed in the charts of HDD and CDD against time spanning almost six decades. Trends and cycles were analysed in a separate project (Wahlgren, 2010) to discover whether or not the cycles or trends were statistically significant and likely to affect the seasonal classification.

Sensitivity analyses of Vancouver's HDD/CDD to changes in the north-eastern Pacific Ocean climate regime

The sensitivity of HDD and CDD in the four BC Hydro sales regions to changes in the North-eastern Pacific Ocean's climate regime was checked against several indices in a separate project (Wahlgren, 2010). Again, the goal was to see if the sensitivity was great enough to affect the classification of months into seasons.

Results of cluster analyses

CWEC data sets—allocation of months to seasons

The CWEC data sets provided spatial information on HDD and CDD representing the more densely populated regions in British Columbia. HDD and CDD results were tabulated in Appendix 1 along with the tree diagrams illustrating results of the cluster analyses.

HDD and CDD results for the twelve stations were summarized in Tables 2 and 3. Summer always included June, July, and August. Winter always included November-March. The shaded values were associated with shoulder months which were defined by the cluster analyses. Figures 1 and 2 are visual representations of Tables 2 and 3 respectively. Months along the time-axis run from April to March to correspond to BC Hydro’s fiscal year of April 1–March 31. In this manner, the summer and winter seasons are kept intact. Calendar year chart presentations interrupt BC’s winter season. The vertical lines bracket the beginning and end of the shoulder month pairs: April and May; September and October.

Table 2

Summary of CWEC Station Results													
HDD													
Month	**Abbotsford**	**Comox**	**Fort St John**	**Kamloops**	**Port Hardy**	**Prince George**	**Prince Rupert**	**Sandspit**	**Smithers**	**Summerland**	**Vancouver**	**Victoria**	***% of all BC shoulder mo.***
Apr	287	283	418	263	343	389	370	365	403	279	279	285	*0.75*
May	184	208	254	114	263	243	291	280	295	133	191	196	*0.58*
Jun	109	111	125	41	195	148	220	195	174	42	88	111	
Jul	48	45	92	8	145	113	157	136	87	19	35	73	
Aug	42	34	118	15	146	94	145	107	124	21	30	62	
Sep	134	136	272	98	203	215	209	158	134	114	127	146	*0.17*
Oct	243	272	428	309	302	410	314	276	416	281	253	254	*0.92*
Nov	382	376	740	453	377	612	441	349	654	423	382	346	
Dec	449	456	910	663	445	747	517	447	805	573	445	426	
Jan	470	494	985	691	481	892	563	513	820	611	459	441	
Feb	396	377	807	536	399	653	464	414	612	463	361	368	
Mar	389	385	714	438	415	554	460	404	606	429	369	367	
	Shading denotes month in shoulder season												

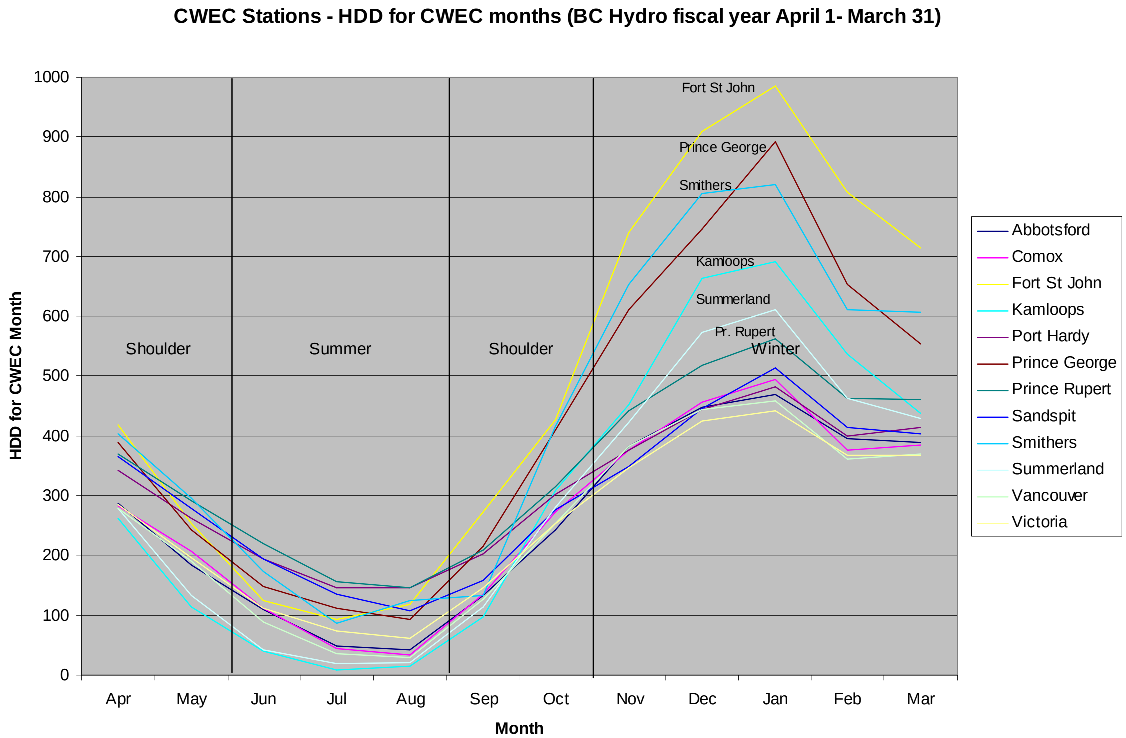


Figure 1: Summary of CWEC Station results for HDD

Table 3

Summary of CWEC Station Results													
CDD													
Month	Abbotsford	Comox	Fort St John	Kamloops	Port Hardy	Prince George	Prince Rupert	Sandspit	Smithers	Summerland	Vancouver	Victoria	*% of all BC shoulder mo.*
Apr	0	0	0	0	0	0	0	0	0	0	0	0	*0.75*
May	6	0	0	11	0	0	0	0	0	3	0	0	*0.58*
Jun	0	2	6	55	0	3	0	0	0	38	0	0	
Jul	13	16	7	112	0	4	0	0	20	84	3	5	
Aug	14	11	12	86	0	8	0	0	2	59	1	3	
Sep	0	0	0	23	0	0	0	0	0	15	0	0	*0.17*
Oct	0	0	0	0	0	0	0	0	0	0	0	0	*0.92*
Nov	0	0	0	0	0	0	0	0	0	0	0	0	
Dec	0	0	0	0	0	0	0	0	0	0	0	0	
Jan	0	0	0	0	0	0	0	0	0	0	0	0	
Feb	0	0	0	0	0	0	0	0	0	0	0	0	
Mar	0	0	0	0	0	0	0	0	0	0	0	0	
	Shading denotes month in shoulder season												

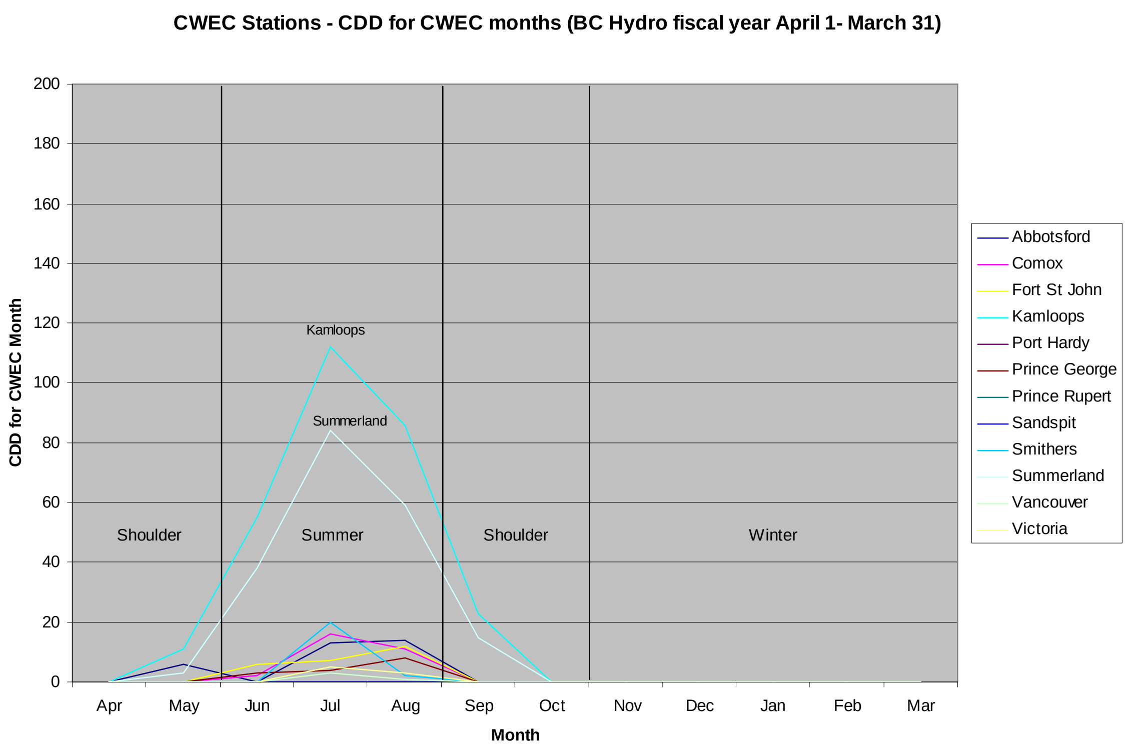


Figure 2: Summary of CWEC Station results for CDD

Environment Canada data sets—allocation of months to seasons

The essential value of the Environment Canada data sets for Vancouver Airport, Victoria Airport, Kelowna Airport and Prince George Airport was to provide a temporal view of HDD and CDD in British Columbia. Trends or cycles in mean monthly HDD and CDD were apparent in the charts shown in this section. Trends may be associated with global climate change and cycles with climate variability (related to, for example, the Pacific Decadal Oscillation, PDO, with a period of 50–60 years; BC, 2002). Trends and/or cycles may affect electrical load demand for space heating in the future. Quantitative analyses of trends and cycles were done in a separate report (Wahlgren, 2010). Here, it is relevant to mention that Wahlgren (2010) used Kamloops Airport air temperature data (which is being collected on an ongoing basis commencing 1994) rather than Kelowna Airport data (which ceased being collected in 2004 and had a major gap 1994–2001).

HDD and CDD results were tabulated in Appendix 2 along with the tree diagrams illustrating results of the cluster analyses. Tables 4–12 summarize the HDD/CDD calculations for the four EC stations. Figures 3–19 are visual representations of the tabulated values. Similar to the analyses for the synthesized CWEC data, charts show how HDD and CDD varied by month. Because the EC data were from actual observations, it was also possible to produce a set of charts showing how HDD/CDD varied through the six decades of 1953–2008.

Results were similar to those for the CWEC data. Summer always included June, July, and August. Winter comprised November–March. April and October were always shoulder months. September and May switched between the shoulder and summer seasons.

Table 4: Summary of Vancouver Airport mean monthly HDD based on 10-year intervals. Compare to Table 5

Summary of Vancouver Airport Results							
HDD							
Month	**Y1953-2008**	Y1953-1959	Y1960-1969	Y1970-1979	Y1980-1989	Y1990-1999	Y2000-2008
Apr	**273**	278	285	292	271	250	264
May	**169**	152	184	190	173	150	161
Jun	**89**	97	85	103	92	82	79
Jul	**35**	38	40	44	40	26	19
Aug	**34**	39	46	46	32	23	21
Sep	**110**	113	116	125	117	89	102
Oct	**240**	247	236	256	237	234	231
Nov	**359**	368	350	383	360	344	351
Dec	**432**	411	432	441	445	435	424
Jan	**447**	456	468	478	435	429	414
Feb	**405**	429	398	411	405	393	399
Mar	**355**	382	370	367	339	336	340
	Shading denotes month in shoulder season						

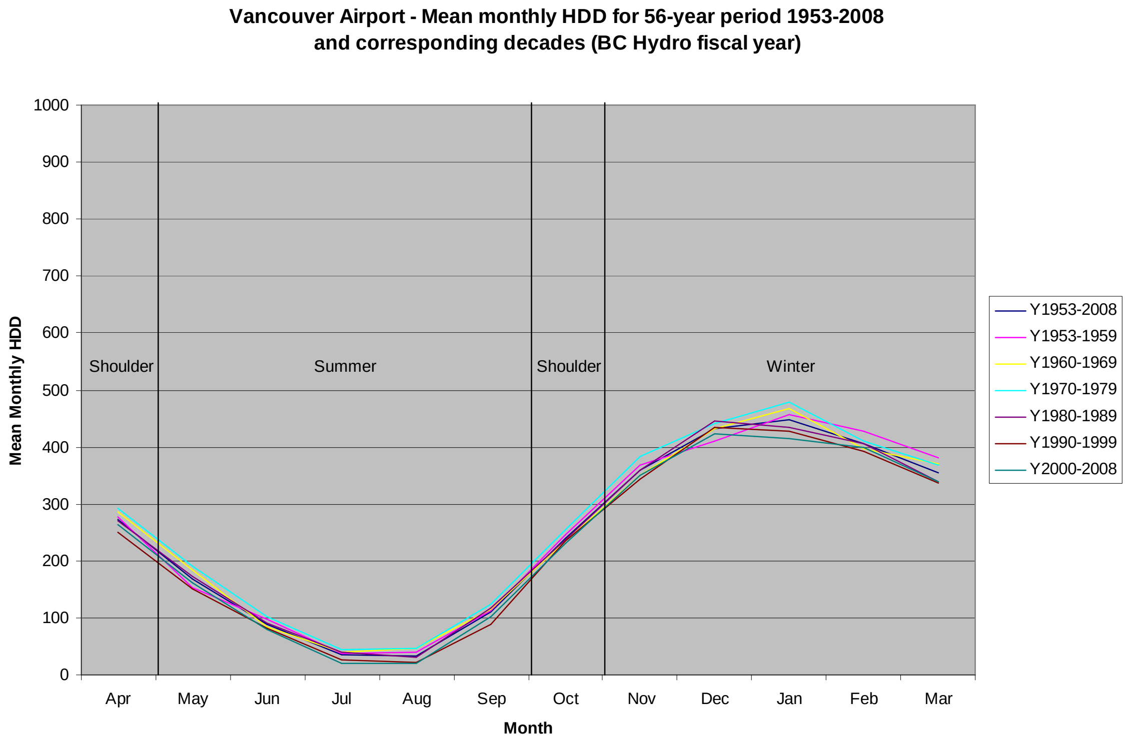


Figure 3: Vancouver Airport mean monthly HDD for 1953–2008 and corresponding decades

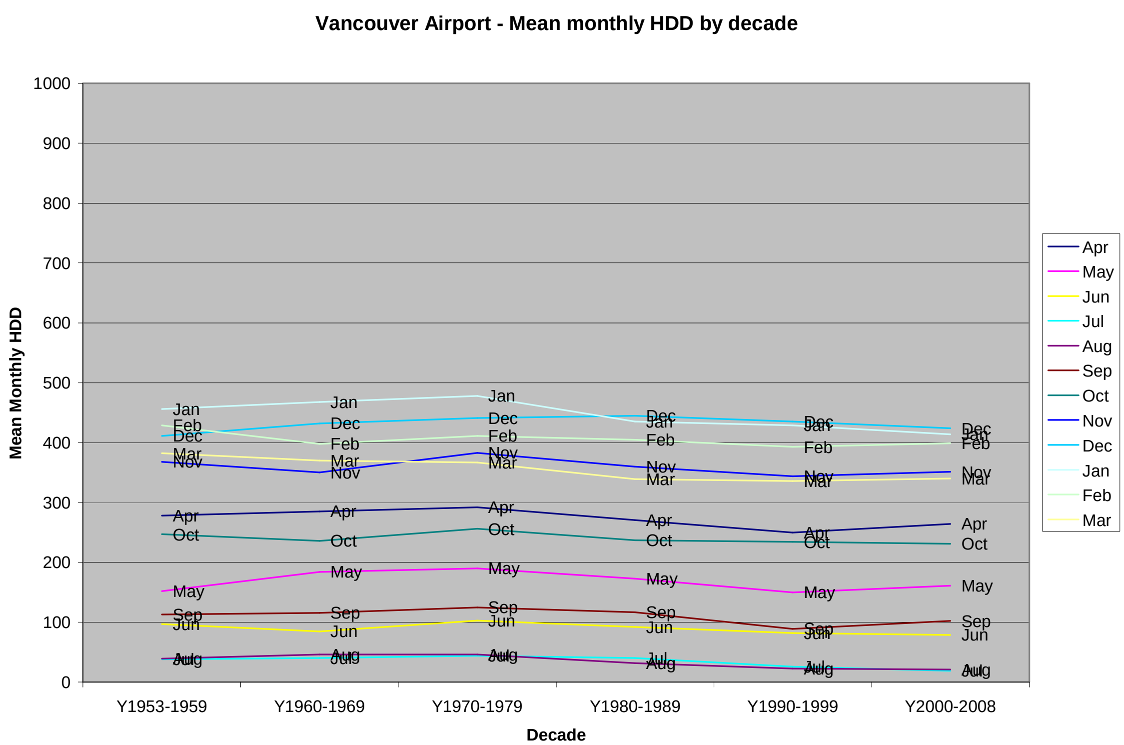


Figure 4: Vancouver Airport mean monthly HDD through six decades with hints of trends and cycles. See Figure 5 which is by half-decade, doubling number of data points. See also Table 13 which recorded significant (0.05 level) decreasing HDD trends for the Lower Mainland in Apr, Jun, Jul, Aug, Sep, Jan, and Mar based on analyses in Wahlgren (2010)

Table 5: Summary of Vancouver Airport mean monthly HDD based on 5-year intervals.
Compare to Table 4

Summary of Vancouver Airport Results

HDD

Month	Y1953-1954	Y1955-1959	Y1960-1964	Y1965-1969	Y1970-1974	Y1975-1979	Y1980-1984	Y1985-1989	Y1990-1994	Y1995-1999	Y2000-2004	Y2005-2008
Median Year Reference for chart plot	1953.5	1957	1962	1967	1972	1977	1982	1987	1992	1997	2002	2006.5
Apr	292	272	274	297	300	285	278	263	242	258	257	273
May	162	148	187	182	189	190	178	168	143	157	170	149
Jun	125	85	87	83	109	97	104	81	83	80	71	88
Jul	46	34	41	39	52	37	47	32	26	25	22	15
Aug	45	37	44	45	42	50	36	28	23	23	21	23
Sep	109	114	117	116	133	116	122	112	93	85	98	107
Oct	242	249	233	238	272	240	251	224	230	238	228	235
Nov	293	398	361	340	375	392	349	372	360	327	350	352
Dec	393	418	437	428	449	432	462	427	442	428	408	444
Jan	451	458	454	483	483	472	436	433	437	421	405	426
Feb	399	440	383	413	409	413	382	428	405	381	399	398
Mar	383	381	370	370	366	367	336	343	332	340	345	334

Shading denotes month in shoulder season

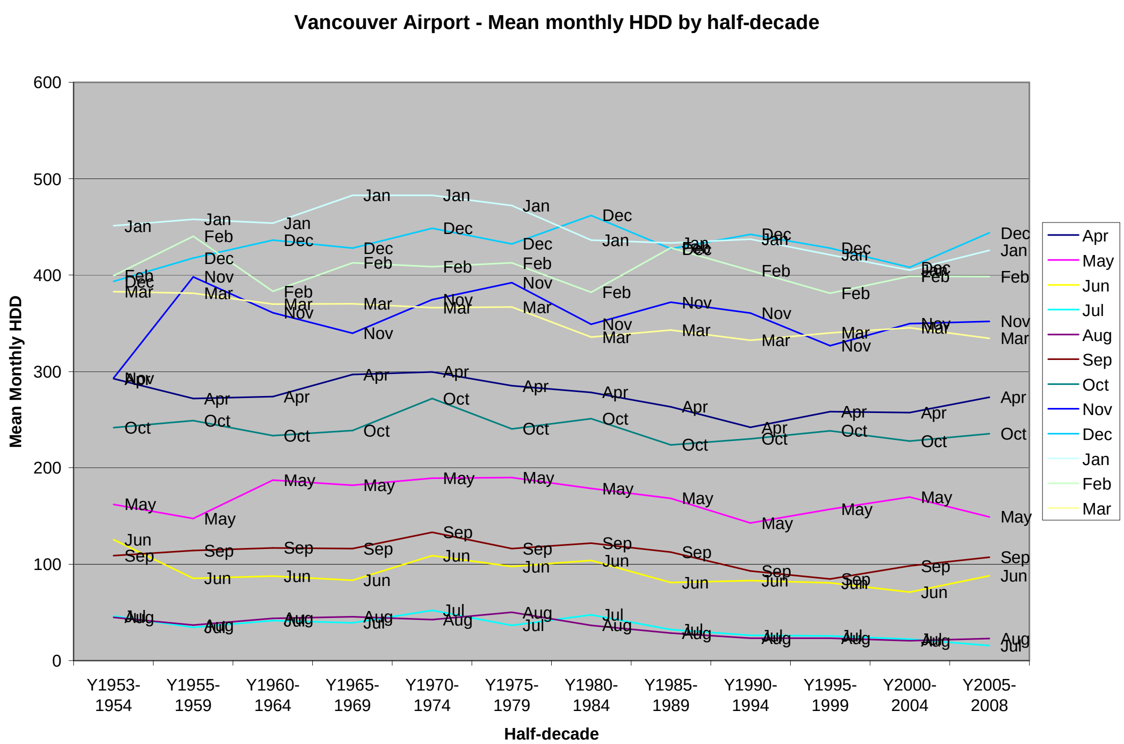


Figure 5: Vancouver Airport mean monthly HDD through six decades. See summary of decreasing HDD trends by month in Table 13

Table 6

Summary of Vancouver Airport Results							
CDD							
Month	**Y1953-2008**	Y1953-1959	Y1960-1969	Y1970-1979	Y1980-1989	Y1990-1999	Y2000-2008
Apr							
May	**2**	2	1	0	6	1	2
Jun	**7**	12	6	4	7	6	9
Jul	**20**	26	18	15	13	23	26
Aug	**16**	8	12	13	14	25	18
Sep	**2**	1	1	1	3	3	2
Oct							
Nov	**0**	0	0	0	0	0	0
Dec	**0**	0	0	0	0	0	0
Jan	**0**	0	0	0	0	0	0
Feb	**0**	0	0	0	0	0	0
Mar	**0**	0	0	0	0	0	0
	Shading denotes month in shoulder season						

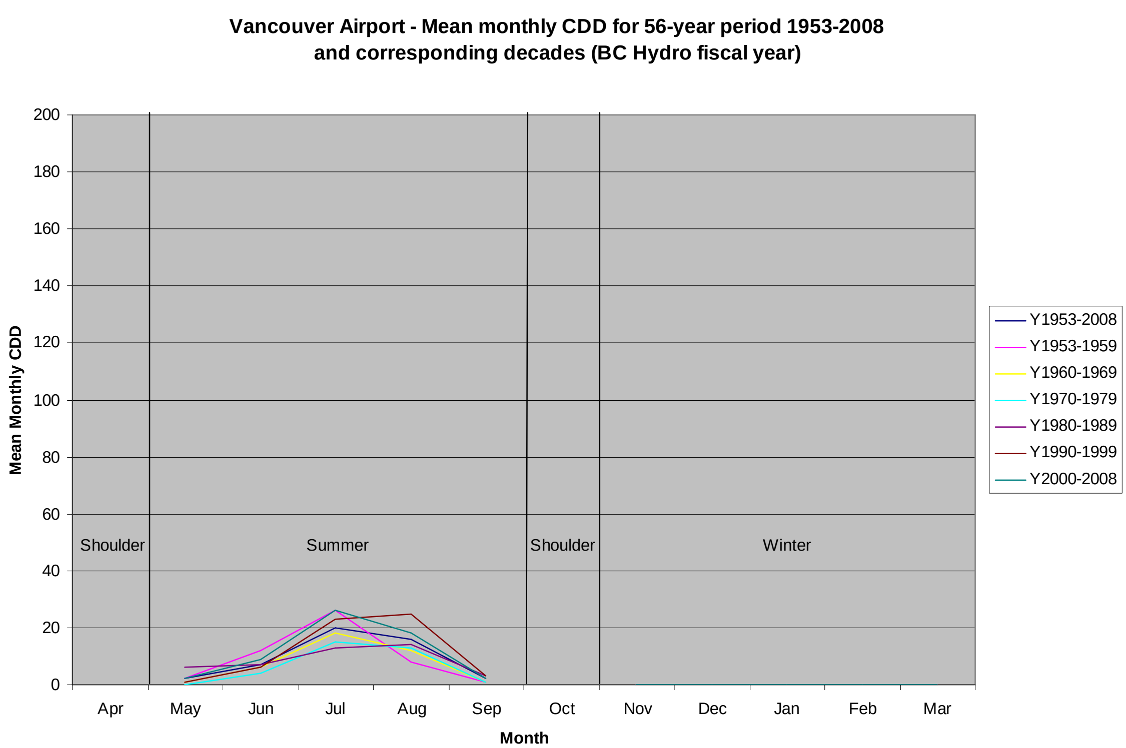


Figure 6: Vancouver Airport mean monthly CDD for 1953–2008 and corresponding decades

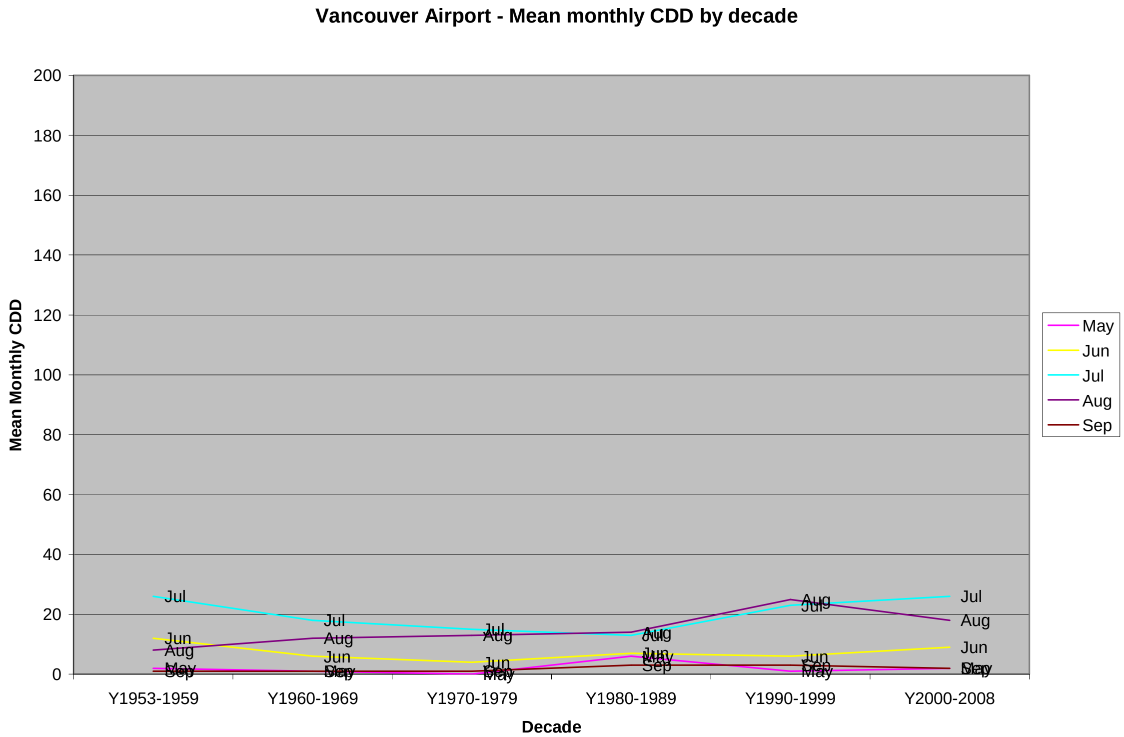


Figure 7: Vancouver Airport mean monthly CDD through six decades. CDD trend summary is in Table 14.

Table 7

Summary of Victoria Airport Results							
HDD							
Month	**Y1953-2008**	Y1953-1959	Y1960-1969	Y1970-1979	Y1980-1989	Y1990-1999	Y2000-2008
Apr	**282**	290	294	298	277	260	274
May	**184**	170	197	203	189	164	176
Jun	**108**	118	108	121	111	100	92
Jul	**55**	65	60	66	60	44	37
Aug	**60**	68	68	74	57	47	45
Sep	**130**	130	136	139	135	115	123
Oct	**250**	256	245	261	247	247	242
Nov	**356**	364	352	375	356	338	354
Dec	**418**	405	419	424	430	410	412
Jan	**431**	442	448	458	420	411	405
Feb	**400**	423	392	405	403	384	400
Mar	**357**	384	370	370	345	338	342
	Shading denotes month in shoulder season						

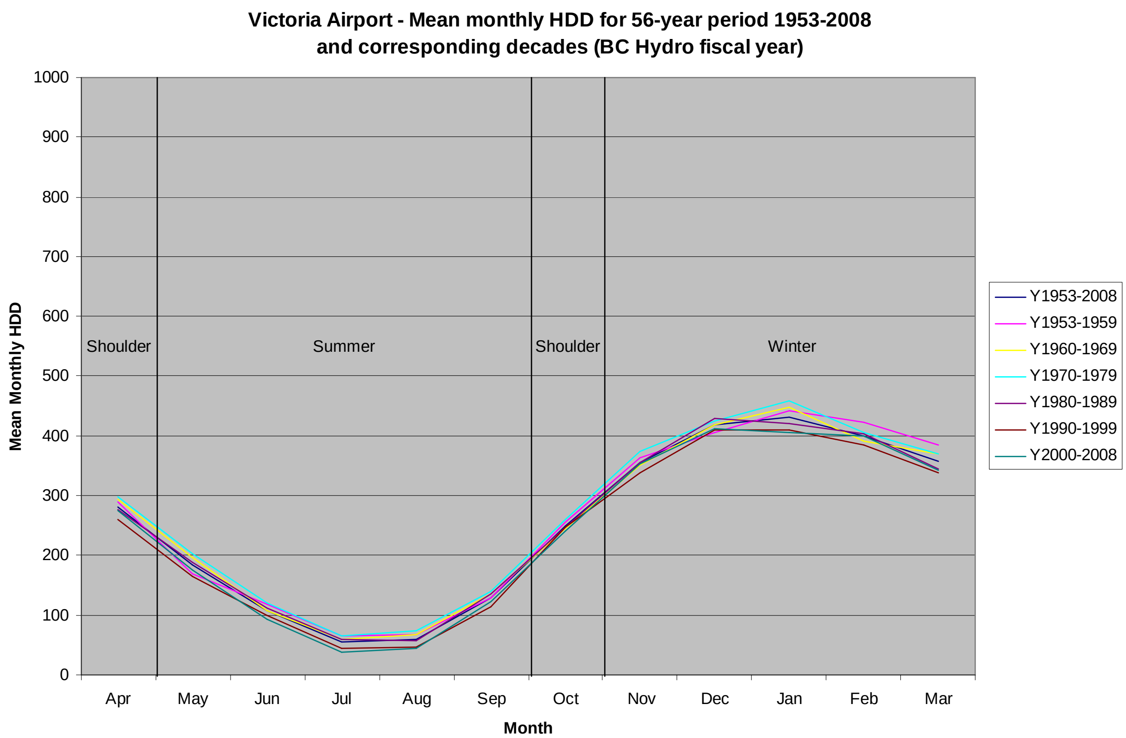


Figure 8: Victoria Airport mean monthly HDD for 1953–2008 and corresponding decades

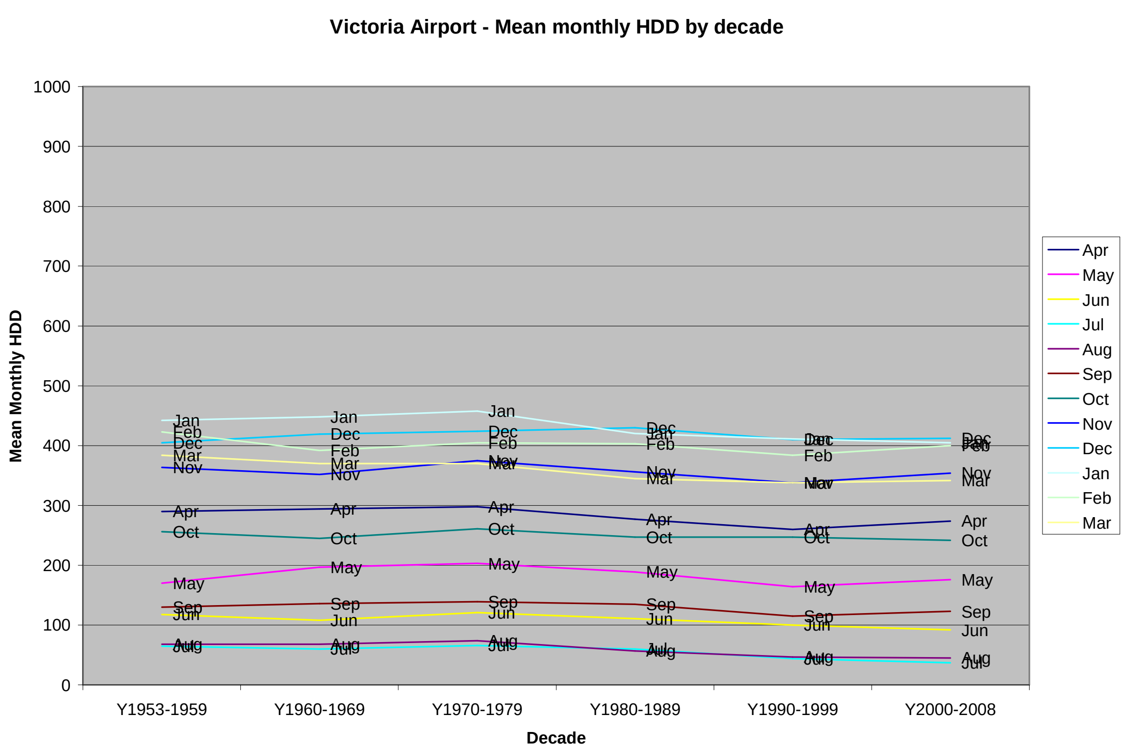


Figure 9: Victoria Airport mean monthly HDD through six decades.
HDD trend summary is in Table 13.

Table 8

Summary of Victoria Airport Results							
CDD							
Month	**Y1953-2008**	Y1953-1959	Y1960-1969	Y1970-1979	Y1980-1989	Y1990-1999	Y2000-2008
Apr	**0**	0	0	0	0	0	0
May	**3**	1	3	3	4	1	3
Jun	**6**	9	4	3	5	5	9
Jul	**12**	17	12	10	7	15	16
Aug	**8**	4	7	9	9	10	8
Sep	**2**	2	2	3	3	1	2
Oct							
Nov	**0**	0	0	0	0	0	0
Dec	**0**	0	0	0	0	0	0
Jan	**0**	0	0	0	0	0	0
Feb	**0**	0	0	0	0	0	0
Mar	**0**	0	0	0	0	0	0
	Shading denotes month in shoulder season						

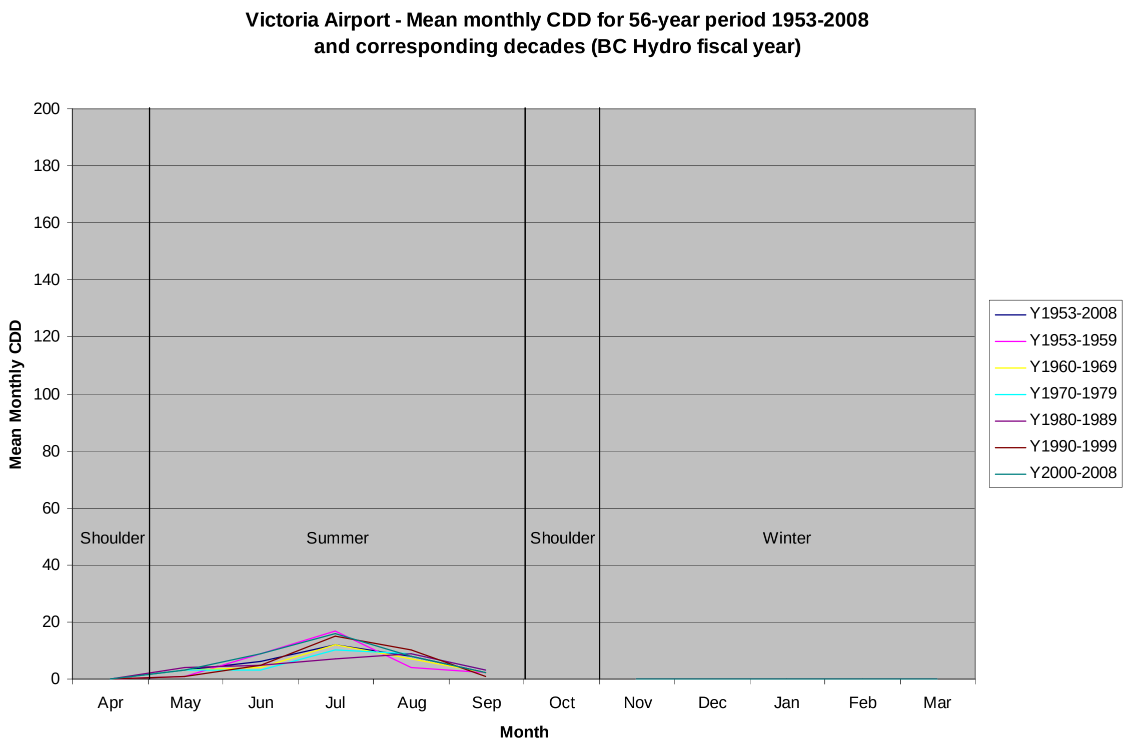


Figure 10: Victoria Airport mean monthly CDD for 1953–2008 and corresponding decades

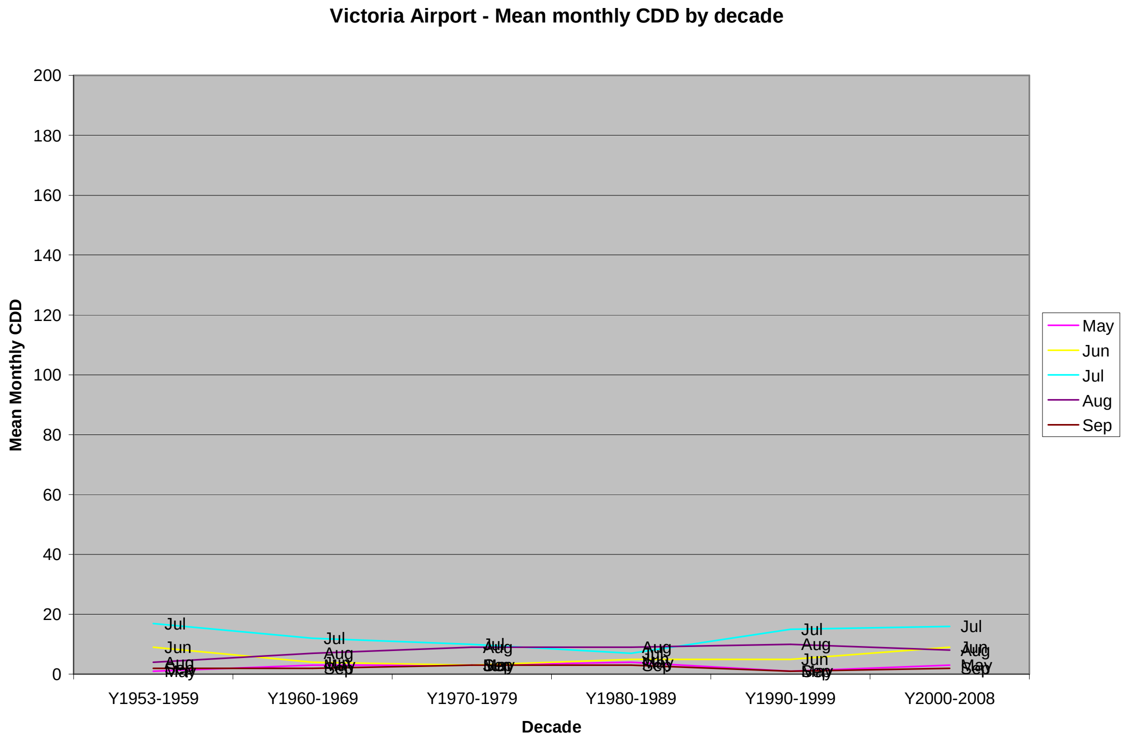


Figure 11: Vancouver Airport mean monthly CDD through six decades. CDD trend summary is in Table 14.

Table 9

Summary of Prince George Airport Results							
HDD							
Month	**Y1953-2008**	Y1953-1959	Y1960-1969	Y1970-1979	Y1980-1989	Y1990-1999	Y2000-2008
Apr	**409**	455	419	410	397	382	406
May	**246**	229	268	266	240	221	245
Jun	**142**	151	148	157	141	129	124
Jul	**86**	97	85	98	87	73	80
Aug	**115**	144	121	116	114	93	112
Sep	**253**	255	259	270	258	224	253
Oct	**413**	427	400	411	400	427	416
Nov	**625**	629	621	661	625	617	595
Dec	**767**	730	783	804	785	748	737
Jan	**842**	934	879	904	763	832	759
Feb	**711**	778	683	736	715	669	702
Mar	**579**	630	599	580	558	553	567
	Shading denotes month in shoulder season						

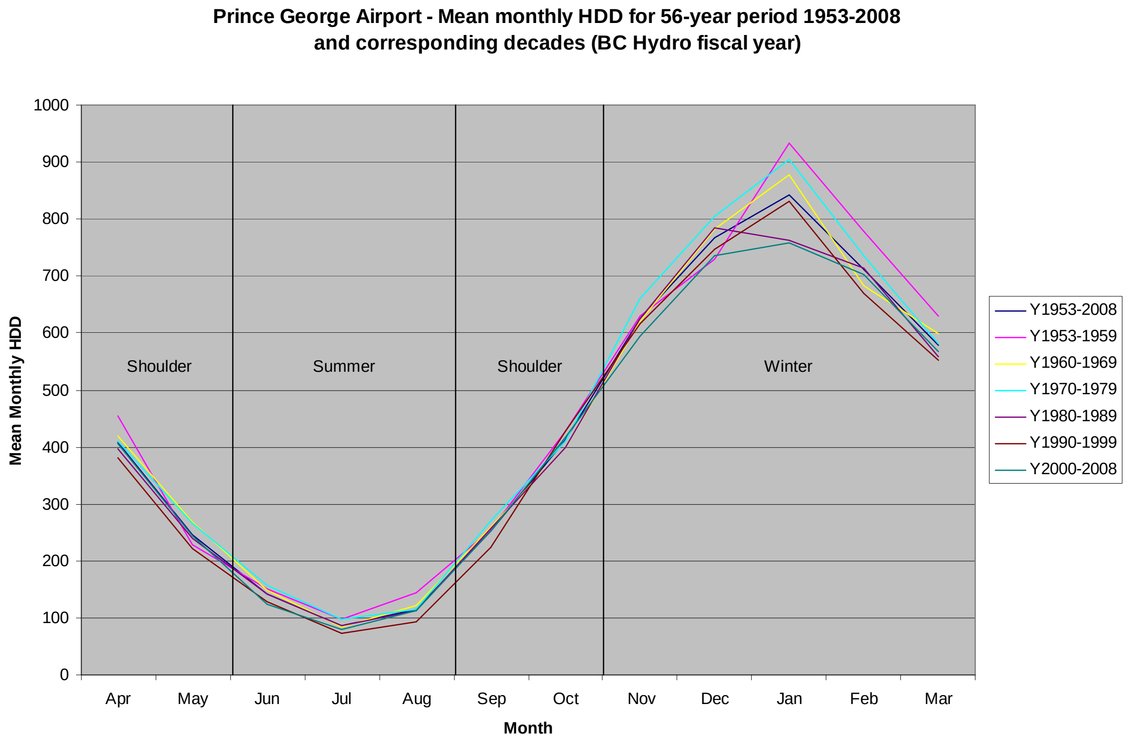


Figure 12: Prince George Airport mean monthly HDD for 1953–2008 and corresponding decades

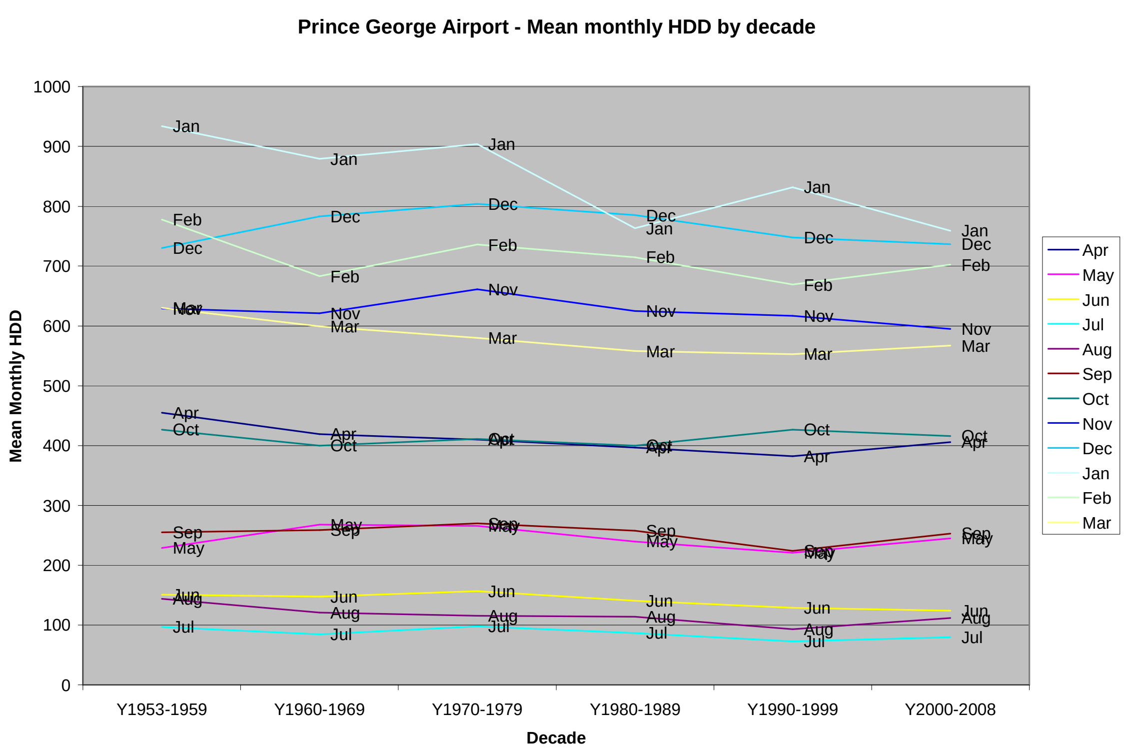


Figure 13: Prince George Airport mean monthly HDD through six decades. HDD trend summary is in Table 13

Table 10

Summary of Prince George Airport Results							
CDD							
Month	**Y1953-2008**	Y1953-1959	Y1960-1969	Y1970-1979	Y1980-1989	Y1990-1999	Y2000-2008
Apr	**1**	0	0	1	0	0	0
May	**3**	1	1	2	17	5	3
Jun	**7**	12	6	4	6	8	8
Jul	**13**	12	11	16	10	12	15
Aug	**9**	4	9	7	7	15	10
Sep	**1**	0	0	0	2	1	1
Oct	**0**	0	0	0	0	0	0
Nov	**0**	0	0	0	0	0	0
Dec	**0**	0	0	0	0	0	0
Jan	**0**	0	0	0	0	0	0
Feb	**0**	0	0	0	0	0	0
Mar	**0**	0	0	0	0	0	0
	Shading denotes month in shoulder season						

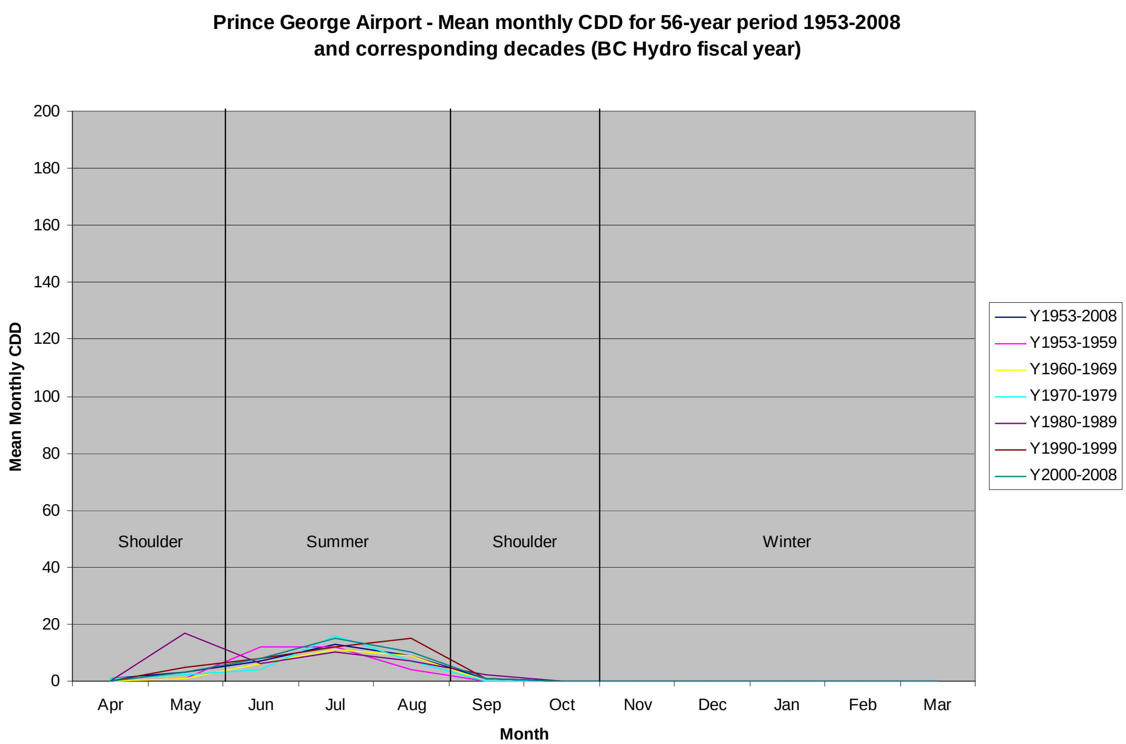


Figure 14: Prince George Airport mean monthly CDD for 1953–2008 and corresponding decades

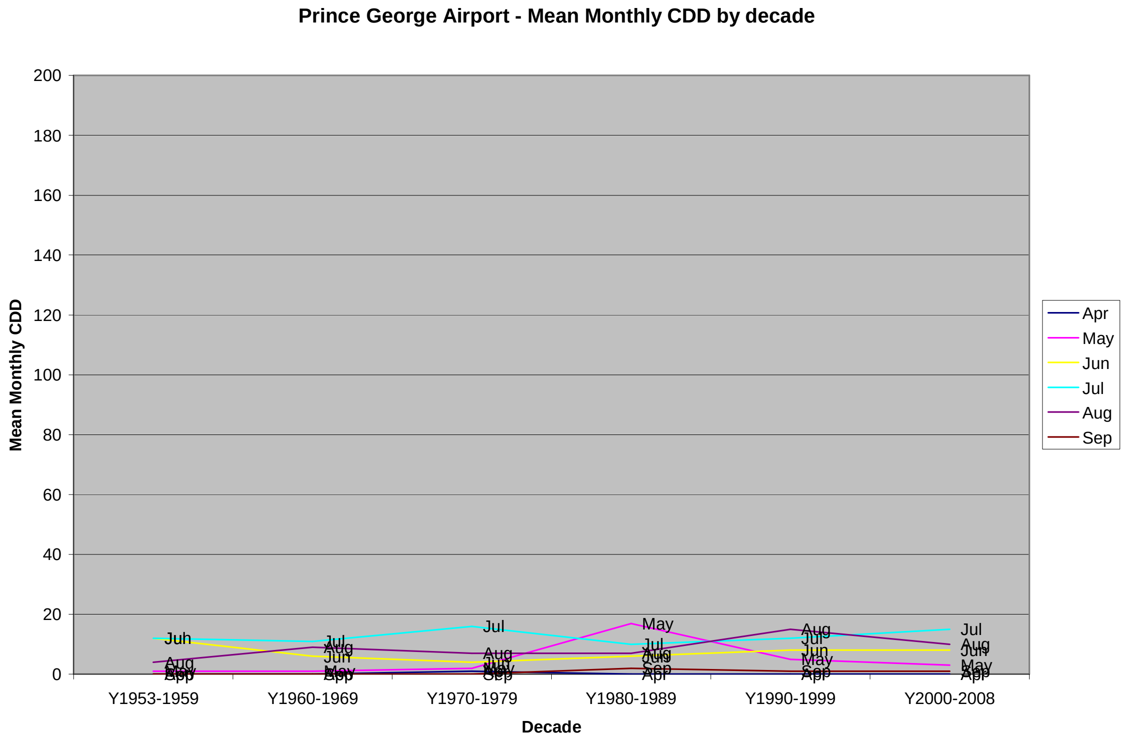


Figure 15: Prince George Airport mean monthly CDD through six decades. CDD trend summary is in Table 14

Table 11

Summary of Kelowna Airport Results						
HDD						
Month	**Y1961-2004**	Y1961-1969	Y1970-1979	Y1980-1989	Y1990-1993	Y2002-2004
Apr	**271**	232	311	272	250	285
May	**134**	91	170	136	114	169
Jun	**46**	20	63	51	48	43
Jul	**16**	7	21	22	13	7
Aug	**23**	16	32	20	21	18
Sep	**128**	84	158	144	103	143
Oct	**310**	259	345	321	310	329
Nov	**496**	465	520	503	498	509
Dec	**619**	595	634	639	641	556
Jan	**658**	653	711	630	657	595
Feb	**568**	529	597	582	553	565
Mar	**430**	408	468	416	408	446
	Shading denotes month in shoulder season					

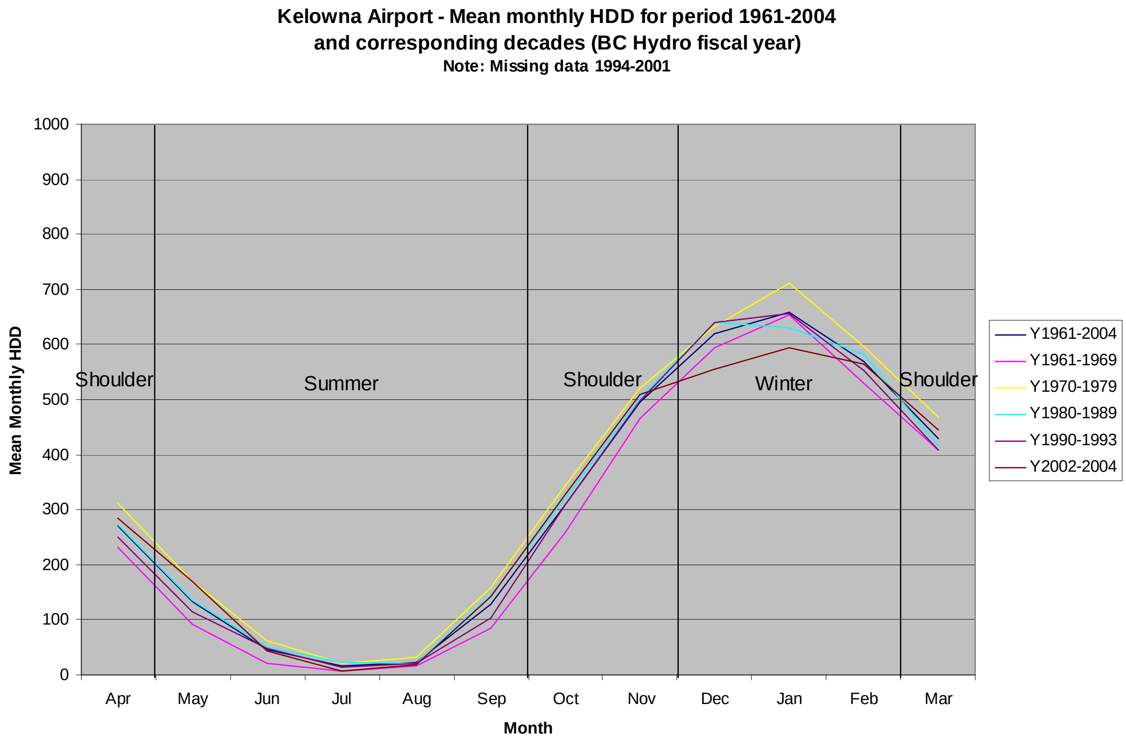


Figure 16: Kelowna Airport mean monthly HDD for 1961–2004 and corresponding decades. Data is missing from 1994–2001

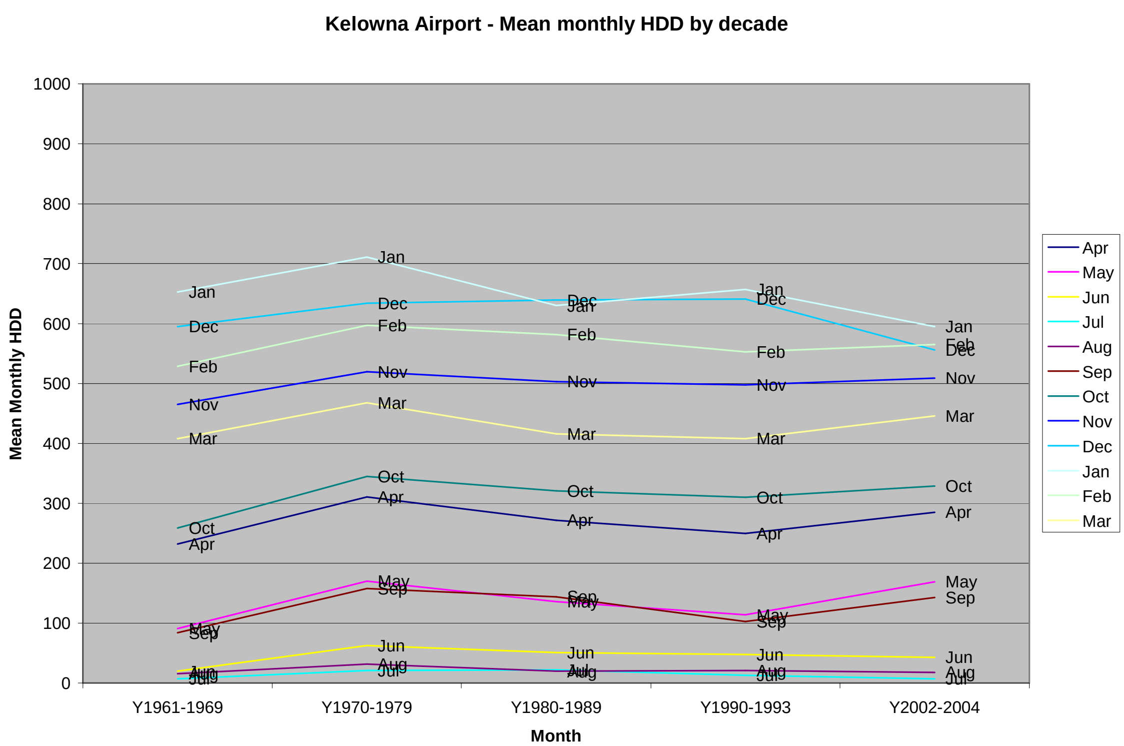


Figure 17: Kelowna Airport mean monthly HDD through five decades

Table 12

Summary of Kelowna Airport Results						
CDD						
Month	**Y1961-2004**	Y1961-1969	Y1970-1979	Y1980-1989	Y1990-1993	Y2002-2004
Apr	**2**	2	0	0	0	0
May	**14**	24	4	9	22	1
Jun	**52**	92	28	44	45	45
Jul	**102**	157	78	82	82	109
Aug	**84**	132	62	62	91	70
Sep	**13**	30	2	9	8	7
Oct	**1**	1	0	0	0	0
Nov	**0**	0	0	0	0	0
Dec	**0**	0	0	0	0	0
Jan	**0**	0	0	0	0	0
Feb	**0**	0	0	0	0	0
Mar	**0**	0	0	0	0	0
	Shading denotes month in shoulder season					

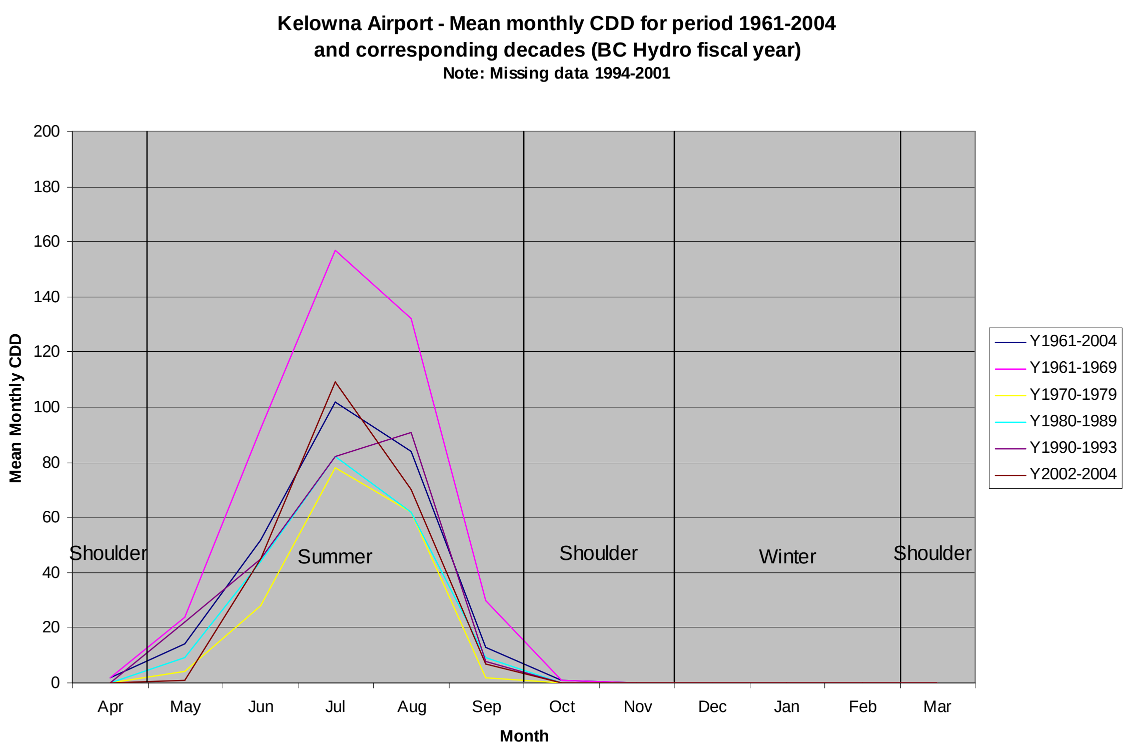


Figure 18: Kelowna Airport mean monthly CDD for 1961–2004 and corresponding decades. Data is missing from 1994–2001

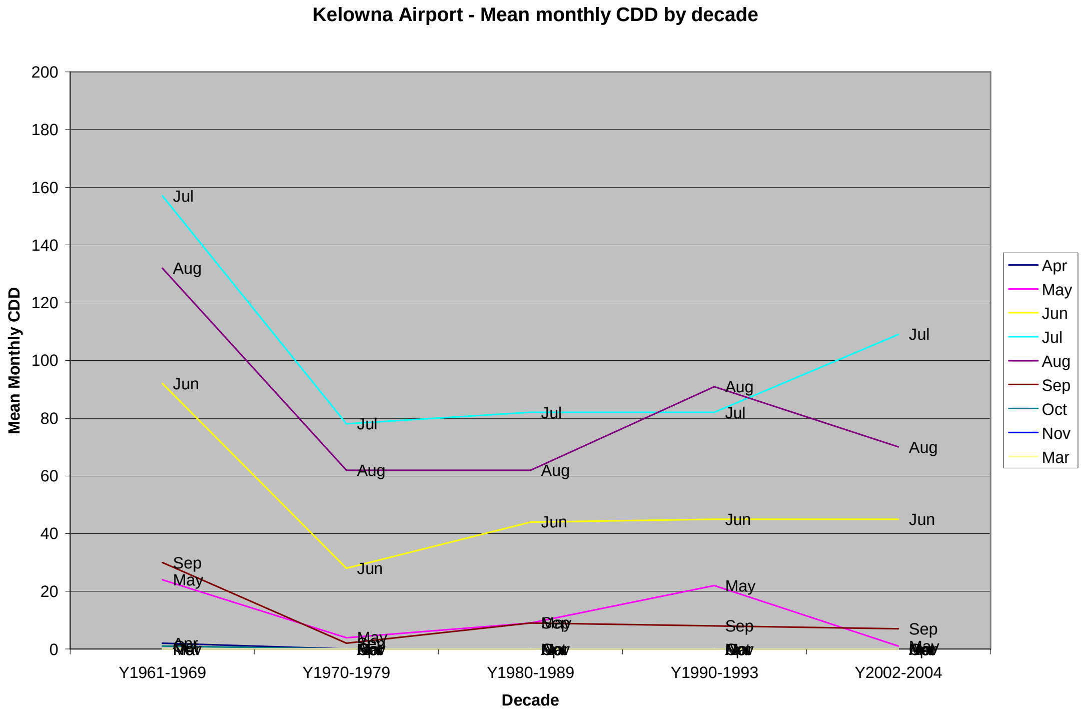


Figure 19: Kelowna Airport mean monthly CDD through five decades

Results of analyses of heating and cooling degree day relationships between Vancouver and other BC stations

For practical reasons, related to the structure of BC Hydro's rate class and site type data sets, the Vancouver Airport station weather data is used often as a proxy for weather throughout the rest of BC. This was the case for weather sensitivity analyses. Therefore, it was of interest to examine the relationships between monthly HDD/CDD in Victoria, Kelowna, and Prince George to monthly HDD/CDD in Vancouver.

Heating degree days

Simple regression and polynomial (order = 2) regression tested monthly HDD relationships between Vancouver and the three other stations (Figures 20–23). The relationships were significant at the 95% level, supporting the practice of using, when necessary, Vancouver HDD data as a proxy for HDD in the rest of BC.

Figure 20 shows that Vancouver monthly HDDs are excellent proxies for Victoria HDDs. Loads in Lower Mainland and Vancouver Island can be treated as being from a single region for season definition purposes — together, these two regions comprise 70% of the BC Hydro system total load, 85% of the BC Hydro distribution grid total energy delivered to residential electrically heated buildings, and 84% of the BC Hydro distribution grid total electrical demand of these buildings (Wahlgren, 2009). Where the HDD correlation is weaker, as for Kelowna (Figure 22), the system load proportion affected is small, reducing the influence of the weaker correlation on the analyses.

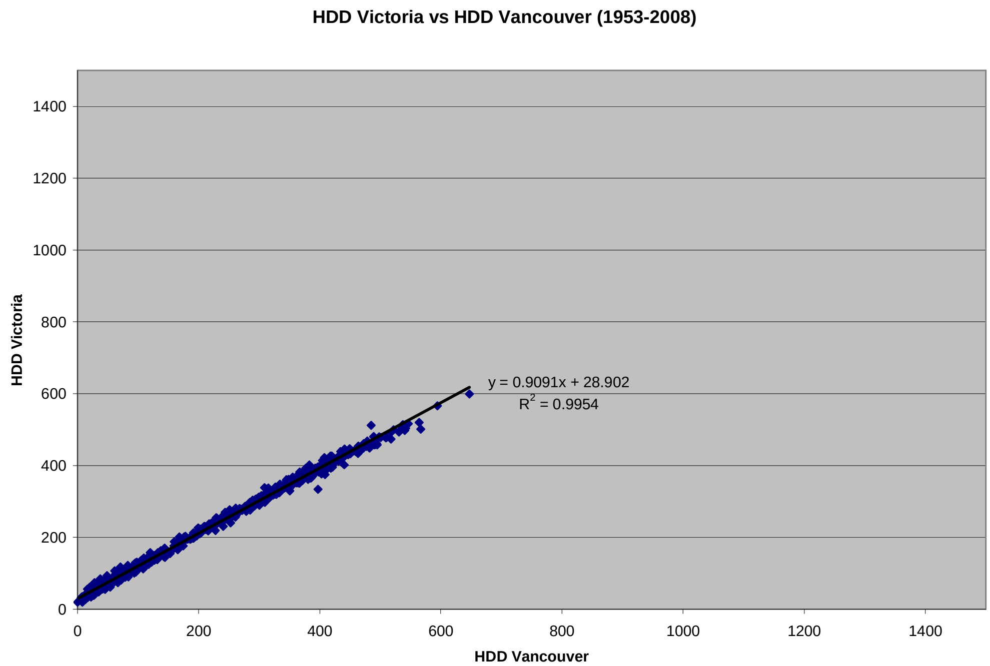


Figure 20: Regression line for monthly HDD values in Victoria against HDD in Vancouver. Regression coefficient (0.9091) suggests that in a given month, Victoria experiences 10% less HDDs than Vancouver. For 56 years of observations, there were 672 monthly mean HDD values. The relationship is significant at the 95% level

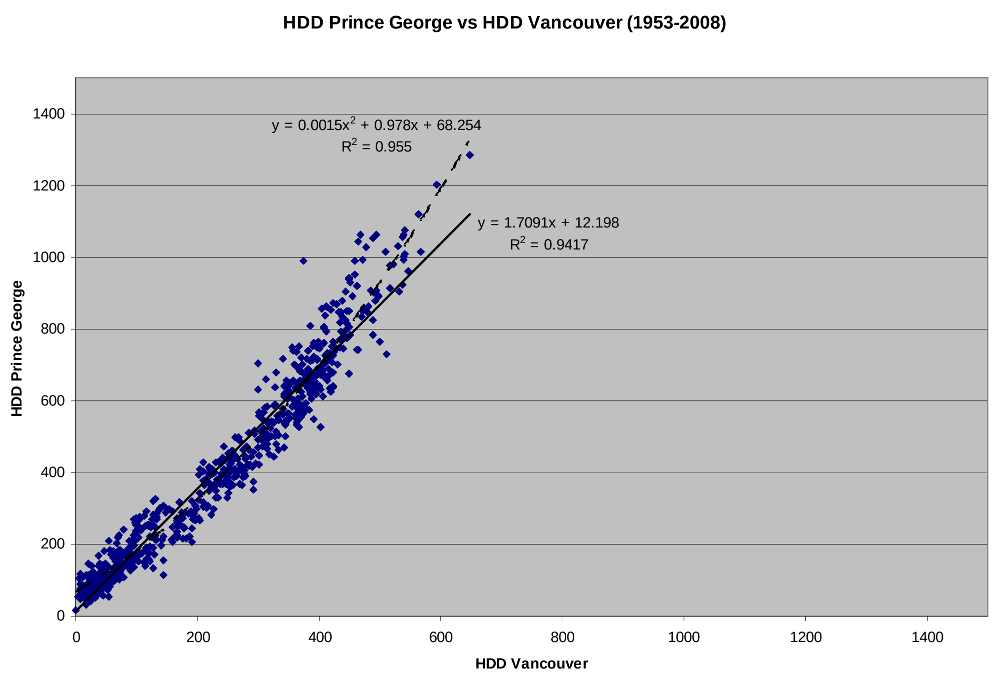


Figure 21: Regression lines between HDD values in Prince George against HDD in Vancouver. The linear regression coefficient suggests that in a given month, Prince George experiences 1.7 times more HDDs than Vancouver. For 56 years of observations, there were 672 monthly mean HDD values. Both relationships were significant at the 95% level. The polynomial of order 2 is a better fit than the linear regression and better represents the physical reality that Prince George, being more northerly and continental than Vancouver, experiences colder winters than Vancouver

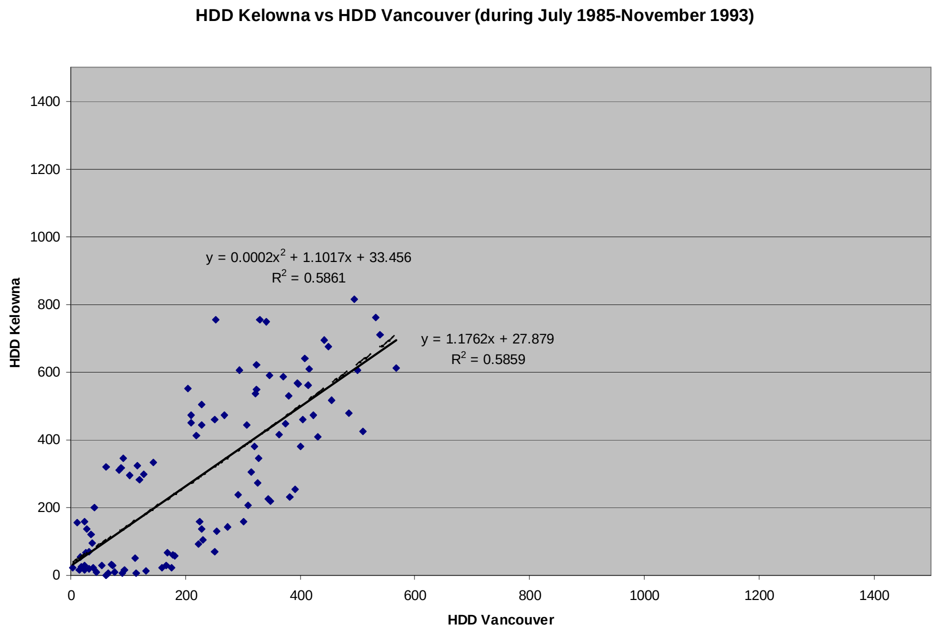


Figure 22: Regression lines between HDD values in Kelowna against HDD in Vancouver for July 1985 to November 1993. The linear regression coefficient suggests that in a given month Kelowna experiences 1.2 times more HDDs than Vancouver. For 101 months of observations, there were 101 monthly mean HDD values. Both relationships were significant at the 95% level. The polynomial of order 2 is a better fit than the linear regression representing the physical reality that Kelowna, being more northerly and continental than Vancouver, experiences colder winters than Vancouver

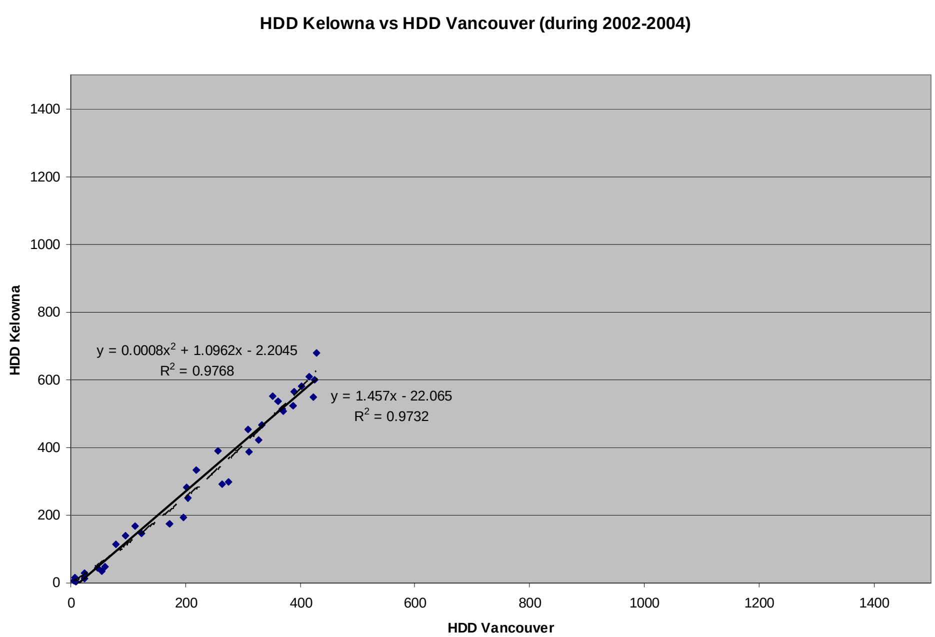


Figure 23: Regression between HDD values in Kelowna against HDD in Vancouver for 2002 to 2004. The linear regression coefficient suggests that in a given month Kelowna experiences 1.5 times more HDDs than Vancouver. For 36 months of observations, there were 36 monthly mean HDD values. Both relationships were significant at the 95% level. The polynomial of order 2 is a better fit than the linear regression representing the physical reality that Kelowna, being more northerly and continental than Vancouver, experiences colder winters than Vancouver

Cooling degree days

Simple regression was used to test the monthly CDD relationships between Vancouver and the three other stations (Figures 24–26). The relationships were significant at the 95% level in all cases, supporting the practice of using, when necessary, Vancouver monthly CDD data as a proxy for CDDs in the rest of BC.

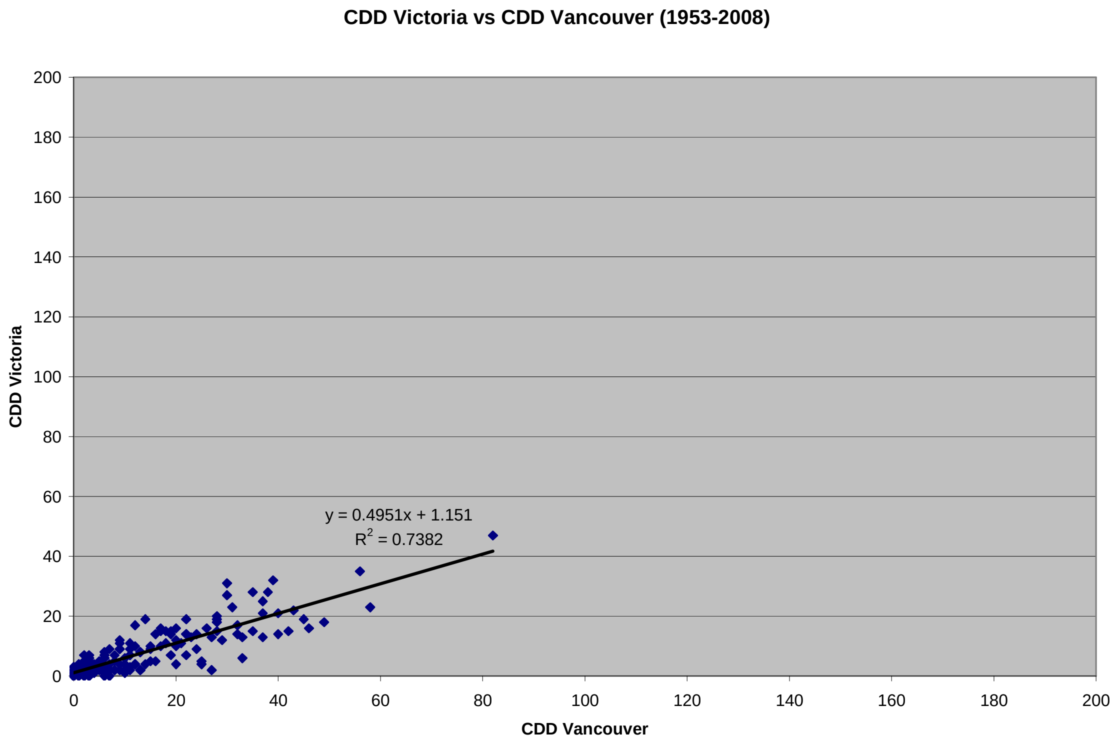


Figure 24: Regression line for the relationship between monthly CDD values in Victoria against CDD in Vancouver. The linear regression coefficient suggests that CDDs in Victoria will be 50% of Vancouver's CDDs in a given month. There were 177 pairs of observations. The relationship is significant at the 95% level

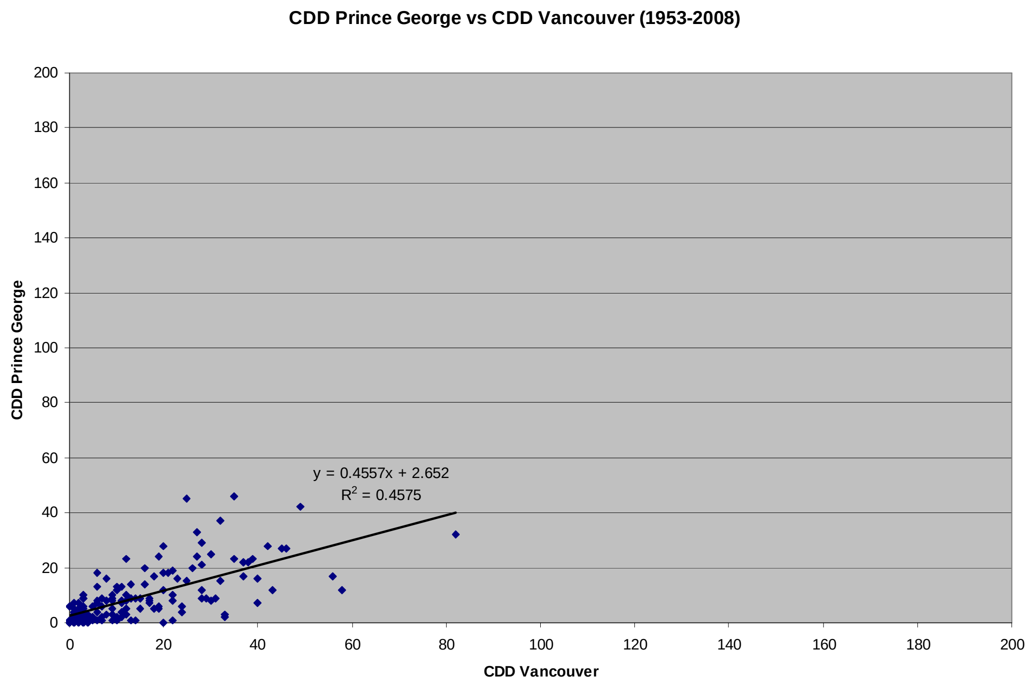


Figure 25: Regression line for the relationship between CDD values in Prince George against CDD in Vancouver. The linear regression coefficient suggests that CDDs in Prince George will be 46% of Vancouver's CDDs in a given month. There were 164 pairs of observations. The relationship is significant at the 95% level

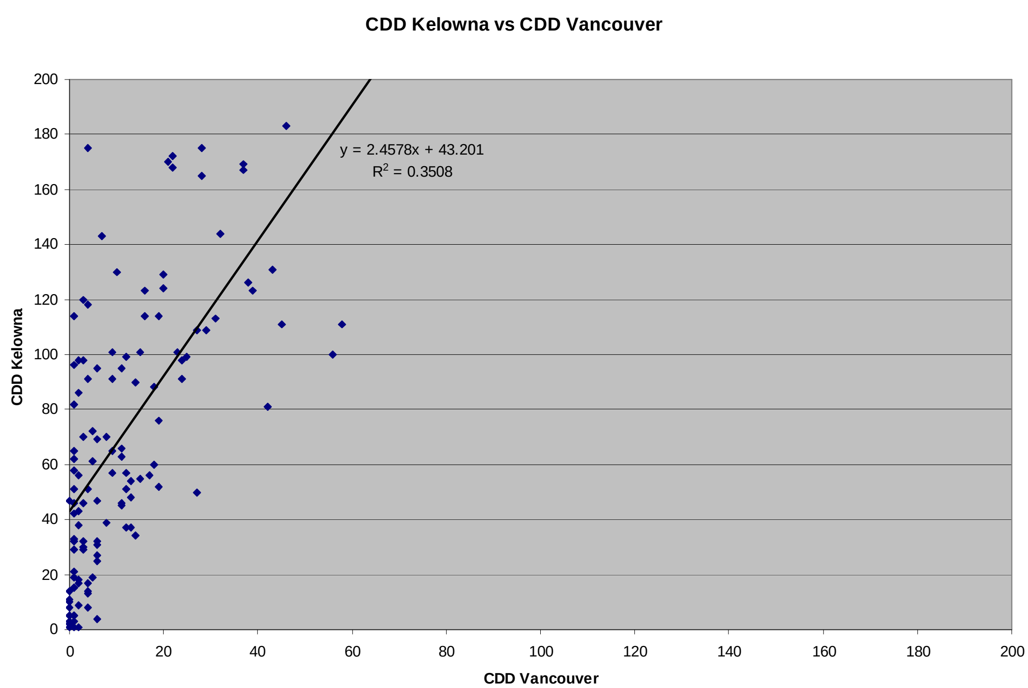


Figure 26: Regression line for the relationship between CDD values in Kelowna against CDD in Vancouver. The linear regression coefficient suggests that CDDs in Kelowna will be 2.5 times Vancouver's CDD's for a given month. There were 173 pairs of observations. The relationship is significant at the 95% level

Results of analyses of temporal stability of HDD and CDD regimes

The charts showing mean monthly HDD/CDD against decades revealed patterns quantitatively indicative of trends. This led to a quantitative consideration of various climate indices that have been applied to BC's climate, primarily by fisheries researchers. Some of the climate indices showed statistically significant correlations with Vancouver HDD data. By extension, as demonstrated in the analyses of HDD/CDD correlations in the section above, these correlations will apply to stations in the rest of BC.

Trends

In the Lower Mainland, HDDs decreased for Apr, Jun, Jul, Aug, Sep, Jan, and Mar (Table 13) while Aug CDD increased (Table 14) during 1953–2009. Taken together, these two trends over 57 years suggested the Vancouver Airport station (and the rest of BC) was experiencing a warming climate. HDD and CDD were not stable over time and will affect, in the long-term, the allocation of months to seasons for BC sites.

Table 13: Decreasing HDDs in Jan, Mar and Apr were likely to have most effect on consumption of electricity by electric heaters. Lack of trends in Kamloops data may be a result of short observation period (16 years) compared to other three regions (57 years). ***Decreasing HDDs were consistent with observed global climate change warming temperature trends***. Table is from Wahlgren (2010)

Month/Station	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Lower Mainland: Vancouver 1953-2009	▼	▬	▼	▼	▼	▼	▬	▬	▬	▼	▬	▼
Vancouver Island: Victoria 1953-2009	▼	▬	▼	▼	▼	▬	▬	▬	▬	▼	▬	▼
Northern Region: Prince George 1953-2009	▼	▬	▼	▬	▼	▬	▬	▬	▬	▼	▬	▬
South Interior: Kamloops 1994-2009	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬

▼ Decreasing HDD significant at 0.05 level ▬ Trend in HDD not significant at 0.05 level

Table 14: Increasing CDDs in May through Sep were likely to have the most effect on consumption of electricity by cooling systems. ***Increasing CDDs were consistent with observed global climate change warming temperature trends.*** The table is from Wahlgren (2010)

Month/Station	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Lower Mainland: Vancouver 1953-2009		▬	▬	▬	▲	▬						
Vancouver Island: Victoria 1953-2009		▬	▬	▬	▬	▬						
Northern Region: Prince George 1953-2009		▬	▬	▬	▬	▬						
South Interior: Kamloops 1994-2009		▬	▬	▬	▬	▬						

▲ Increasing CDD significant at 0.05 level ▬ Trend in CDD not significant at 0.05 level

Cycles

Spectral analyses of the monthly HDD (Vancouver) signals revealed periodicities varying from 2 to about 11 years (Figure 27). The latter is related to the Sun's 11-year sunspot cycle. Longer periods were not observed in the 57 years of observations available for this project. The literature does however mention, for example, the Pacific Decadal Oscillation cycle of 50 to 60 years (BC, 2002). Periodicities stem from primary global, secondary global, and continental-scale climate processes as depicted in Figure 28.

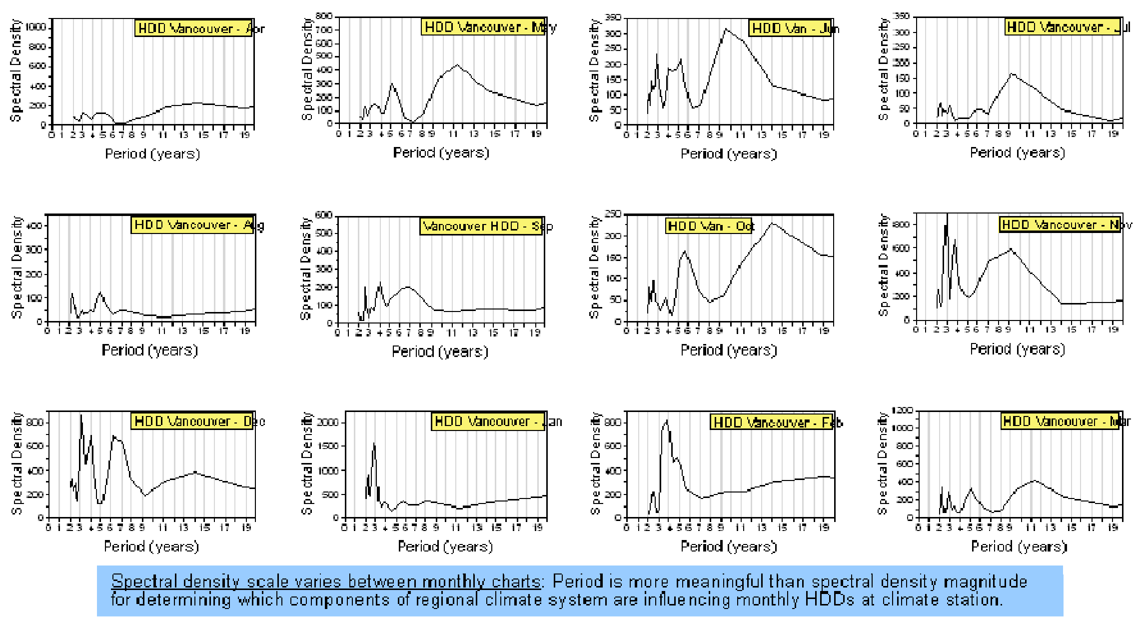


Figure 27: HDD cycle detection by spectral analyses (monthly)—Vancouver HDD example. Figure is from Wahlgren (2010)

Primary global climate processes | Secondary global climate processes | Continental-scale climate processes

Peak (months)	Peak (years)	Monthly Smoothed Sunspot Number	Global Mean Monthly Temperature Anomaly	Southern Oscillation Index	Length of Day (Earth's Angular Momentum) Index	Pacific Decadal Oscillation Index	North Pacific Index	Aleutian Low Pressure Index	Pacific North American Index
21			X			X			
22							X	X	
23	1.9	X				X			X
26	2.2		X			X			
27	2.3			X					
28	2.3	X			X		X		
30	2.5			X				X	X
31	2.6		X						
38	3								X
40	3					X	X	X	
42	4	X	X						
45	4			X	X				X
57	5			X	X				
68	6	X	X			X	X	X	X
75	6				X				
97	8							X	
113	9		X			X	X		X
136	11	X		X					

Cycles originate with these processes | These processes embed cycles from global processes

Figure 28: Spectral analyses revealing periodicities of various climate index signals were used to produce this compendium of climate indices representing various climate processes influencing the regional climates of British Columbia. Figure is from Wahlgren (2010)

Mean monthly HDD and CDD were not stable even in the short term and varied in amplitude from high to low during the course of one or two decades (as seen in Figures 4, 5, 7, 9, 11, 13, 15, 17, and 19. This will affect the allocation of months to seasons as was observed in the analyses with the phenomenon of shoulder months May and September switching in and out of the summer season and November switching from the winter. Table 15 indicates this instability during 1960–1989. Coincidentally, "…a significant inter-decadal climate regime shift occurred in 1976/77 in association with a deepening of the Aleutian low…and changes in the physical and biological environments over the North Pacific and North America…" (Minobe, 1997)

Table 15: Months that became shoulder months by decade 1953–2008. Information is from Appendix Tables A-2-3, A-2-10, A-2-17, A-2-18, and A-2-24.

Station	**1953–1959**	**1960–1969**	**1970–1979 (climate regime shift 1976/77, see text)**	**1980–1989**	**1990–1999**	**2000–2008**
Vancouver		May				
Victoria		May				
Prince George		May/Sep	May/Sep			
Kelowna			Mar/Nov	Mar/Nov		

Overall temporal stability

With significant trends, cycles, and even climate regime shifts affecting HDD and CDD at Vancouver Airport, the allocation of months to seasons is an analytical convenience that must be reviewed periodically to ensure meaningful results from various analyses that depend on the naming of seasons.

Results of sensitivity analyses of Vancouver's HDD to changes in the NE Pacific Ocean climate regime

The essential point has been made in the previous section that HDD and CDD regimes are not necessarily stable through time. Fluctuations in HDD and CDD ought to be recognized in weather sensitivity analyses and factored into load demand analyses. Here is a brief exploration of the sensitivity of Vancouver's HDD to changes in the NE Pacific Ocean climate regime.

Five climate indices relevant to BC are:

- Southern Oscillation Index
- Pacific Decadal Oscillation Index
- North Pacific Index
- Aleutian Low Pressure Index
- Pacific North American Index

An in-depth consideration of the climate indices is beyond the scope of this document but a brief review in the context of understanding HDD/CDD temporal stability—and therefore seasonal stability—is presented in this section.

A more detailed examination of these and other climate indices for degree-day forecasting was presented in Wahlgren (2010).

Southern Oscillation Index

The Southern Oscillation Index (SOI) is calculated by dividing the difference in pressure anomalies at Tahiti and Darwin by the standard deviation of the difference and multiplying by a factor of ten (Queensland Government, 2009):

$$SOI = \frac{PA(Tahiti) - PA(Darwin)}{Std\_Dev\_Diff} \times 10$$

During the data set period of 1953–2008, the Southern Oscillation Index (SOI) fluctuated considerably as shown in Figure 29. Regression analysis failed to detect a significant relationship between Vancouver's HDD and the SOI (Figure 30).

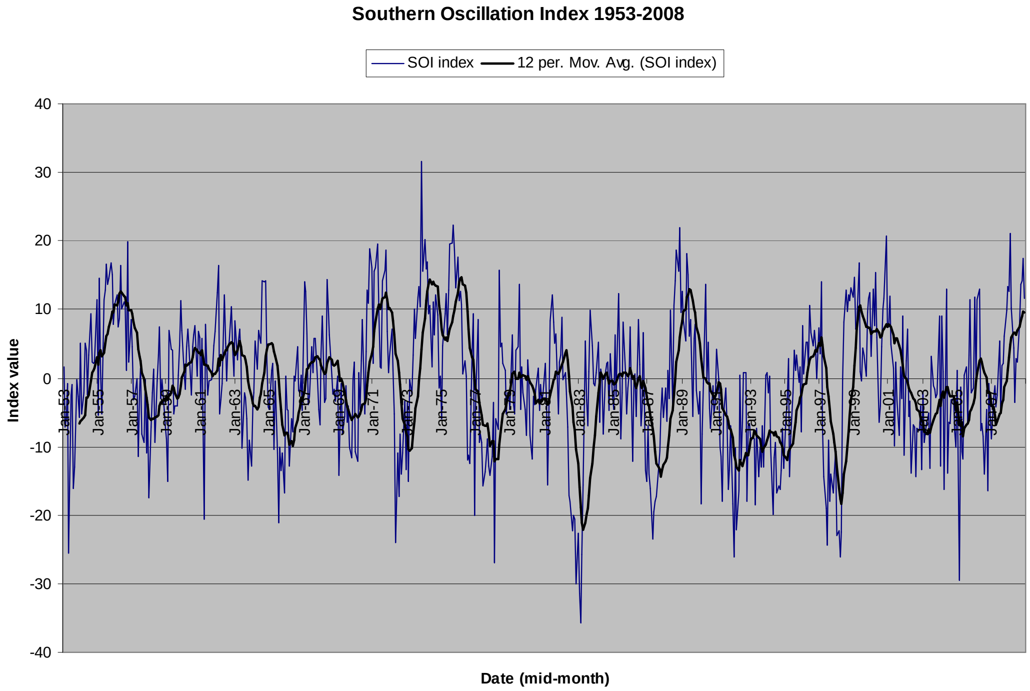


Figure 29: Southern Oscillation Index 1953–2008 charted from monthly values. The 12 month moving average is superimposed. Data is from Queensland Government (2009)

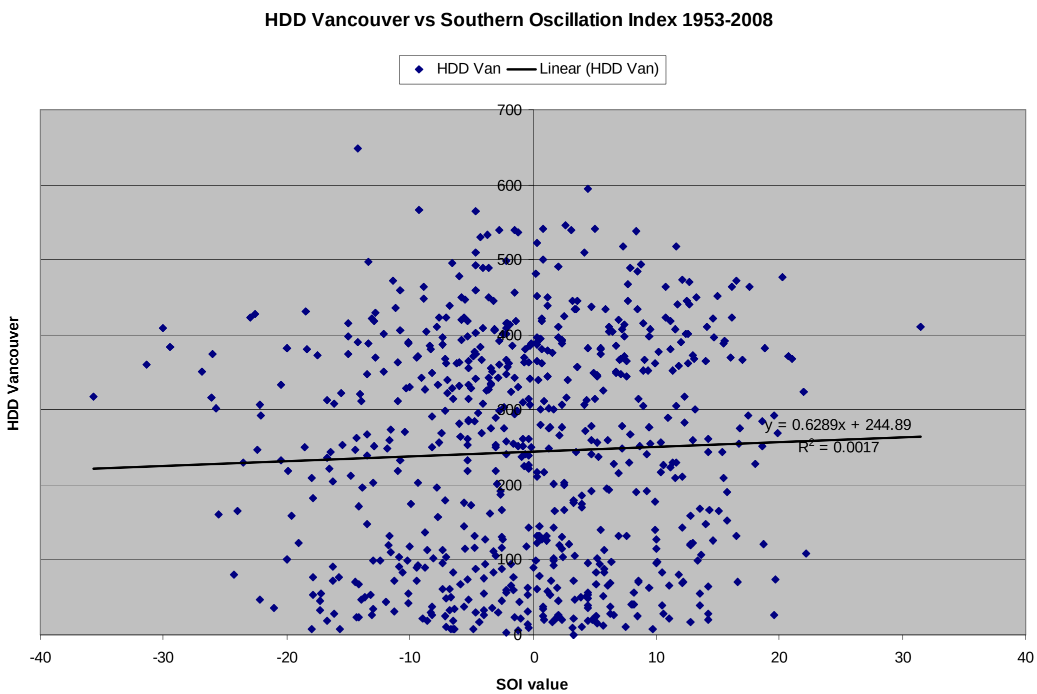


Figure 30: The linear regression for the relationship between HDD Vancouver and SOI was not statistically significant [did not reject the null hypothesis that the slope of the line was zero (n=672; coefficient of correlation R = 0.04; 95% level of significance)]

Pacific Decadal Oscillation Index

The Pacific Decadal Oscillation (PDO) Index is based on analyses of North Pacific sea surface temperatures (SSTs). Mantua and others (1997) referred to, "...the time history of the leading eigenvector of North Pacific SST as an index for the state of the PDO." The PDO Index document (JISAO, 2009) explained the index values as:

Updated standardized values for the PDO index, derived as the leading PC [principal component] of monthly SST anomalies in the North Pacific Ocean, poleward of 20N. The monthly mean global average SST anomalies are removed to separate this pattern of variability from any "global warming" signal that may be present in the data.

During the data set period of 1953–2008, the PDO Index fluctuated considerably as shown in Figure 31. Regression analysis detected a significant relationship between Vancouver's HDD and the PDO Index (Figure 32).

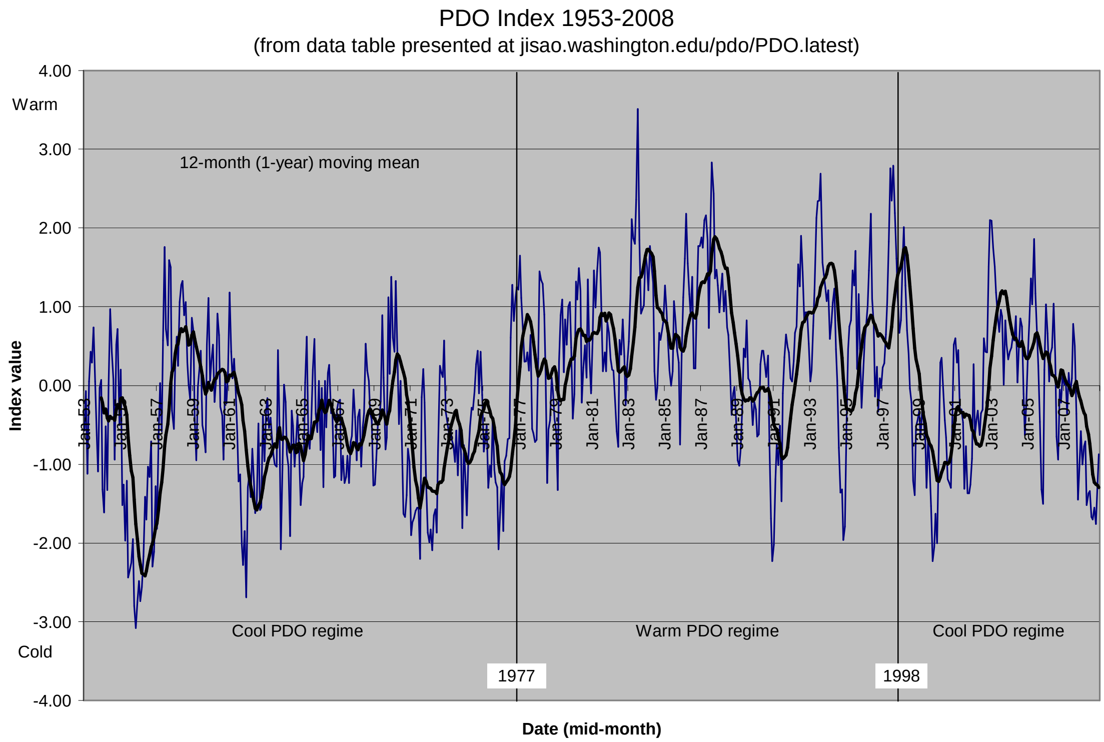


Figure 31: Pacific Decadal Oscillation Index monthly values from 1953–2008. The 12-month running mean is superimposed. Data is from JISAO (2009) the Joint Institute for the Study of the Atmosphere and Ocean (University of Washington and the National Oceanic and Atmospheric Administration, USA)

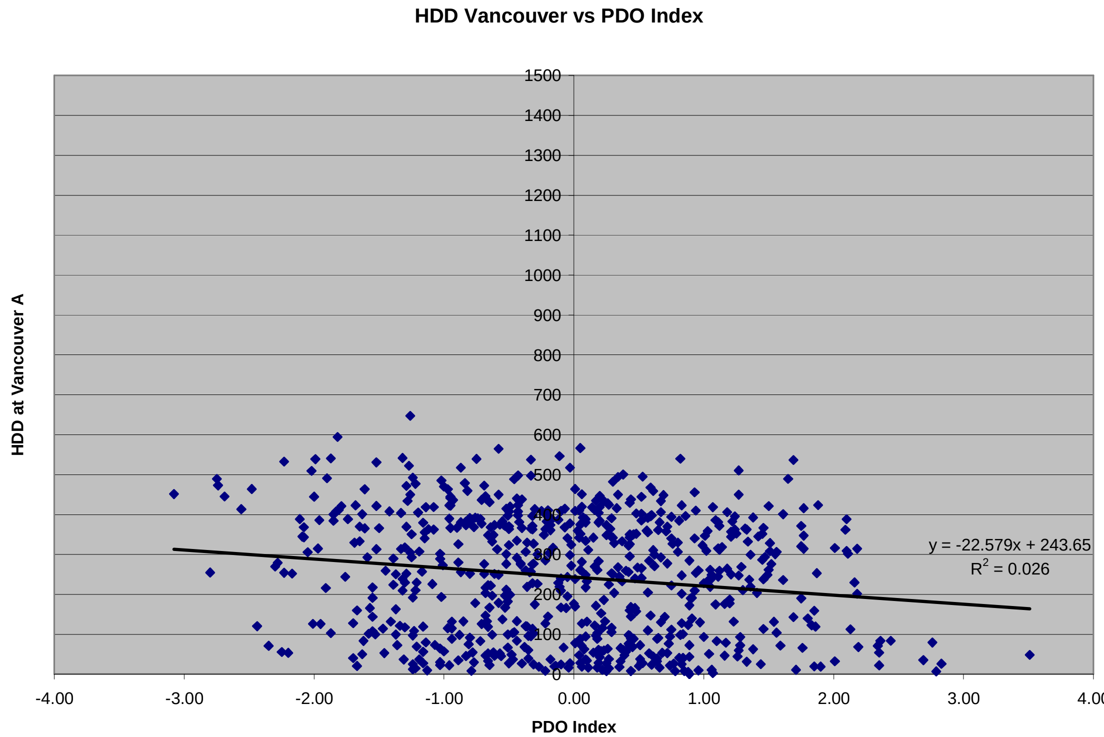


Figure 32: The linear regression for the relationship between HDD Vancouver and PDO Index was statistically significant [rejected the null hypothesis that the slope of the line was zero (n=672; coefficient of correlation R = 0.16; 95% level of significance)]

North Pacific Index

The Aleutian Low (Figure 33) is revealed on mean pressure maps and represents frequent passage of deep depressions (low pressure systems) across the North Pacific (Petterssen, 1969, p. 191). The physical mechanism explaining the relationship between sea level pressure (SLP) and air temperatures across British Columbia is given concisely by Minobe (1997, p. 683):

The relation between the SLP and air-temperature is a consequence of the strengthened (weakened) Aleutian low enhancing (reducing) the advection of warmer air onto the west cost (*sic*) of North America…"

The North Pacific (NP) Index, "…is the area-weighted sea level pressure over the region 30N–65N, 160E–140W, available since 1899" (Hurrell, 2009). During the data set period of 1953–2008, the NP Index fluctuated considerably as shown in Figure 34.

Regression analysis detected a significant relationship between Vancouver's HDD and the NP Index (Figure 35).

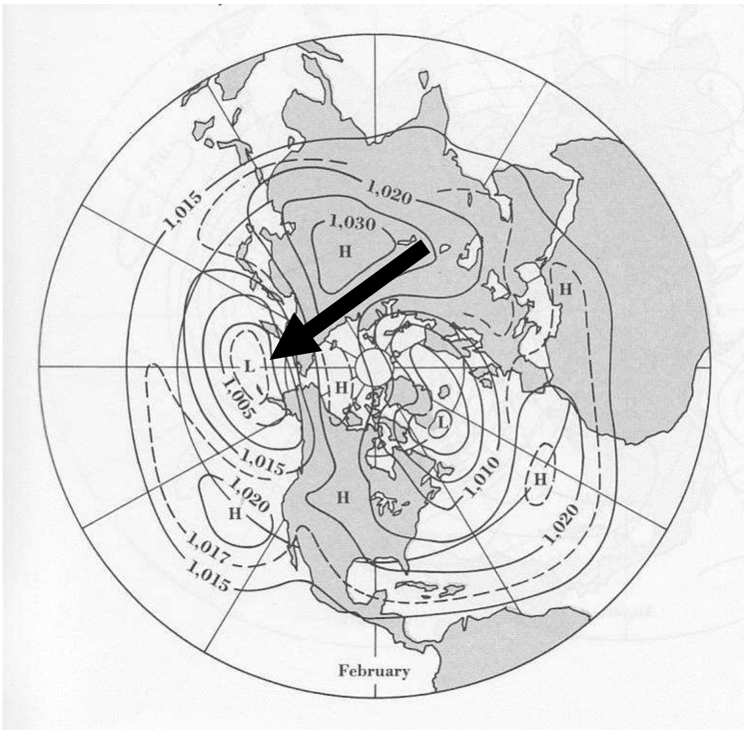


Figure 33: Mean surface pressure (mb) distribution in Northern Hemisphere winter showing mean position of Aleutian Low (arrow). Map is from Petterssen (1969, p. 191)

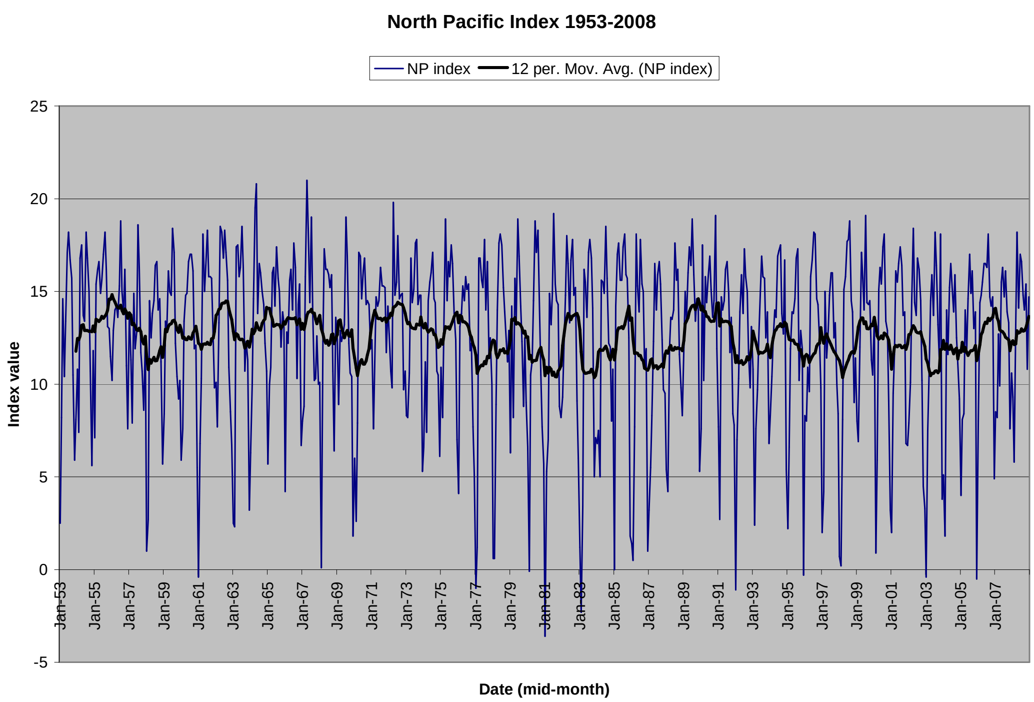


Figure 34: North Pacific Index monthly values from 1953–2008. The 12-month running mean is superimposed. NP Index data provided by the Climate Analysis Section, NCAR, Boulder, USA, Trenberth and Hurrell (1994)

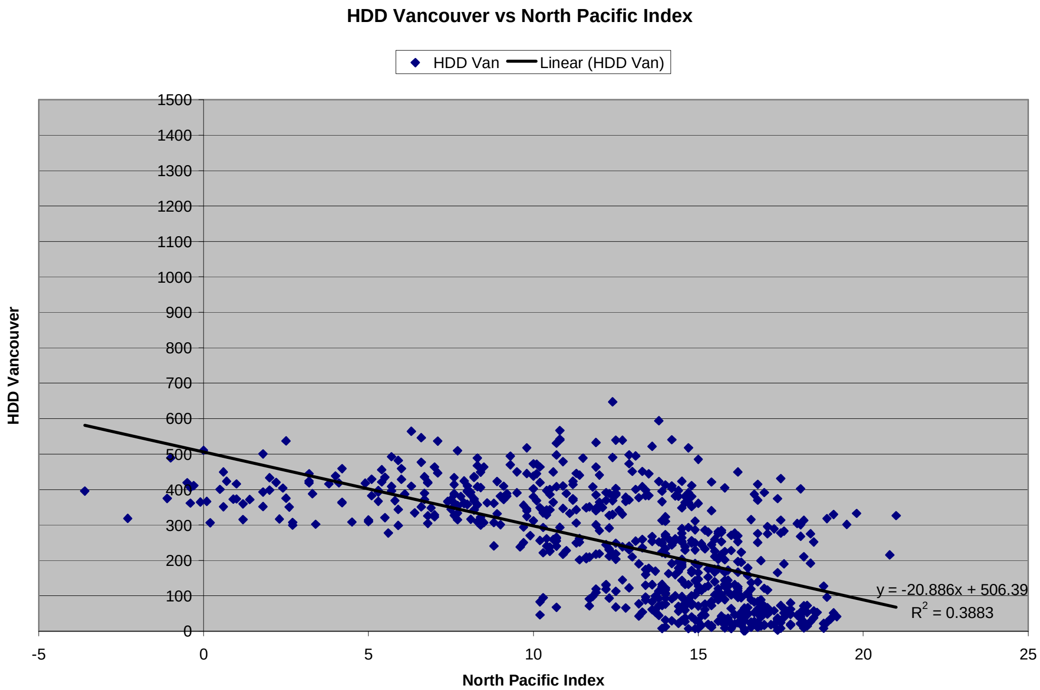


Figure 35: The linear regression for the relationship between HDD Vancouver and NP Index was significant [rejected the null hypothesis that the slope of the line was zero (n=672; coefficient of correlation R = 0.62; 95% level of significance)]

Aleutian Low Pressure Index

The Aleutian Low Pressure Index (ALPI), "…measures the relative intensity of the Aleutian Low pressure system of the north Pacific (December through March). It is calculated as the mean area (km^2) with sea level pressure ≤ 100.5 kPa and expressed as an anomaly from the 1950-1997 mean. A positive index value reflects a relatively strong, or intense Aleutian Low" (Beamish and others, 1997). The winter position of the Aleutian Low is shown in Figure 33. The annual fluctuations of the ALPI are presented in Figure 36.

Regression analysis detected a significant relationship between Vancouver's HDD and the NP Index (Figure 37).

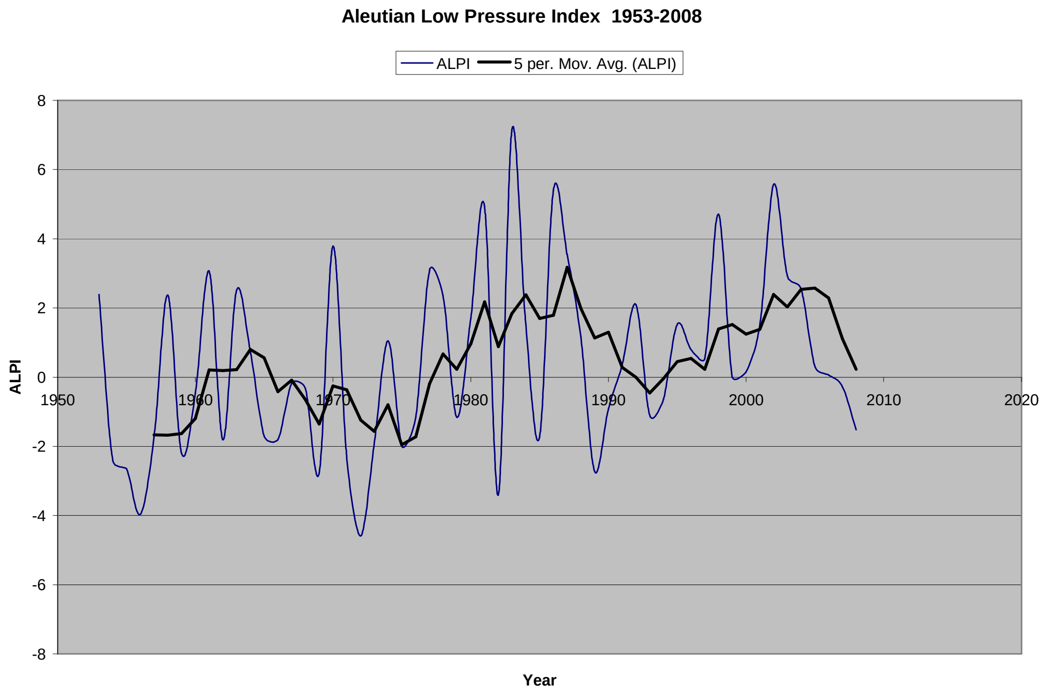


Figure 36: Aleutian Low Pressure Index annual values from 1953–2008. The 5-year running mean is superimposed. Data is from Fisheries and Oceans Canada-Pacific Region (2009)

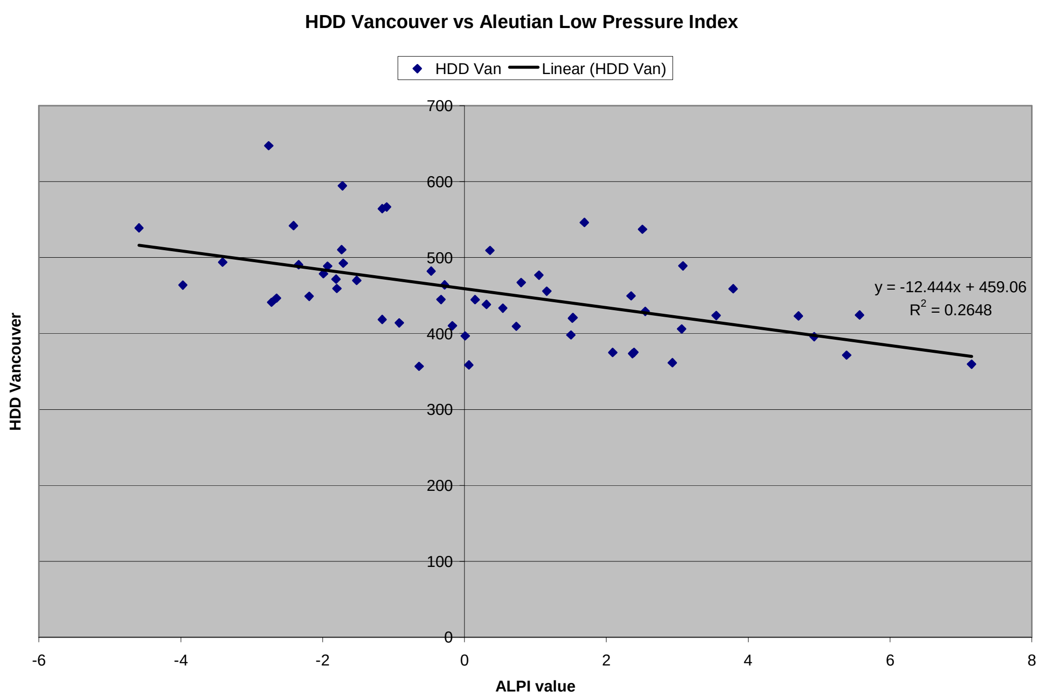


Figure 37: The linear regression for the relationship between HDD Vancouver and ALPI was significant [rejected the null hypothesis that the slope of the line was zero (n=672; coefficient of correlation R = 0.51; 95% level of significance)]

Pacific North American Index

The Pacific North American Index (PNAI, Figures 38 and 39) represents intensities of four major pressure cells surrounding North America (and BC). Intensities and geographical distribution of cells influences air temperature (therefore H-CDD) in BC.

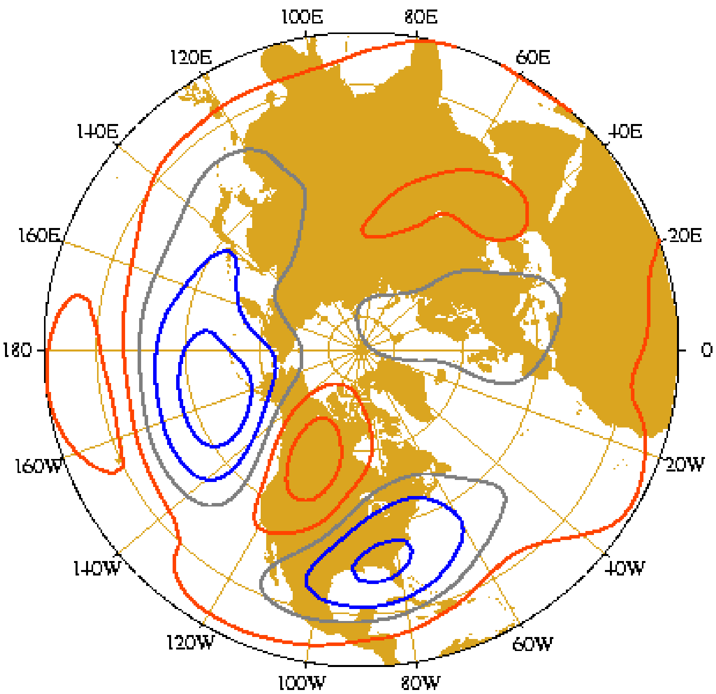


Figure 38: The Pacific North American Index represents intensities of four major pressure cells surrounding BC. Source for graphic: Joint Institute for the Study of the Atmosphere and Ocean; http://jisao.washington.edu/data_sets/pna/

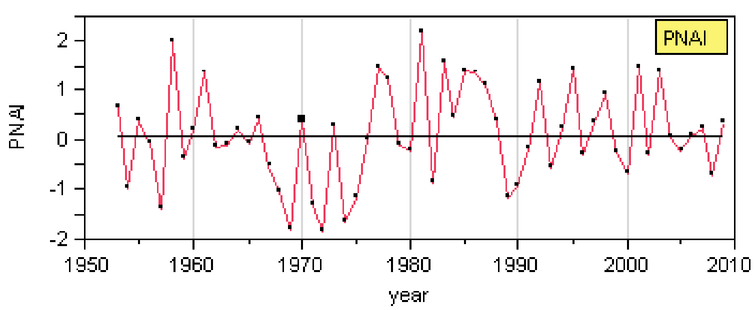


Figure 39: The Pacific North American Index has positive and negative phases. Chart is from Wahlgren (2010)

Important points about the Pacific North American Index (based on Data Set Summary by NASA Goddard Space Flight Center, Global Change Master Directory; see Figure 40) included:

- PNA pattern coverage of Earth's surface is greatest in winter
- Aleutian Low contracts in Spring to Gulf of Alaska
- Subtropical low near Hawaii strongest in Spring
- PNA pattern weakest in June/July
- PNA pattern strengthens during late summer/fall

Additional information (from NOAA National Weather Service, Climate Prediction Center) included these points:

- PNA pattern is believed to be natural climate variability
- PNA is linked to El Niño / Southern Oscillation
- PNA positive phase → Pacific warm episodes (El Niño) → BC experiences above-average temperatures
- PNA negative phase → Pacific cold episodes (La Niña)
- PNA has minimal impact on BC's surface temperature variability in summer

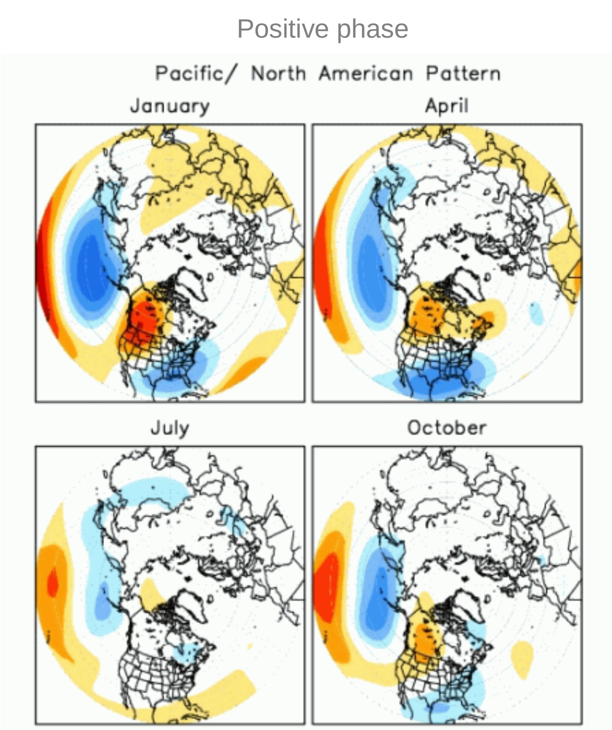
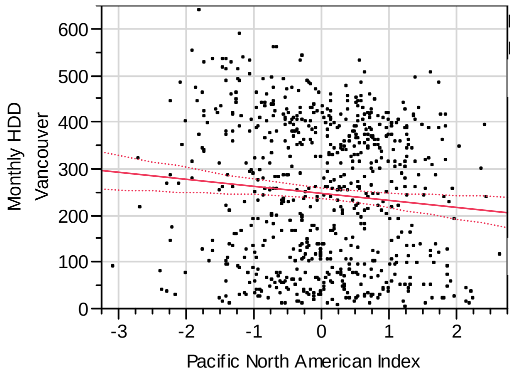


Figure 40: The seasonal views of the four low pressure cells surrounding and overlying BC. Source: NOAA National Weather Service Climate Prediction Center; http://www.cpc.ncep.noaa.gov/data/teledoc/pna_map.shtml

Vancouver's HDDs showed a statistically significant relationship to the Pacific North American Index. The relationship for all 678 observations from 1953 to 2009 is shown in Figure 41.



Monthly HDD Vancouver = 246.81763 - 14.737397*Pacific North American Index

Summary of Fit

RSquare	0.009296
RSquare Adj	0.00783
Root Mean Square Error	152.2662
Mean of Response	246.1843
Observations (or Sum Wgts)	678

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	147057	147057	6.3428
Error	676	15673049	23185	Prob > F
C. Total	677	15820105		0.0120*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	246.81763	5.85315	42.17	<.0001*
Pacific North American Index	-14.7374	5.851694	-2.52	0.0120*

Figure 41: JMP software output showing statistically significant relationship (0.05 level) between Monthly HDD in Vancouver and PNAI (data from Jan 1953 to Jun 2009)

The monthly relationships were stronger (Figure 42).

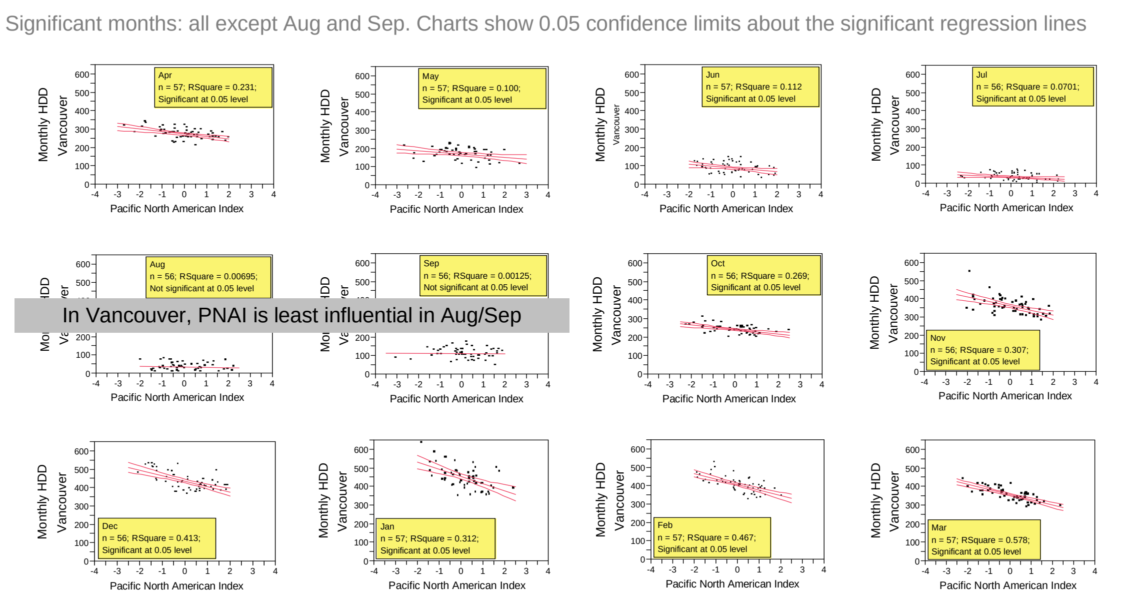


Figure 42: JMP software output showing statistically significant relationships (0.05 level) by month between Monthly HDD in Vancouver and PNAI (data from Jan1953 to Jun 2009). With 56 or 57 observations for monthly HDDs, RSquare was as follows: Apr (0.231), May (0.100), Jun (0.112), Jul (0.0701), Aug (0.00695; not significant), Sep (0.00125; not significant), Oct (0.269), Nov (0.307), Dec (0.413), Jan (0.312), Feb (0.467), and Mar (0.578). Original figure appeared in Wahlgren (2010)

Strength of HDD relationships to indices

Rodionov and others (2005) pointed out that the relatively low coefficients of correlation between North Pacific climate variables and the indices are because the indices measure the intensity of the Aleutian Low, not its geographical position. The position of the Low also affects the climate of the NE Pacific region.

An overview of strength of fit between Vancouver HDDs and climate indices by month is provided in Table 16. Four of these indices (Mean Smoothed Sunspot Number, Global Mean Monthly Temperature Anomaly, Southern Oscillation Index, and Length of Day Index have global influence, not restricted to the North Pacific.

Table 16: Climate indexes are Mean Smoothed Sunspot Number (MSSN), Global Mean Monthly Temperature Anomaly (GMMTA), Southern Oscillation Index (SOI), Length of Day Index (LODI), Pacific Decadal Oscillation (PDO), North Pacific Index (NPI), Aleutian Low Pressure Index (ALPI), and Pacific North American Index (PNAI). LODI is a measure (units of ms) related to Earth's angular momentum, indexing major storm activity in the Earth's climate system. These storms are usually related to El Niño events which affect sea surface temperatures offshore BC, hence land air temperature and degree-days across BC. This table appeared in Wahlgren (2010). Highlighted cells are a guide to the best monthly fits given by ANOVA Prob > F. The lower the value, the better the fit.

Strength of fit between HDD Vancouver and climate indices by month

HDD data for 1953-2009

	ANOVA Prob > F							
Month	**MSSN**	**GMMTA**	**SOI**	**LODI**	**PDO**	**NPI**	**ALPI**	**PNAI**
Apr	0.2364	0.0003	0.027	0.0768	0.0001	0.0001	0.0407	0.0002
May	0.2175	0.083	0.0138	0.162	0.0002	0.0001	0.5862	0.0165
Jun	0.3675	0.0338	0.0127	0.0856	0.003	0.1437	0.0523	0.0108
Jul	0.5708	0.0017	0.8259	0.0055	0.164	0.1291	0.3396	0.0486
Aug	0.9341	0.0001	0.0456	0.0009	0.047	0.022	0.0011	0.5412
Sep	0.6987	0.0099	0.16	0.1705	0.0881	0.0001	0.4403	0.7963
Oct	0.547	0.0251	0.2499	0.0568	0.2143	0.0027	0.1751	0.0001
Nov	0.9692	0.0205	0.8835	0.551	0.0479	0.0015	0.0472	0.0001
Dec	0.2038	0.106	0.1632	0.2203	0.0563	0.0001	0.7625	0.0001
Jan	0.4936	0.0006	0.5112	0.0529	0.0002	0.0001	0.0001	0.0001
Feb	0.5609	0.0049	0.1296	0.8037	0.0004	0.0001	0.0001	0.0001
Mar	0.5594	0.0002	0.0001	0.7747	0.0001	0.0001	0.0001	0.0001

Note: Decision for which of tied values to use was made by choosing fit with highest R^2 (bolded cells)

Conclusions

Using HDD and CDD as weather proxies, winter months, without exception spatially or temporally, were delineated clearly as comprising November–March. Summer months always contained June, July, and August. Some stations and some decades included May or September into the summer season. Coincidentally, May and/or September shifted in or out of membership in the shoulder season. The shoulder season always included April and October. A compromise, suitable for any location in BC, was to include April, May, September, and October in the shoulder season. March, which had been classified previously as a shoulder season month (Andrew Berrisford, BC Hydro, personal communication) was shown to be exclusively a winter month in British Columbia.

Months can be grouped into three seasons appropriate for weather sensitivity analyses in British Columbia. Winter weather sensitivity can be gauged using data from the months

November–March. Summer weather sensitivity can be gauged using data from the months June, July, and August. Shoulder season analyses should reference April, May, September, and October.

Climate variability (cyclical related to, for example, the Pacific Decadal Oscillation) or change (trend) may affect the membership of months in the shoulder season at a specific site over time or for spatially distributed sites. The climate cycles observed in the analyses have periods ranging up to 11 years. Longer cycles of 50 to 60 years are known to affect BC's climate. The observed climate trend shows warming, evidenced by months with decreasing HDD and increasing CDD, during the past 55 years.

Cycles and trends in HDD and CDD ought to be recognized and accounted for in weather sensitivity analyses, classification of seasons and should be factored into load demand analyses. Quantitative knowledge of these cycles and trends has predictive benefits for load analysis.

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Appendix 1

Results from CWEC datasets

- Abbotsford
- Comox
- Fort St John
- Kamloops
- Port Hardy
- Prince George
- Prince Rupert
- Sandspit
- Smithers
- Summerland
- Vancouver
- Victoria

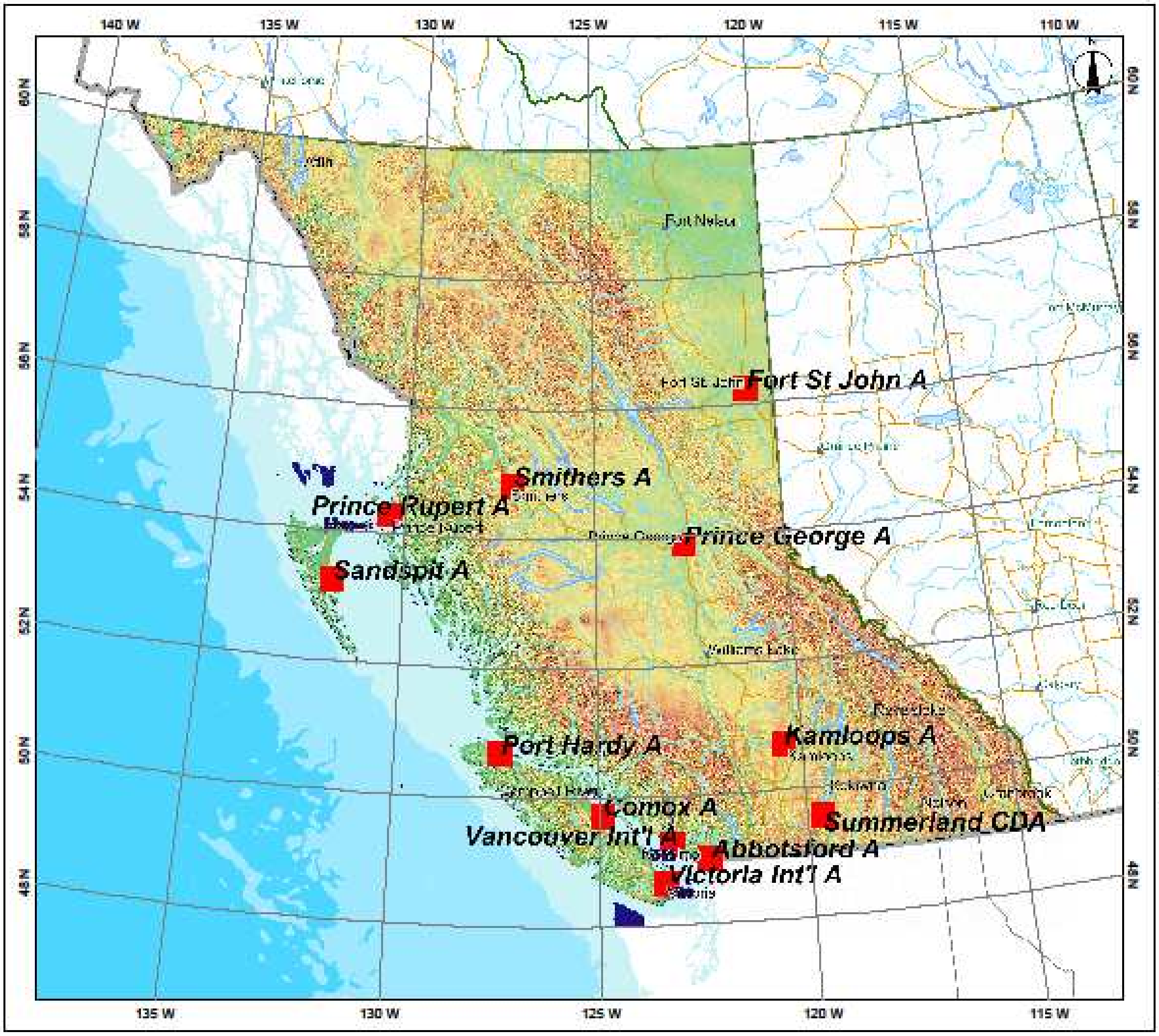

Figure A-1-1: CWEC Stations

Table A-1-1: Results from CWEC data set for Abbotsford

Abbotsford Airport (CWEC)			
Month	**HDD**	**CDD**	**Season**
April	287		Shoulder
May	184	6	Summer
June	109	0	Summer
July	48	13	Summer
August	42	14	Summer
September	134		Summer
October	243		Shoulder
November	382		Winter
December	449		Winter
January	470		Winter
February	396		Winter
March	389		Winter

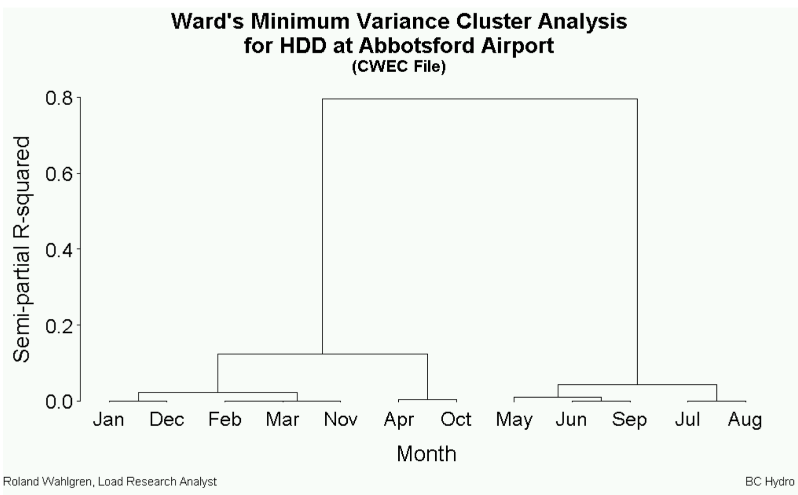

Figure A-1-2: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

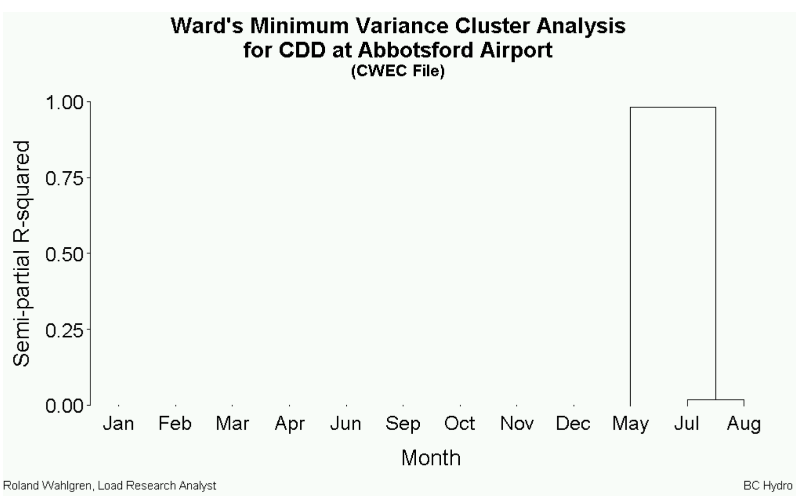

Figure A-1-3: Cooling degree days occur in May, July, and August

Table A-1-2: Results from CWEC data set for Comox

Comox Airport (CWEC)			
Month	**HDD**	**CDD**	**Season**
April	283		Shoulder
May	208		Shoulder
June	111	2	Summer
July	45	16	Summer
August	34	11	Summer
September	136		Summer
October	272		Shoulder
November	376		Winter
December	456		Winter
January	494		Winter
February	377		Winter
March	385		Winter

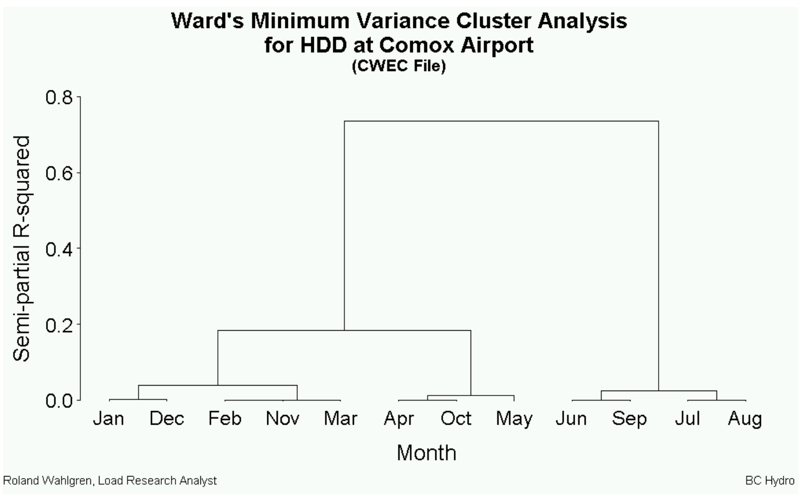

Figure A-1-4: Cluster analysis result: Summer months (June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, May, October)

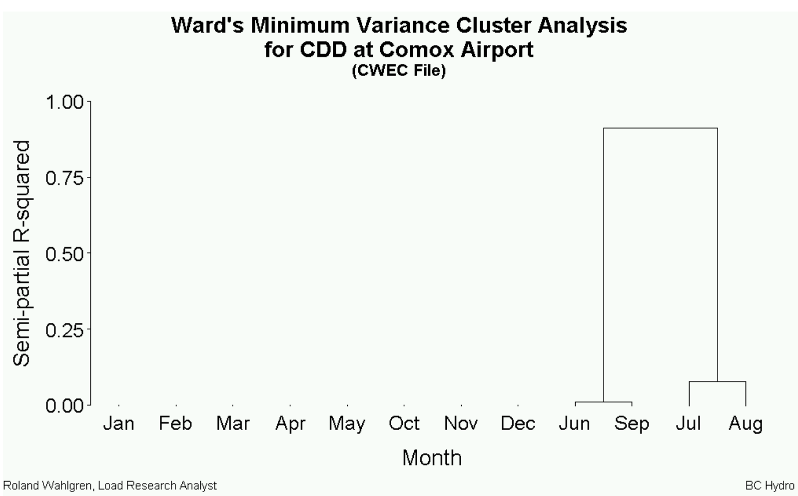

Figure A-1-5: Cooling degree days occur in June, July, August, and September

Table A-1-3: Results from CWEC data set for Fort St John

Fort St John Airport			
Month	**HDD**	**CDD**	**Season**
April	418		Shoulder
May	254		Shoulder
June	125	6	Summer
July	92	7	Summer
August	118	12	Summer
September	272		Shoulder
October	428		Shoulder
November	740		Winter
December	910		Winter
January	985		Winter
February	807		Winter
March	714		Winter

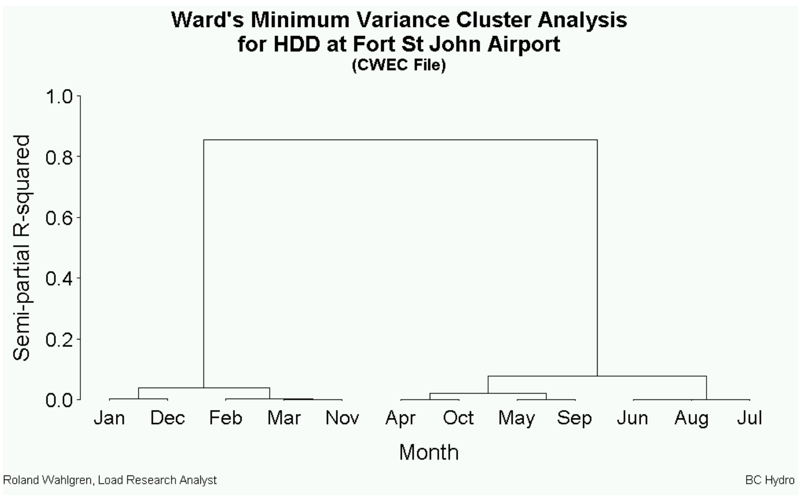

Figure A-1-6: Cluster analysis result: Summer months (June, July, August); Winter months (November, December, January, February, March); and Shoulder months (April, May, September, October)

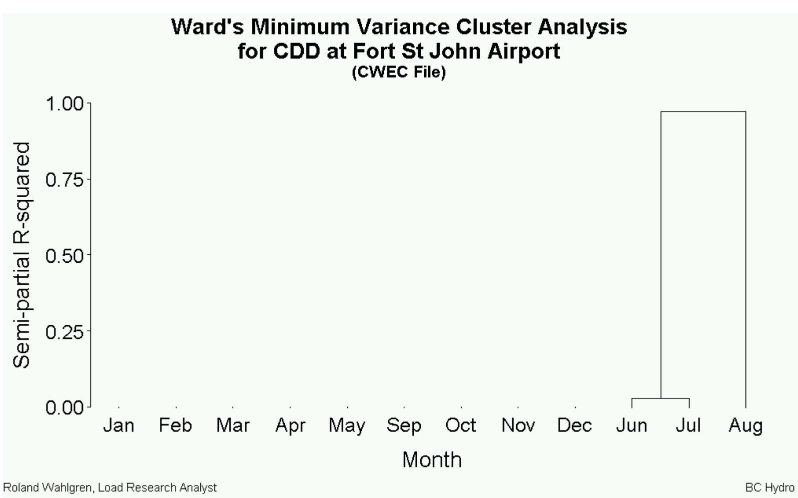

Figure A-1-7: Cooling degree days occur in June, July, and August

Table A-1-4: Results from CWEC data set for Kamloops

Kamloops Airport			
Month	**HDD**	**CDD**	**Season**
April	263		Shoulder
May	114	11	Summer
June	41	55	Summer
July	8	112	Summer
August	15	86	Summer
September	98	23	Summer
October	309		Shoulder
November	453		Winter
December	663		Winter
January	691		Winter
February	536		Winter
March	438		Winter

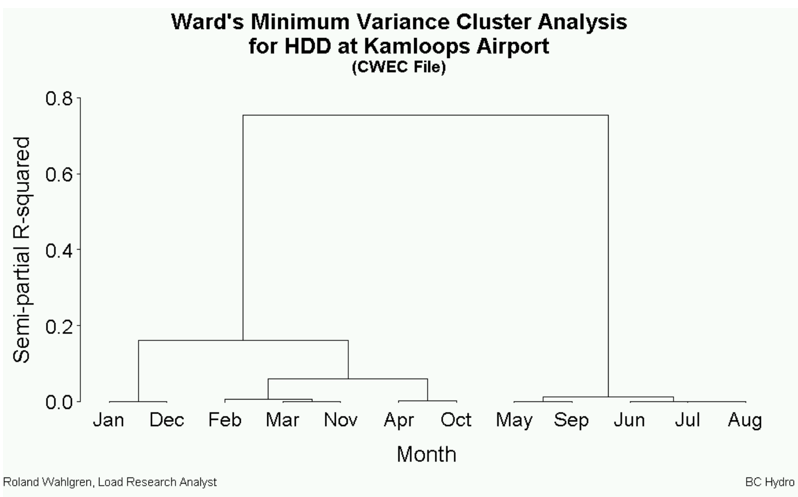

Figure A-1-8: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

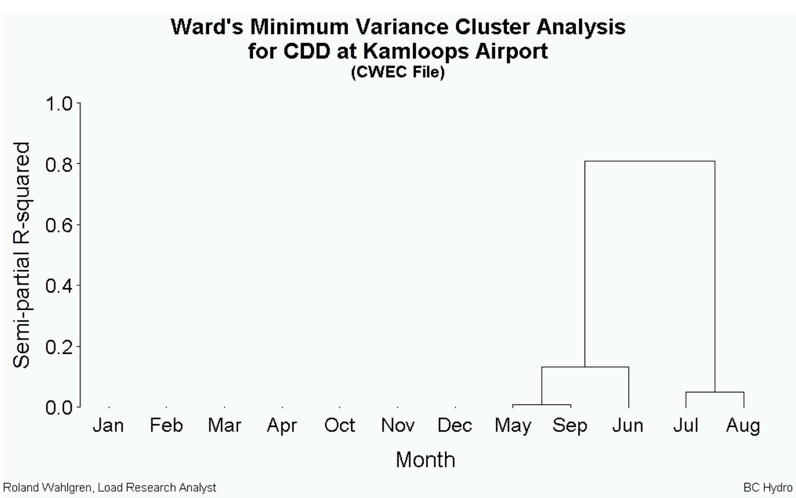

Figure A-1-9: Cooling degree days occur in May, June, July, August, and September

Table A-1-5: Results from CWEC data set for Port Hardy

Port Hardy Airport			
Month	**HDD**	**CDD**	**Season**
April	343		Winter
May	263		Shoulder
June	195		Summer
July	145		Summer
August	146		Summer
September	203		Summer
October	302		Shoulder
November	377		Winter
December	445		Winter
January	481		Winter
February	399		Winter
March	415		Winter

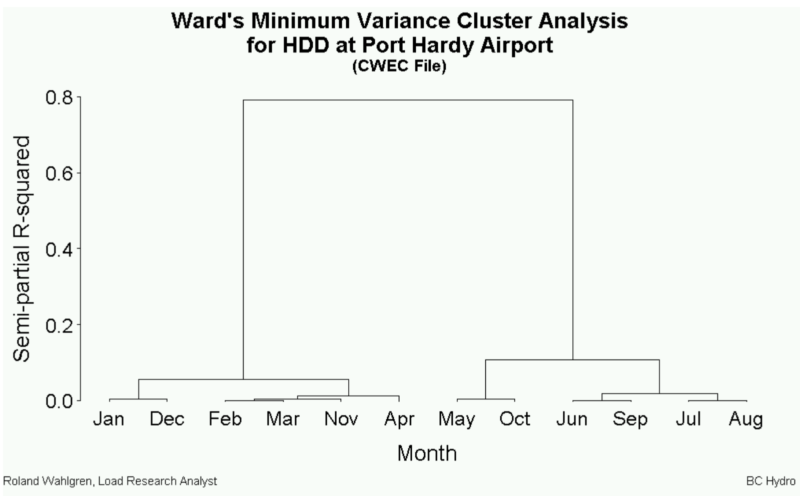

Figure A-1-10: Cluster analysis result: Summer months (June, July, August, September); Winter months (November, December, January, February, March, April); and Shoulder months (May, October)

Cooling degree days do not occur at Port Hardy Airport.

Table A-1-6: Results from CWEC data set for Prince George

Prince George Airport			
Month	**HDD**	**CDD**	**Season**
April	389		Winter
May	243		Summer
June	148	3	Summer
July	113	4	Summer
August	94	8	Summer
September	215		Summer
October	410		Winter
November	612		Winter
December	747		Winter
January	892		Winter
February	653		Winter
March	554		Winter

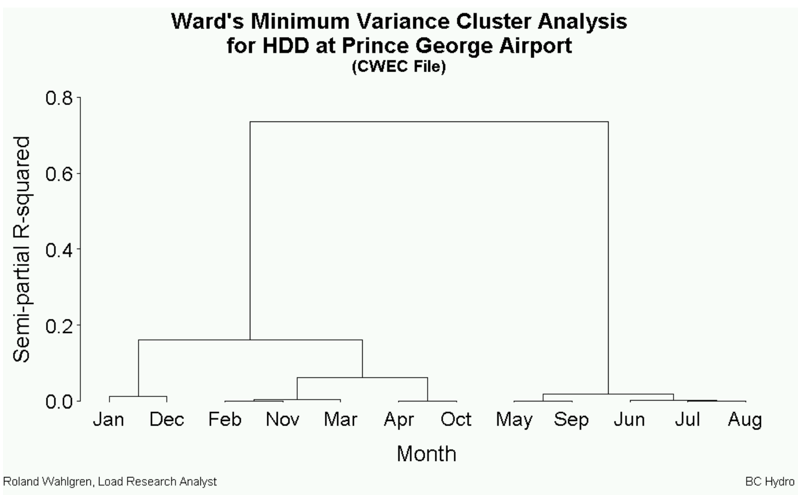

Figure A-1-11: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (October, November, December, January, February, March, April); and Shoulder months (none)

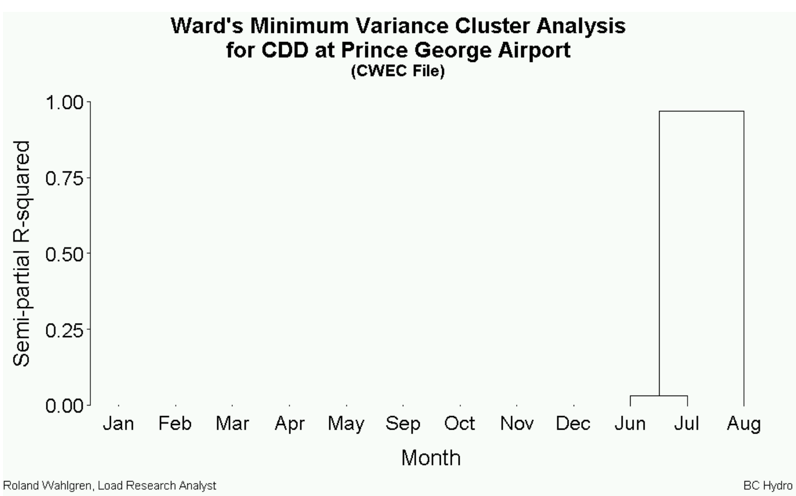

Figure A-1-12: Cooling degree days occur in June, July, and August

Table A-1-7: Results from CWEC data set for Prince Rupert

Prince Rupert Airport			
Month	**HDD**	**CDD**	**Season**
April	370		Shoulder
May	291		Shoulder
June	220		Summer
July	157		Summer
August	145		Summer
September	209		Summer
October	314		Shoulder
November	441		Winter
December	517		Winter
January	563		Winter
February	464		Winter
March	460		Winter

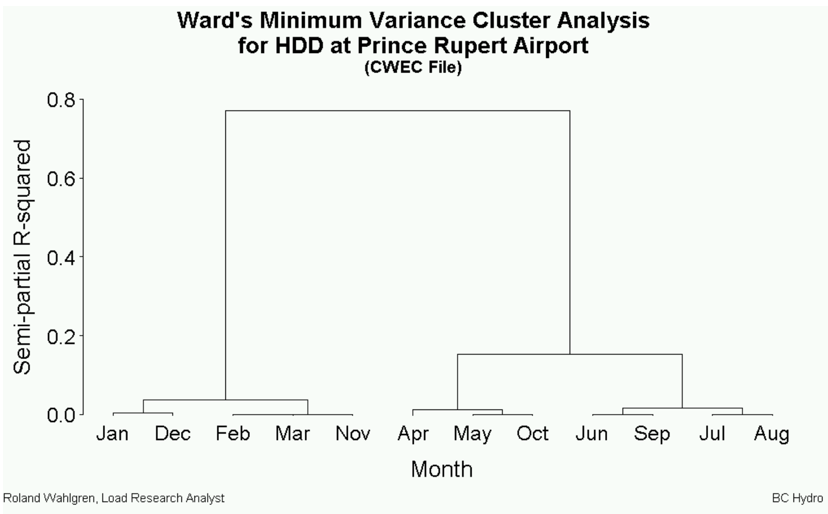

Figure A-1-13: Cluster analysis result: Summer months (June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, May, October)

Cooling degree days do not occur at Prince Rupert Airport.

Table A-1-8: Results from CWEC data set for Sandspit

Sandspit Airport			
Month	**HDD**	**CDD**	**Season**
April	365		Winter
May	280		Shoulder
June	195		Summer
July	136		Summer
August	107		Summer
September	158		Summer
October	276		Shoulder
November	349		Winter
December	447		Winter
January	513		Winter
February	414		Winter
March	404		Winter

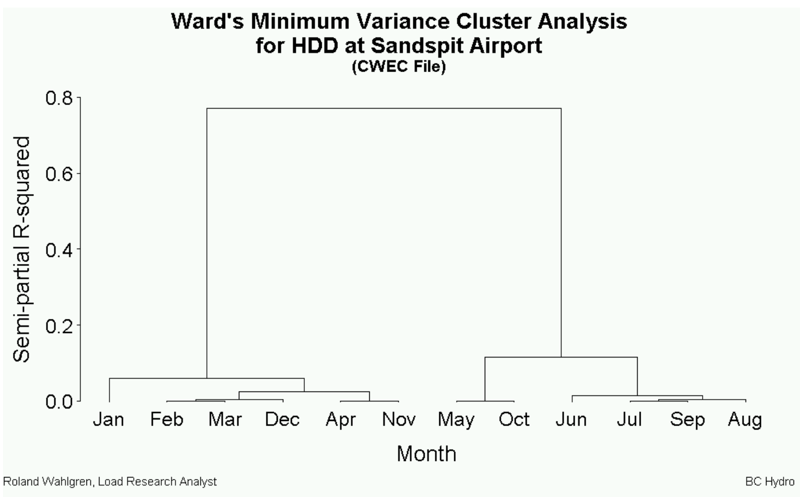

Figure A-1-14: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March, April); and Shoulder months (May, October)

Cooling degree days do not occur at Sandspit Airport.

Table A-1-9: Results from CWEC data set for Smithers

Smithers Airport			
Month	HDD	CDD	Season
April	403		Shoulder
May	295		Shoulder
June	174		Summer
July	87	20	Summer
August	124	2	Summer
September	134		Shoulder
October	416		Shoulder
November	654		Winter
December	805		Winter
January	820		Winter
February	612		Winter
March	606		Winter

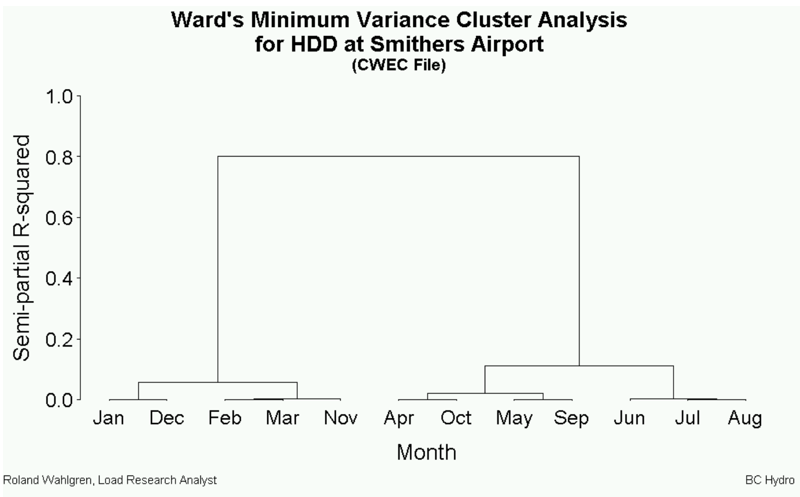

Figure A-1-15: Cluster analysis result: Summer months (June, July, August); Winter months (November, December, January, February, March); and Shoulder months (April, May, September, October)

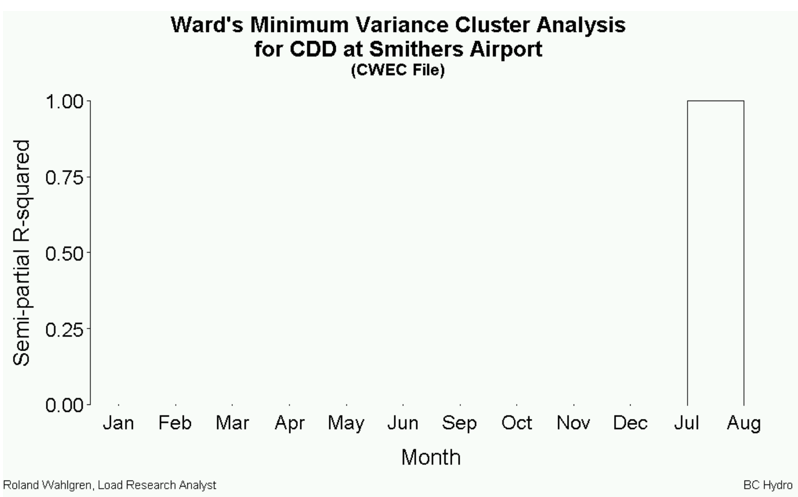

Figure A-1-16: Cooling degree days occur in July, and August

Table A-1-10: Results from CWEC data set for Summerland

Summerland CDA			
Month	**HDD**	**CDD**	**Season**
April	279		Shoulder
May	133	3	Summer
June	42	38	Summer
July	19	84	Summer
August	21	59	Summer
September	114	15	Summer
October	281		Shoulder
November	423		Winter
December	573		Winter
January	611		Winter
February	463		Winter
March	429		Winter

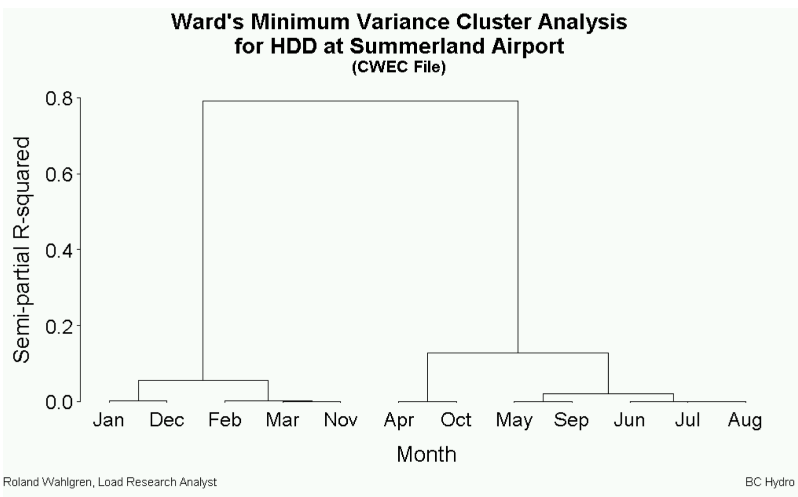

Figure A-1-17: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

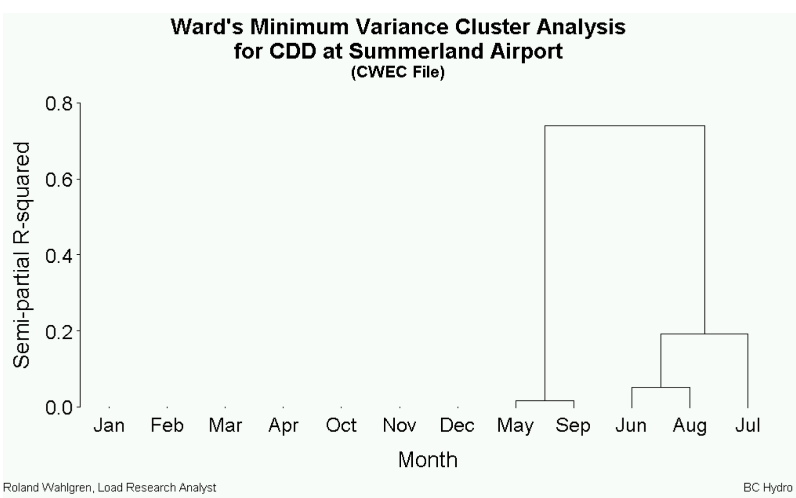

Figure A-1-18: Cooling degree days occur in May, June, July, August, and September

Table A-1-11: Results from CWEC data set for Vancouver

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	279		Shoulder
May	191		Shoulder
June	88		Summer
July	35	3	Summer
August	30	1	Summer
September	127		Summer
October	253		Shoulder
November	382		Winter
December	445		Winter
January	459		Winter
February	361		Winter
March	369		Winter

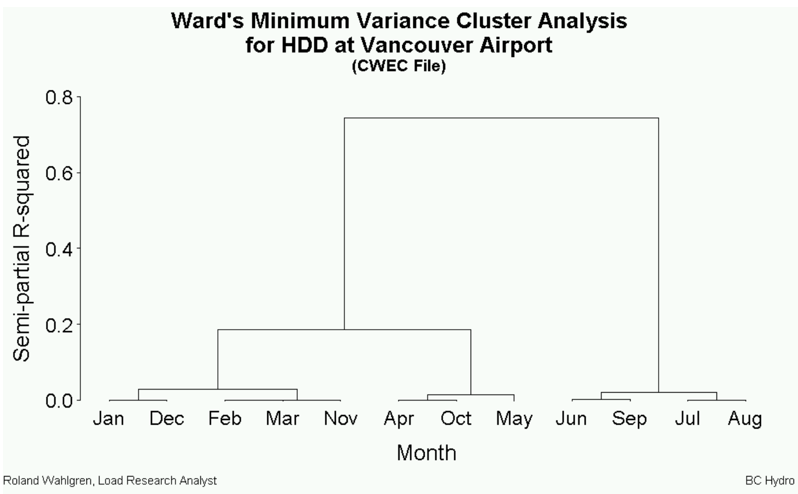

Figure A-1-19: Cluster analysis result: Summer months (June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, May, October)

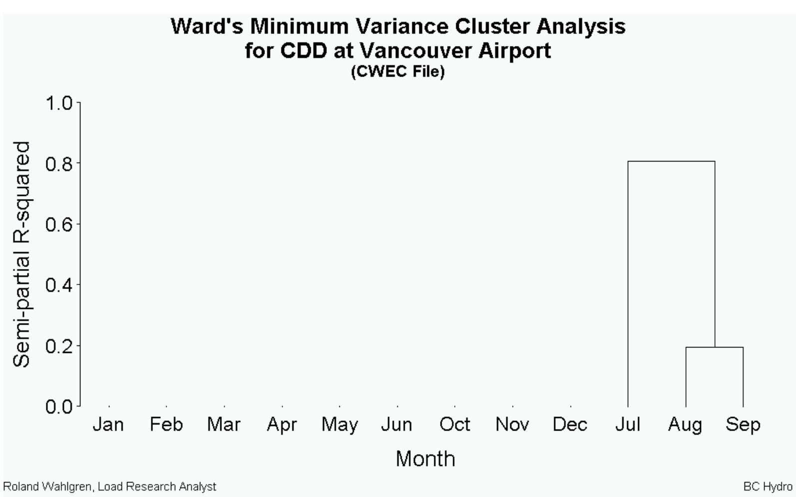

Figure A-1-20: Cooling degree days occur in July, August, and September

Table A-1-12: Results from CWEC data set for Victoria

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	285		Shoulder
May	196		Summer
June	111		Summer
July	73	5	Summer
August	62	3	Summer
September	146		Summer
October	254		Shoulder
November	346		Winter
December	426		Winter
January	441		Winter
February	368		Winter
March	367		Winter

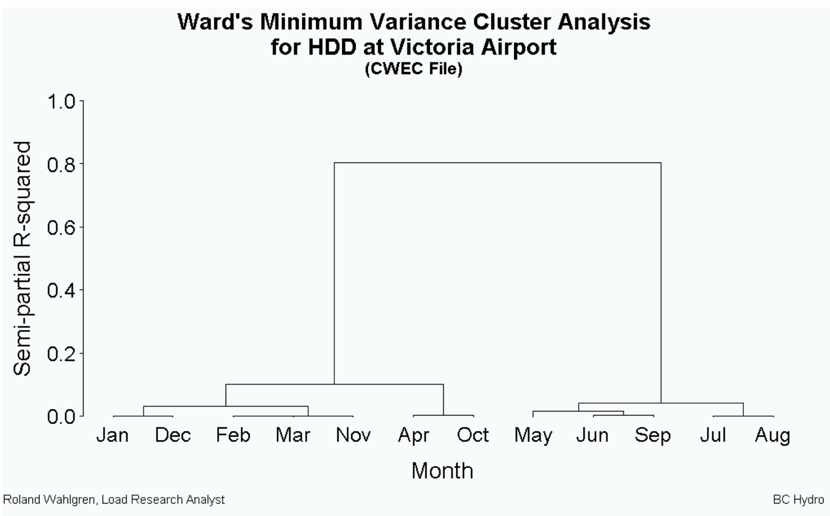

Figure A-1-21: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

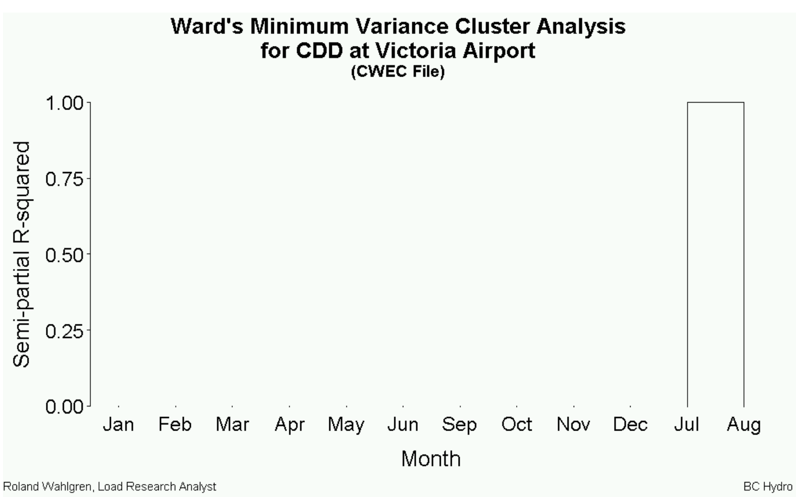

Figure A-1-22: Cooling degree days occur in July and August

Appendix 2

Results from Environment Canada multi-decade data sets

- **Vancouver 1953 to 2008**
- Vancouver 1953 to 1959
- Vancouver 1960 to 1969
- Vancouver 1970 to 1979
- Vancouver 1980 to 1989
- Vancouver 1990 to 1999
- Vancouver 2000 to 2008

- **Victoria 1953 to 2008**
- Victoria 1953 to 1959
- Victoria 1960 to 1969
- Victoria 1970 to 1979
- Victoria 1980 to 1989
- Victoria 1990 to 1999
- Victoria 2000 to 2008

- **Kelowna 1953 to 2008**
- Kelowna 1953 to 1959
- Kelowna 1960 to 1969
- Kelowna 1970 to 1979
- Kelowna 1980 to 1989
- Kelowna 1990 to 1999
- Kelowna 2000 to 2008

- **Prince George 1953 to 2008**
- Prince George 1953 to 1959
- Prince George 1960 to 1969
- Prince George 1970to 1979
- Prince George 1980 to 1989
- Prince George 1990 to 1999
- Prince George 2000 to 2008

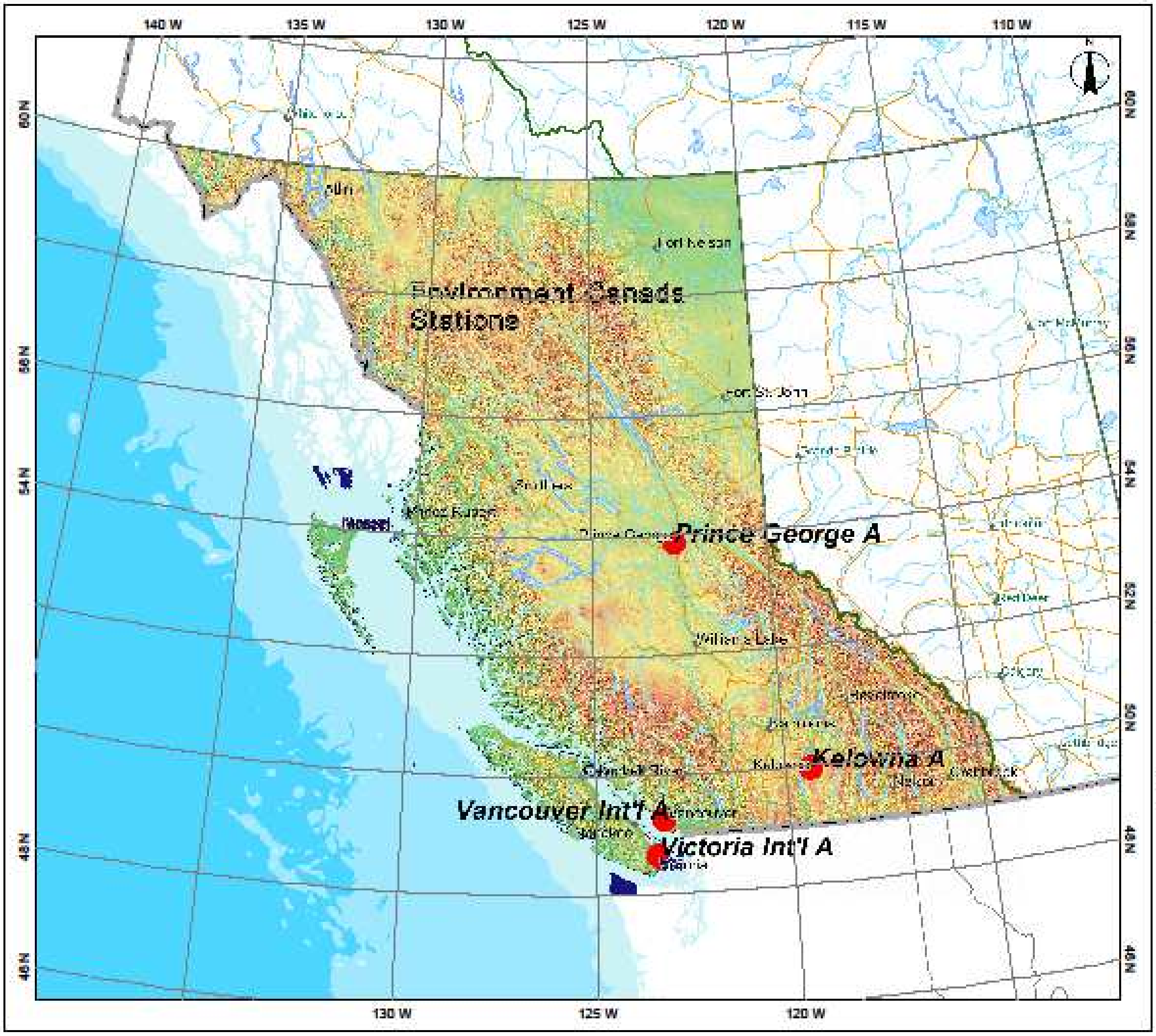

Figure A-2-1: Locations of Environment Canada stations at Vancouver Airport, Victoria Airport, Kelowna Airport, and Prince George Airport.

Table A-2-1: Results from EC data set for Vancouver 1953 to 2008

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	273		Shoulder
May	169	2	Summer
June	89	7	Summer
July	35	20	Summer
August	34	16	Summer
September	110	2	Summer
October	240		Shoulder
November	359		Winter
December	432		Winter
January	447		Winter
February	405		Winter
March	355		Winter

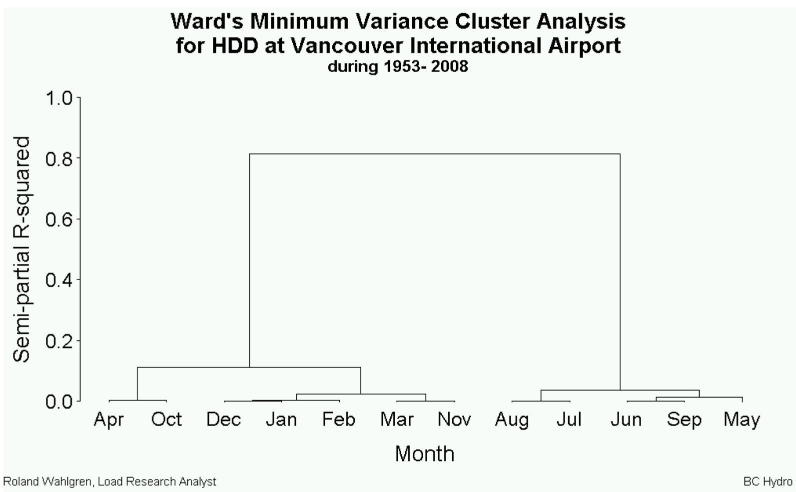

Figure A-2-2: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

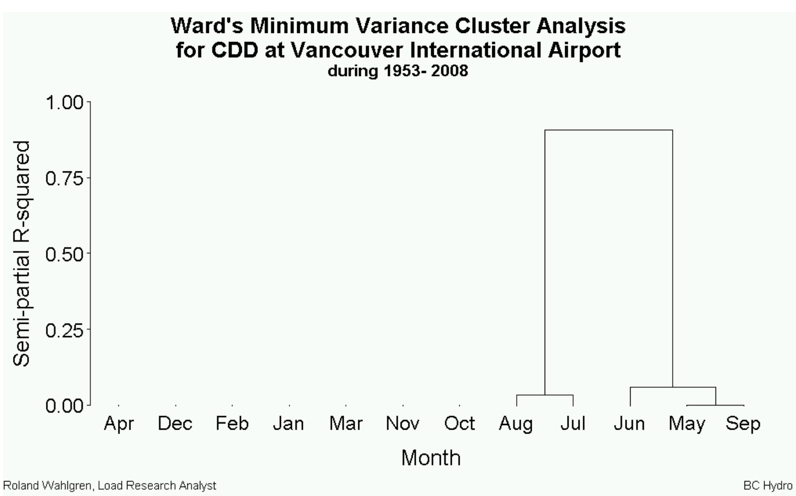

Figure A-2-3: Cooling degree days occur in May, June, July, August, and September

Table A-2-2: Results from EC data set for Vancouver 1953 to 1959

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	278		Shoulder
May	152	2	Summer
June	97	12	Summer
July	38	26	Summer
August	39	8	Summer
September	113	1	Summer
October	247		Shoulder
November	368		Winter
December	411		Winter
January	456		Winter
February	429		Winter
March	382		Winter

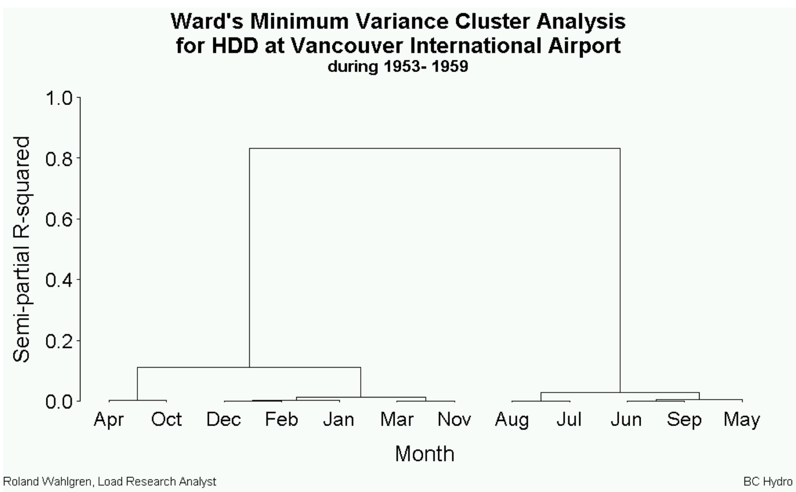

Figure A-2-4: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

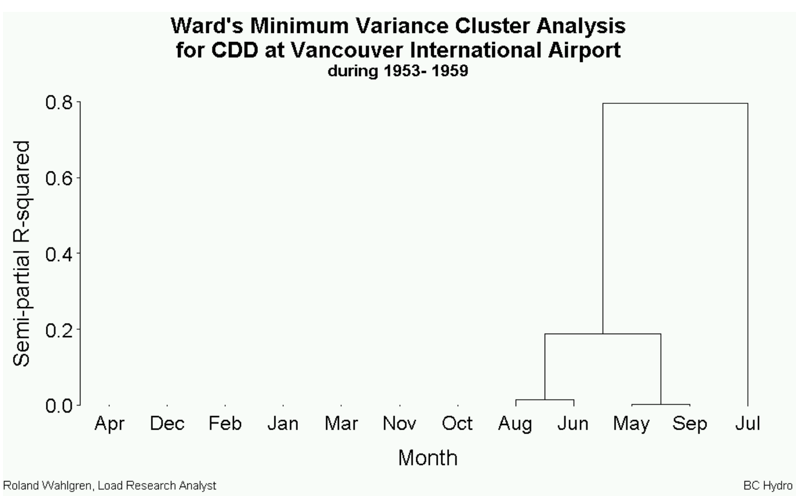

Figure A-2-5: Cooling degree days occur in May, June, July, August, and September

Table A-2-3: Results from EC data set for Vancouver 1960 to 1969

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	285		Shoulder
May	184	1	Shoulder
June	85	6	Summer
July	40	18	Summer
August	46	12	Summer
September	116	1	Summer
October	236		Shoulder
November	350		Winter
December	432		Winter
January	468		Winter
February	398		Winter
March	370		Winter

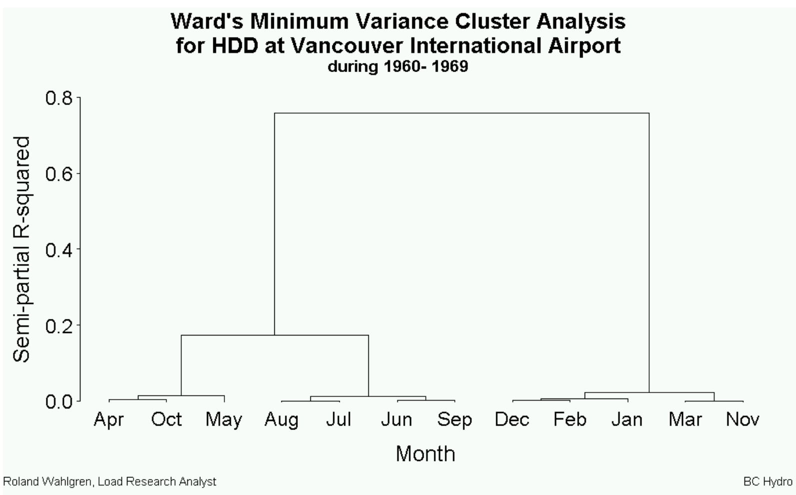

Figure A-2-6: Cluster analysis result: Summer months (June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, May October)

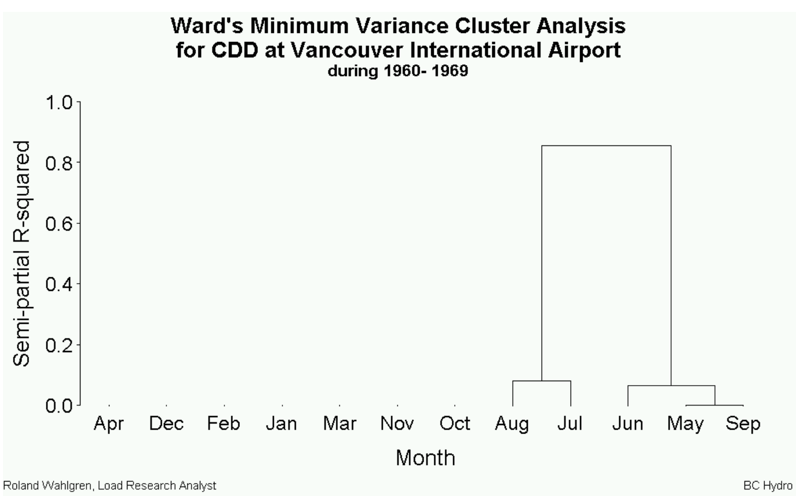

Figure A-2-7: Cooling degree days occur in May, June, July, August, and September

Table A-2-4: Results from EC data set for Vancouver 1970 to 1979

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	292		Shoulder
May	190		Summer
June	103	4	Summer
July	44	15	Summer
August	46	13	Summer
September	125	1	Summer
October	256		Shoulder
November	383		Winter
December	441		Winter
January	478		Winter
February	411		Winter
March	367		Winter

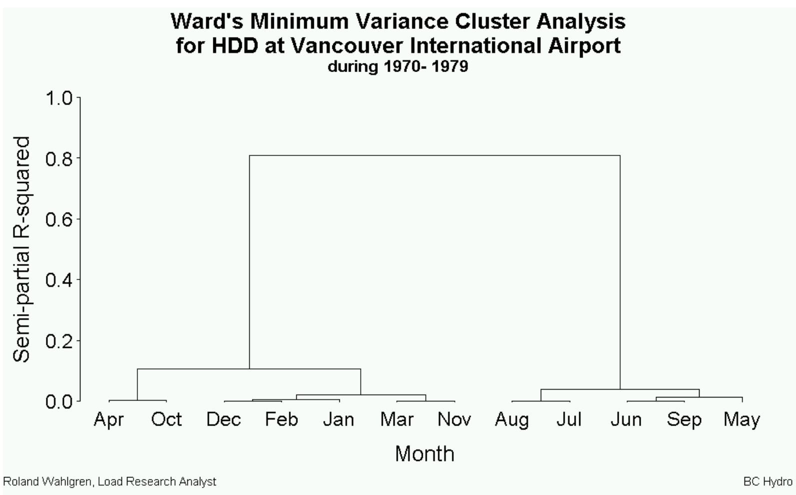

Figure A-2-8: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

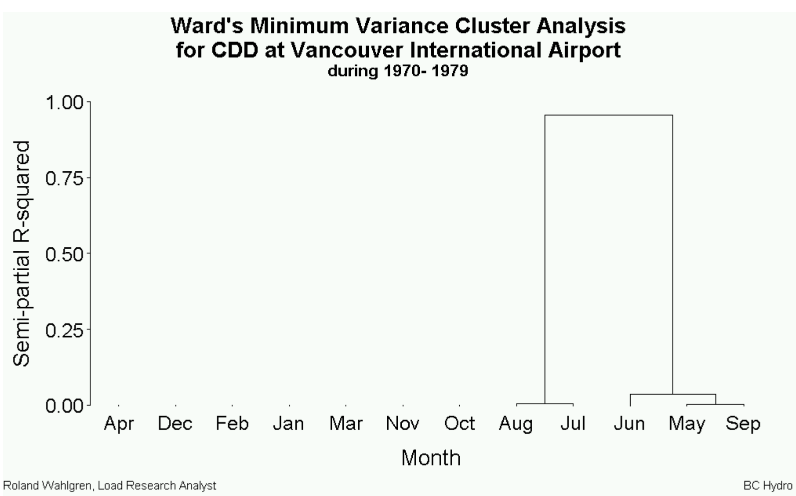

Figure A-2-9: Cooling degree days occur in May, June, July, August, and September

Table A-2-5: Results from EC data set for Vancouver 1980 to 1989

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	271		Shoulder
May	173	6	Summer
June	92	7	Summer
July	40	13	Summer
August	32	14	Summer
September	117	3	Summer
October	237		Shoulder
November	360		Winter
December	445		Winter
January	435		Winter
February	405		Winter
March	339		Winter

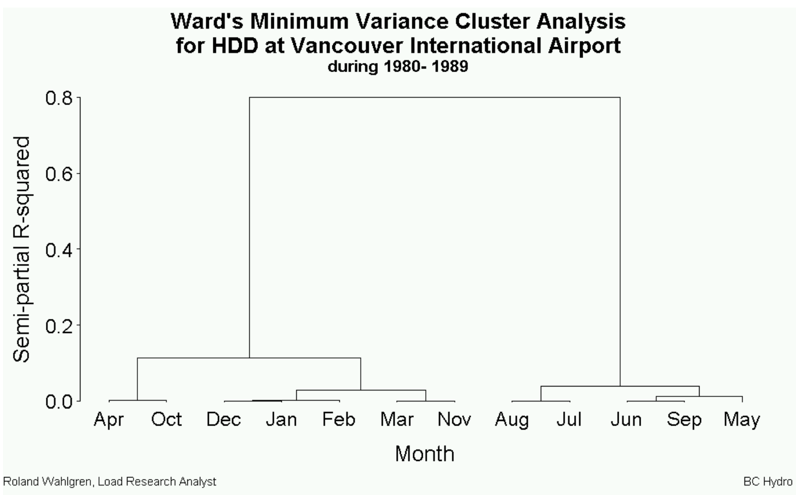

Figure A-2-10: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

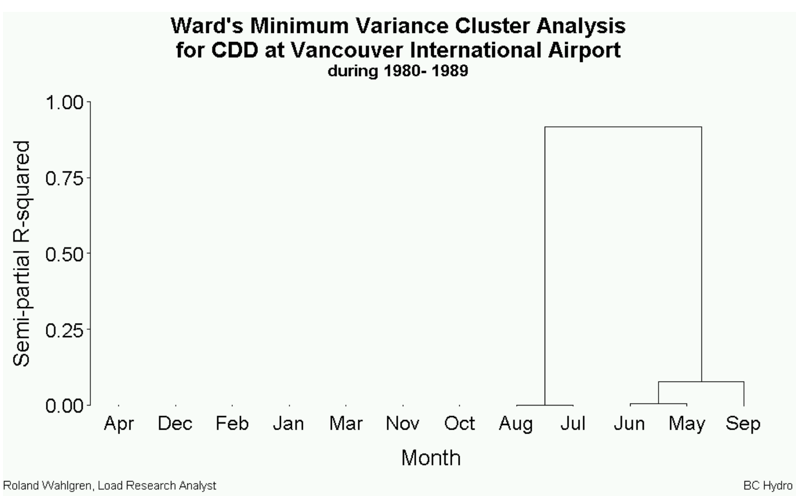

Figure A-2-11: Cooling degree days occur in May, June, July, August, and September

Table A-2-6: Results from EC data set for Vancouver 1990 to 1999

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	250		Shoulder
May	150	1	Summer
June	82	6	Summer
July	26	23	Summer
August	23	25	Summer
September	89	3	Summer
October	234		Shoulder
November	344		Winter
December	435		Winter
January	429		Winter
February	393		Winter
March	336		Winter

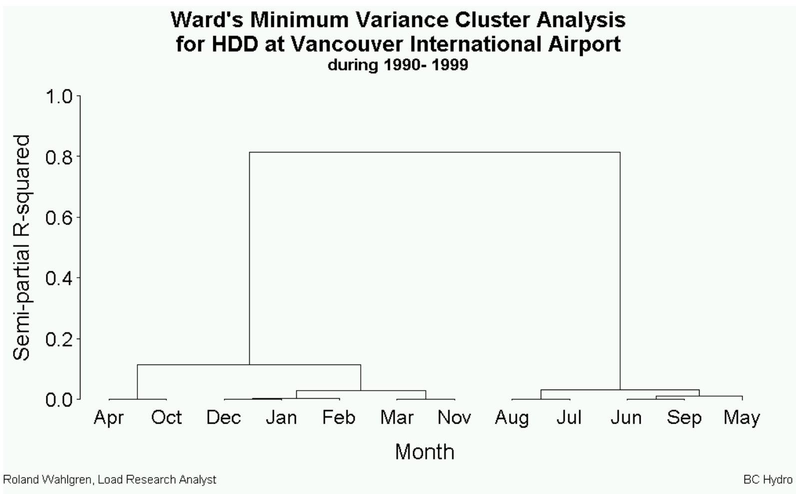

Figure A-2-12: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

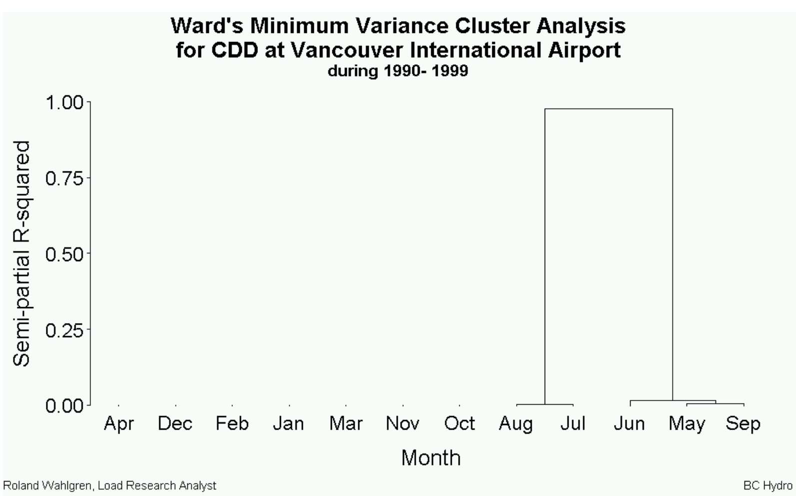

Figure A-2-13: Cooling degree days occur in May, June, July, August, and September

Table A-2-7: Results from EC data set for Vancouver 2000 to 2008

Vancouver International Airport			
Month	**HDD**	**CDD**	**Season**
April	264		Shoulder
May	161	2	Summer
June	79	9	Summer
July	19	26	Summer
August	21	18	Summer
September	102	2	Summer
October	231		Shoulder
November	351		Winter
December	424		Winter
January	414		Winter
February	399		Winter
March	340		Winter

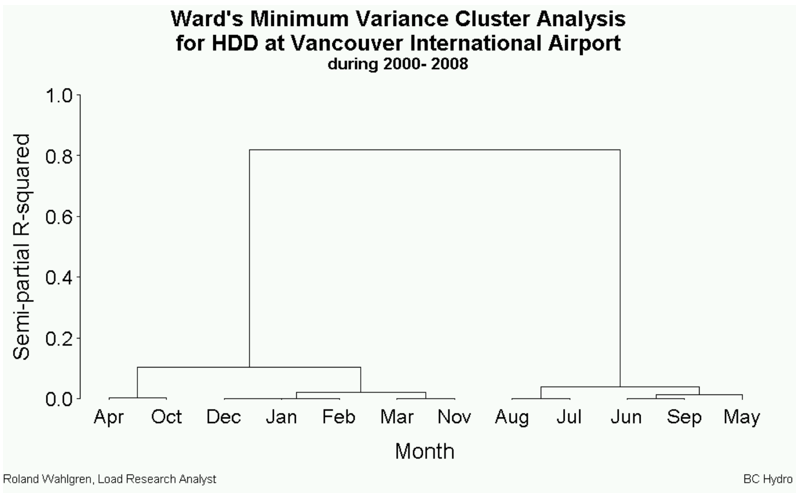

Figure A-2-14: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

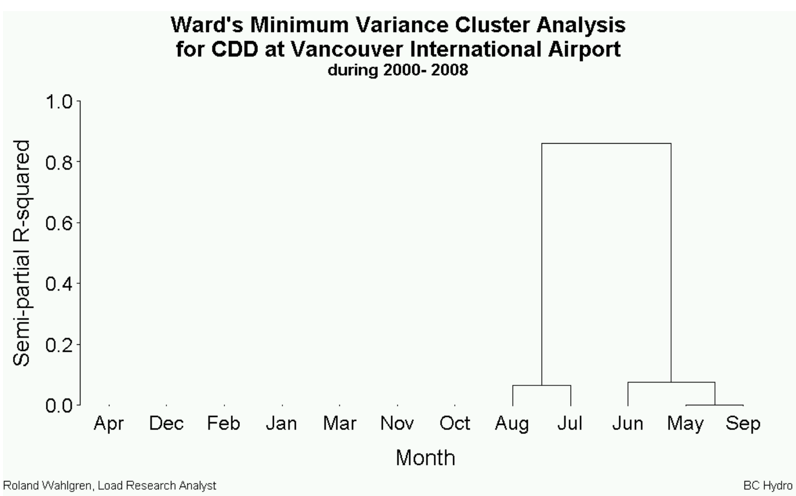

Figure A-2-15: Cooling degree days occur in May, June, July, August, and September

Table A-2-8: Results from EC data set for Victoria 1953 to 2008

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	282		Shoulder
May	184	3	Summer
June	108	6	Summer
July	55	12	Summer
August	60	8	Summer
September	130	2	Summer
October	250		Shoulder
November	356		Winter
December	418		Winter
January	431		Winter
February	400		Winter
March	357		Winter

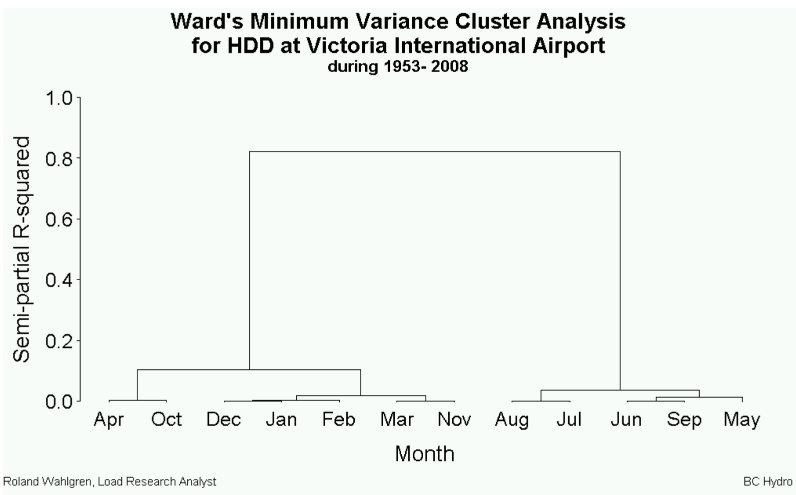

Figure A-2-16: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

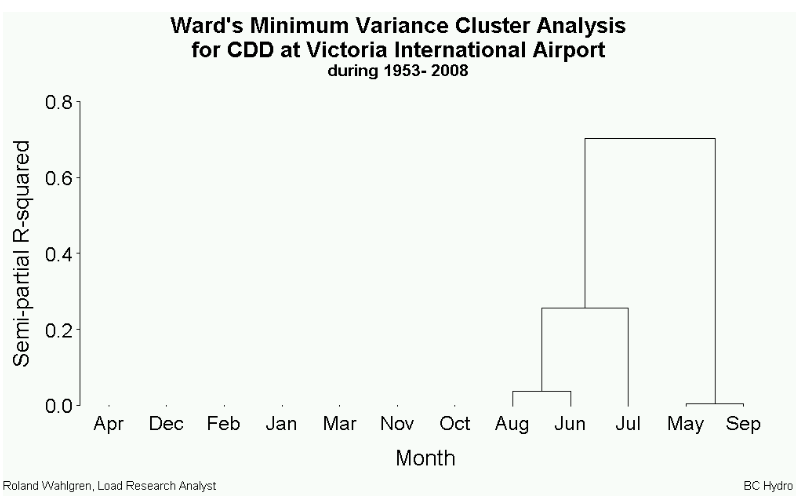

Figure A-2-17: Cooling degree days occur in May, June, July, August, and September

Table A-2-9: Results from EC data set for Victoria 1953 to 1959

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	290		Shoulder
May	170	2	Summer
June	118	9	Summer
July	65	17	Summer
August	68	4	Summer
September	130	2	Summer
October	256		Shoulder
November	364		Winter
December	405		Winter
January	442		Winter
February	423		Winter
March	384		Winter

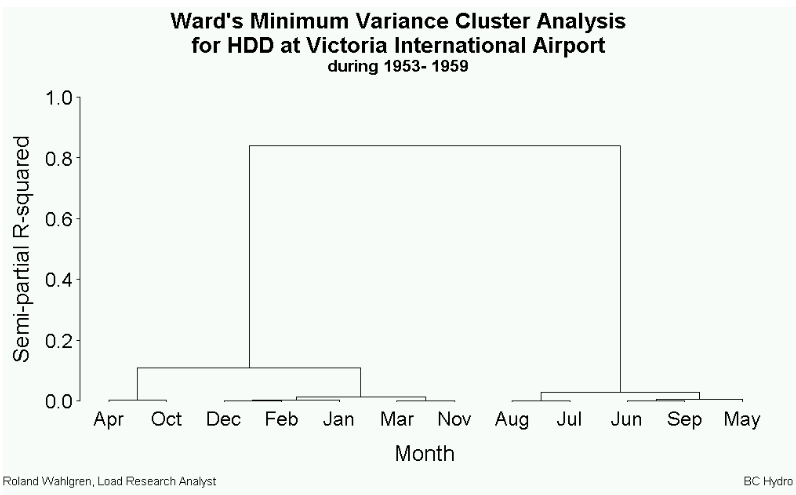

Figure A-2-18: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

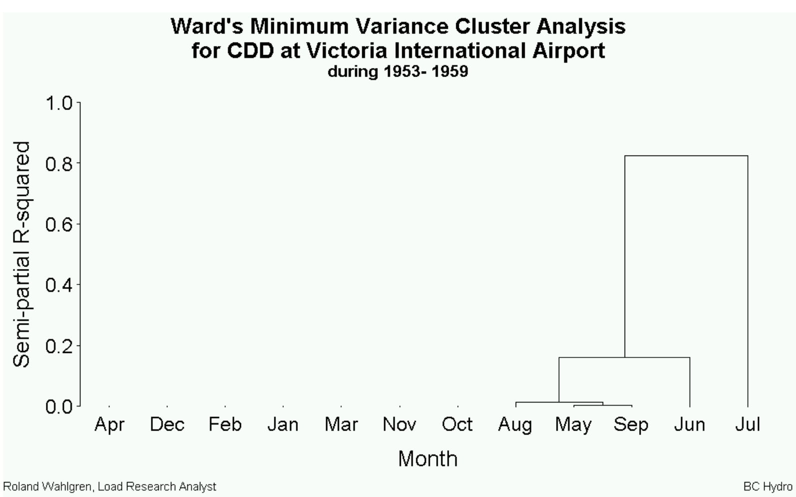

Figure A-2-19: Cooling degree days occur in May, June, July, August, and September

Table A-2-10: Results from EC data set for Victoria 1960 to 1969

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	294		Winter
May	197	3	Shoulder
June	108	4	Summer
July	60	12	Summer
August	68	7	Summer
September	136	2	Summer
October	245		Shoulder
November	352		Winter
December	419		Winter
January	448		Winter
February	392		Winter
March	370		Winter

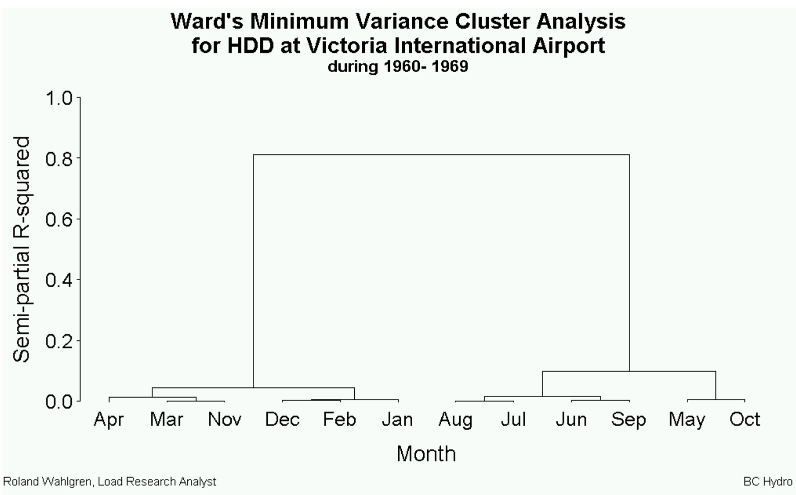

Figure A-2-20: Cluster analysis result: Summer months (June, July, August, September); Winter months (November, December, January, February, March, April); and Shoulder months (May, October)

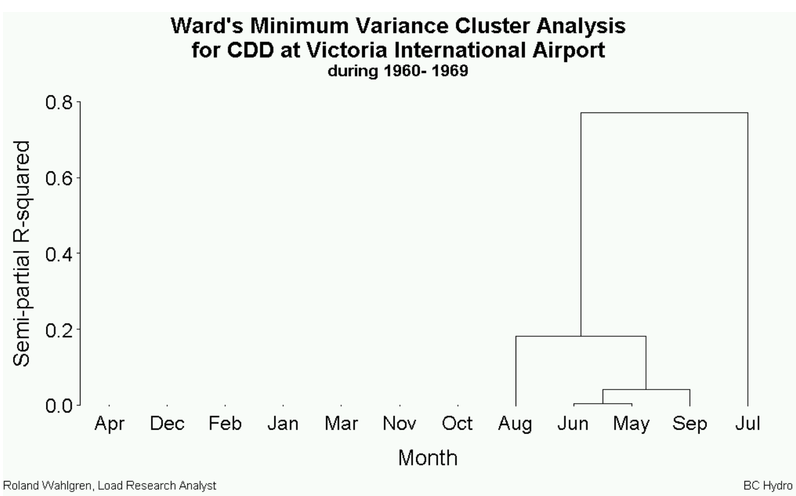

Figure A-2-21: Cooling degree days occur in May, June, July, August, and September

Table A-2-11: Results from EC data set for Victoria 1970 to 1979

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	298		Shoulder
May	203	3	Summer
June	121	3	Summer
July	66	10	Summer
August	74	9	Summer
September	139	3	Summer
October	261		Shoulder
November	375		Winter
December	424		Winter
January	458		Winter
February	405		Winter
March	370		Winter

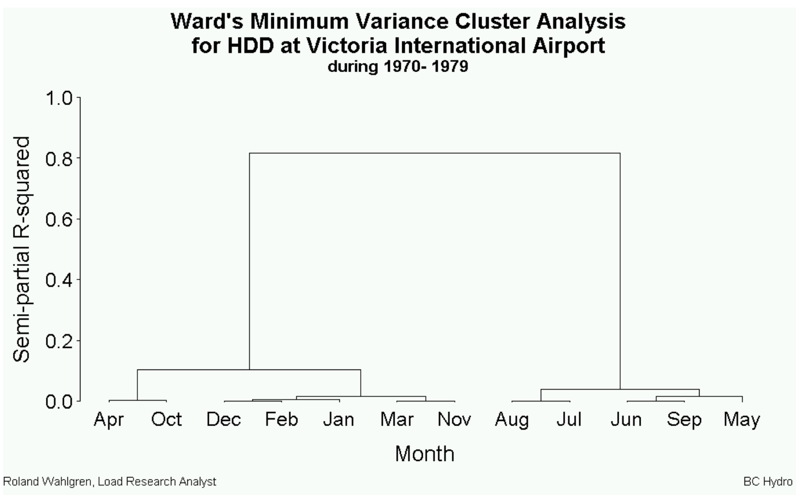

Figure A-2-22: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

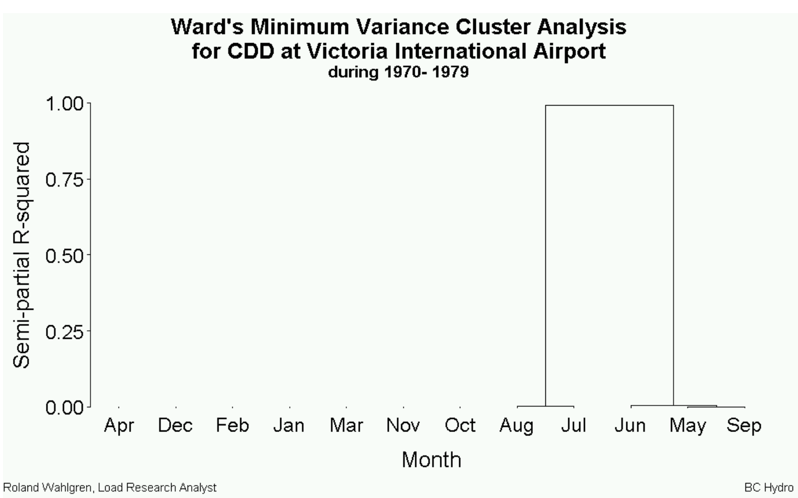

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Figure A-2-23: Cooling degree days occur in May, June, July, August, and September

Table A-2-12: Results from EC data set for Victoria 1980 to 1989

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	277		Shoulder
May	189	4	Summer
June	111	5	Summer
July	60	7	Summer
August	57	9	Summer
September	135	3	Summer
October	247		Shoulder
November	356		Winter
December	430		Winter
January	420		Winter
February	403		Winter
March	345		Winter

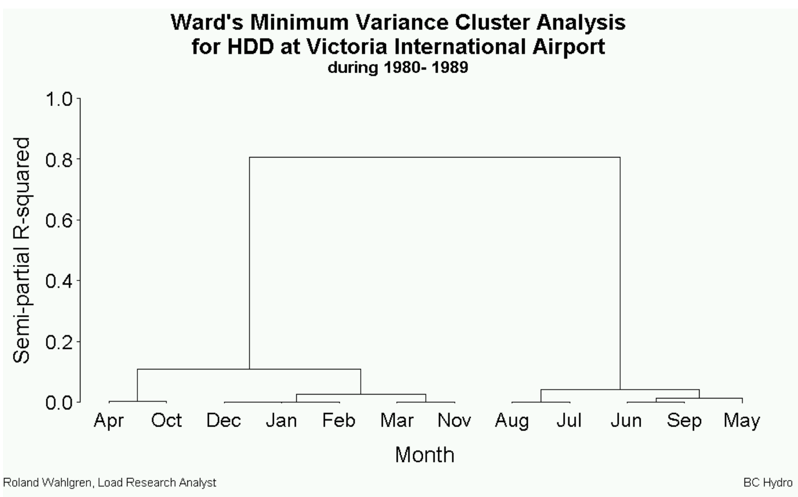

Figure A-2-24: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

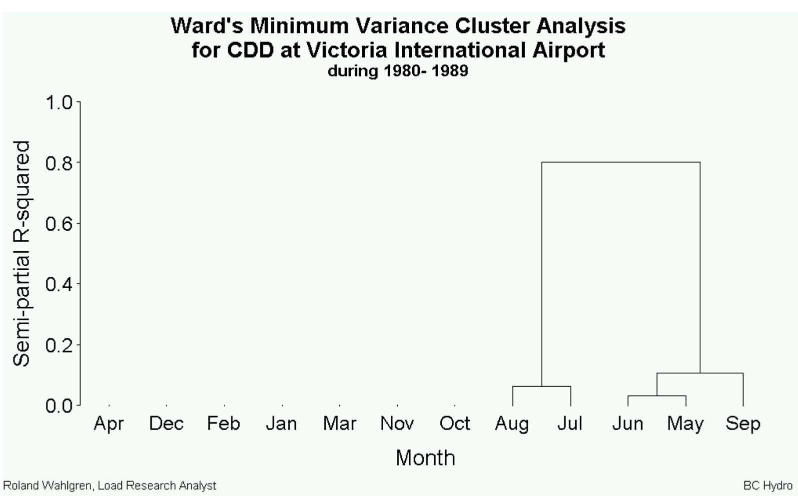

Figure A-2-25: Cooling degree days occur in May, June, July, August, and September

Table A-2-13: Results from EC data set for Victoria 1990 to 1999

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	260		Shoulder
May	164	1	Summer
June	100	5	Summer
July	44	15	Summer
August	47	10	Summer
September	115	1	Summer
October	247		Shoulder
November	338		Winter
December	410		Winter
January	411		Winter
February	384		Winter
March	338		Winter

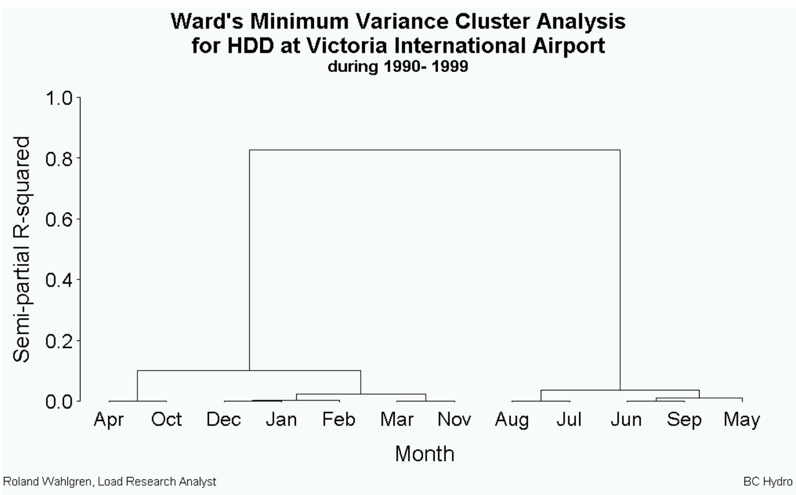

Figure A-2-26: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

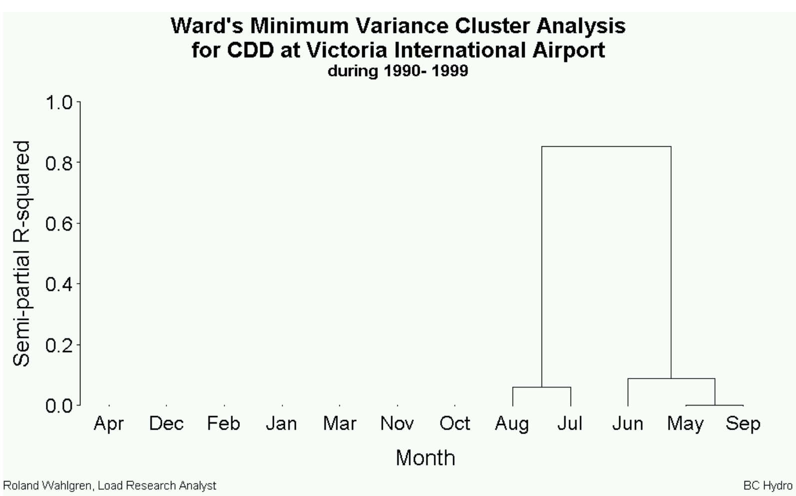

Figure A-2-27: Cooling degree days occur in May, June, July, August, and September

Table A-2-14: Results from EC data set for Victoria 2000 to 2008

Victoria International Airport			
Month	**HDD**	**CDD**	**Season**
April	274		Shoulder
May	176	3	Summer
June	92	9	Summer
July	37	16	Summer
August	45	8	Summer
September	123	2	Summer
October	242		Shoulder
November	354		Winter
December	412		Winter
January	405		Winter
February	400		Winter
March	342		Winter

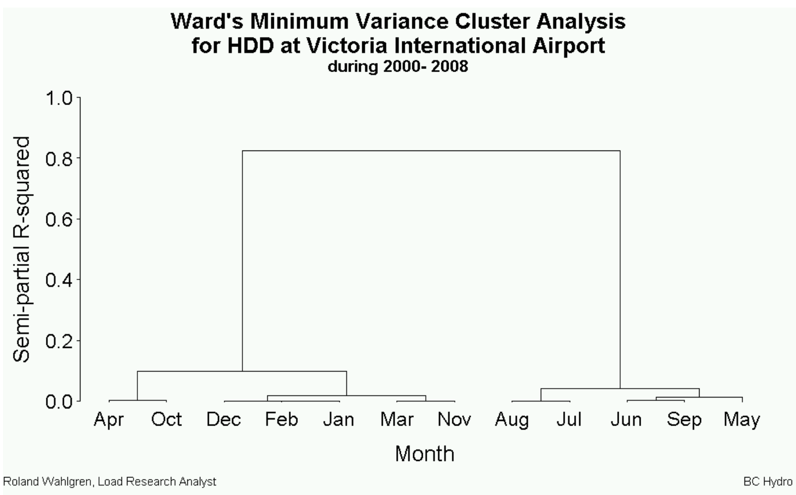

Figure A-2-28: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

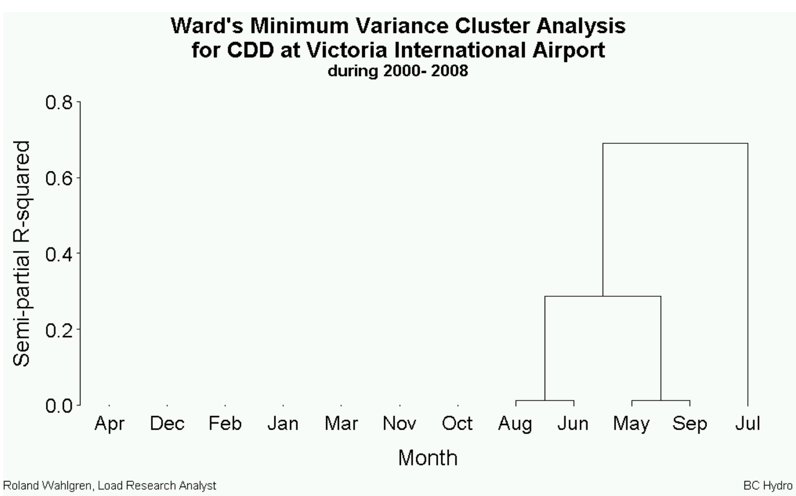

Figure A-2-29: Cooling degree days occur in May, June, July, August, and September

Table A-2-15: Results from EC data set for Prince George 1953 to 2008

Prince George Airport			
Month	**HDD**	**CDD**	**Season**
April	409	1	Shoulder
May	246	3	Summer
June	142	7	Summer
July	86	13	Summer
August	115	9	Summer
September	253	1	Summer
October	413		Shoulder
November	625		Winter
December	767		Winter
January	842		Winter
February	711		Winter
March	579		Winter

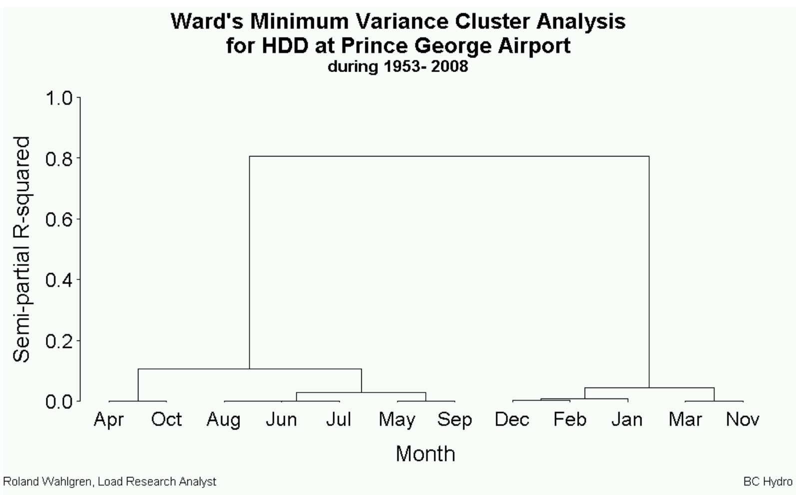

Figure A-2-30: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

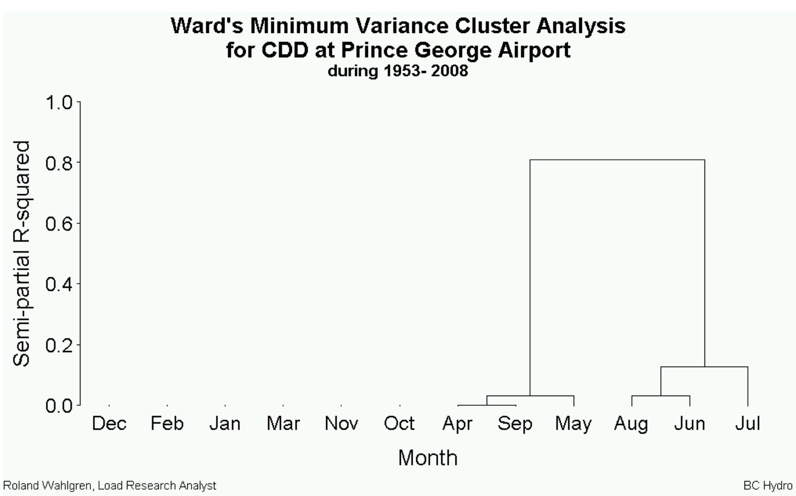

Figure A-2-31: Cooling degree days occur in April, May, June, July, August, and September

Table A-2-16: Results from EC data set for Prince George 1953 to 1959

Prince George Airport			
Month	HDD	CDD	Season
April	455		Shoulder
May	229	1	Summer
June	151	12	Summer
July	97	12	Summer
August	144	4	Summer
September	255		Summer
October	427		Shoulder
November	629		Winter
December	730		Winter
January	934		Winter
February	778		Winter
March	630		Winter

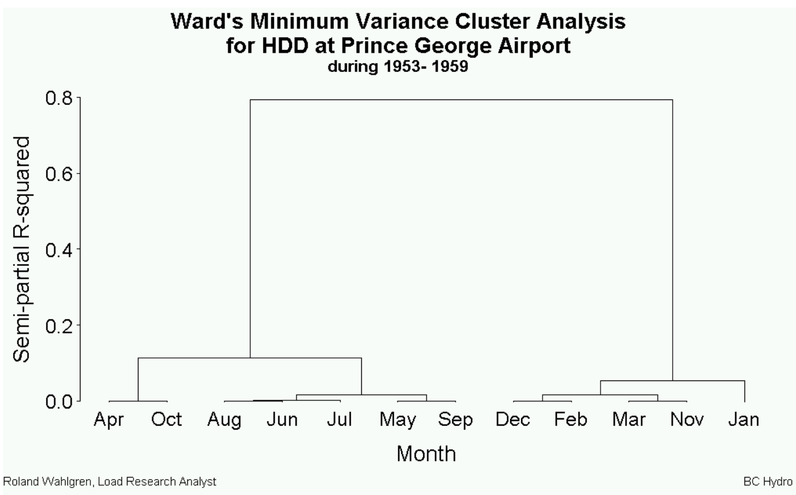

Figure A-2-32: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

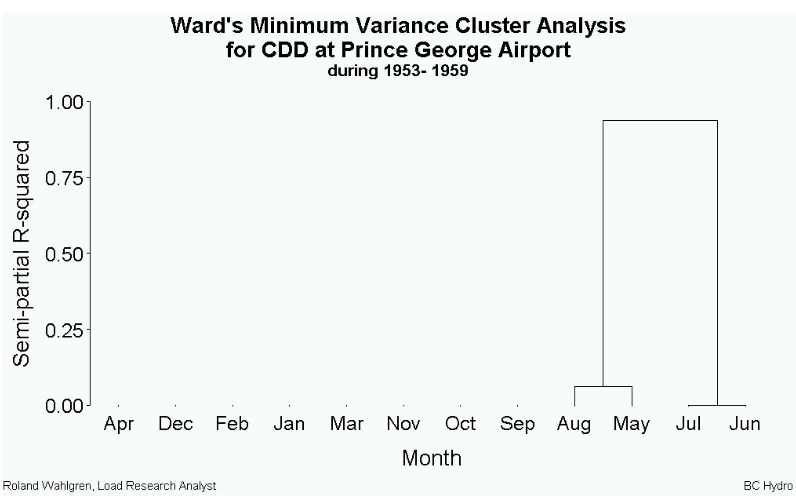

Figure A-2-33: Cooling degree days occur in May, June, July, and August

Table A-2-17: Results from EC data set for Prince George 1960 to 1969

Prince George Airport			
Month	**HDD**	**CDD**	**Season**
April	419		Shoulder
May	268	1	Shoulder
June	148	6	Summer
July	85	11	Summer
August	121	9	Summer
September	259		Shoulder
October	400		Shoulder
November	621		Winter
December	783		Winter
January	879		Winter
February	683		Winter
March	599		Winter

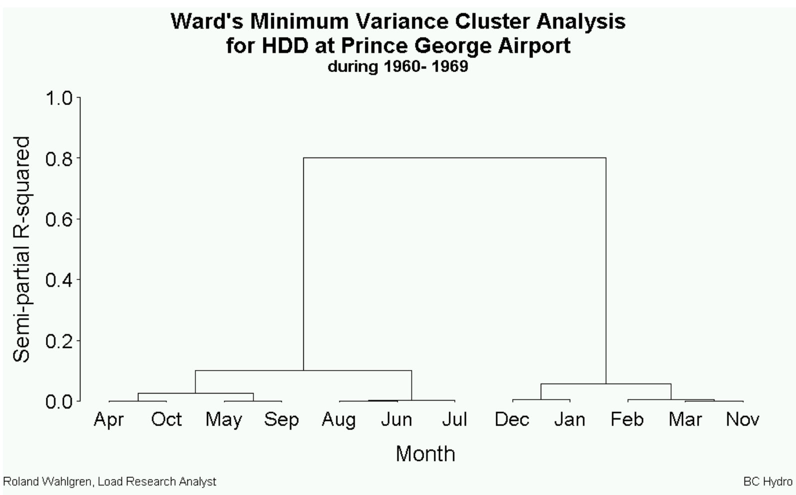

Figure A-2-34: Cluster analysis result: Summer months (June, July, August); Winter months (November, December, January, February, March); and Shoulder months (April, May, September, October)

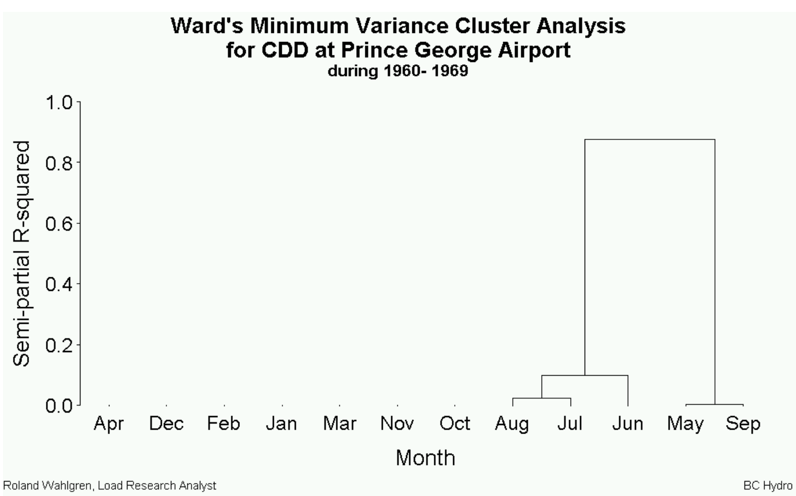

Figure A-2-35: Cooling degree days occur in May, June, July, August, and September (0.3 CDD, not shown in Table A-2-17 whose values are rounded to nearest integer)

Table A-2-18: Results from EC data set for Prince George 1970 to 1979

Prince George Airport			
Month	**HDD**	**CDD**	**Season**
April	410	1	Shoulder
May	266	2	Shoulder
June	157	4	Summer
July	98	16	Summer
August	116	7	Summer
September	270		Shoulder
October	411		Shoulder
November	661		Winter
December	804		Winter
January	904		Winter
February	736		Winter
March	580		Winter

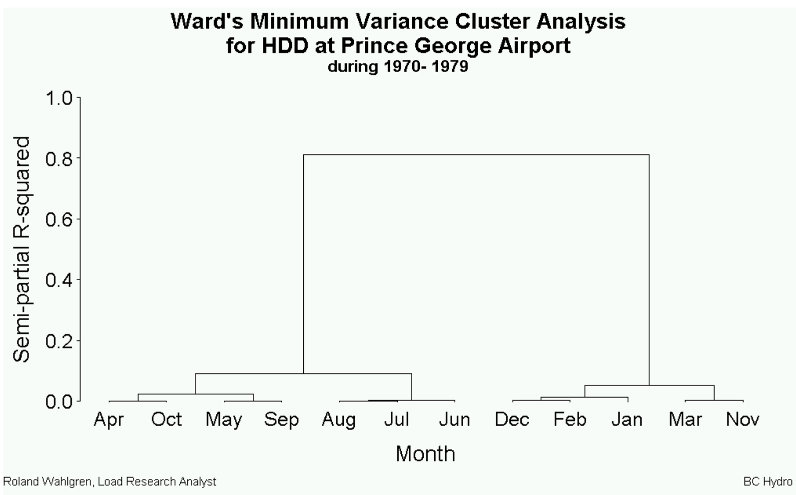

Figure A-2-36: Cluster analysis result: Summer months (June, July, August); Winter months (November, December, January, February, March); and Shoulder months (April, May, September, October)

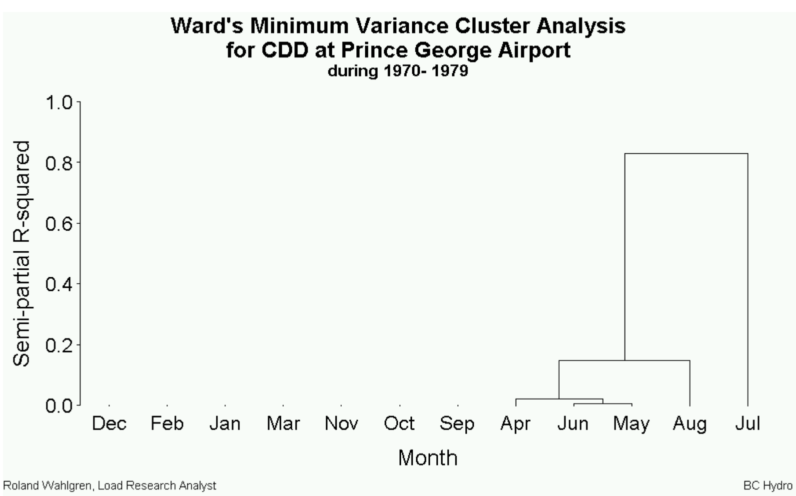

Figure A-2-37: Cooling degree days occur in April, May, June, July, and August

Table A-2-19: Results from EC data set for Prince George 1980 to 1989

Prince George Airport			
Month	**HDD**	**CDD**	**Season**
April	397		Shoulder
May	240	17	Summer
June	141	6	Summer
July	87	10	Summer
August	114	7	Summer
September	258	2	Summer
October	400		Shoulder
November	625		Winter
December	785		Winter
January	763		Winter
February	715		Winter
March	558		Winter

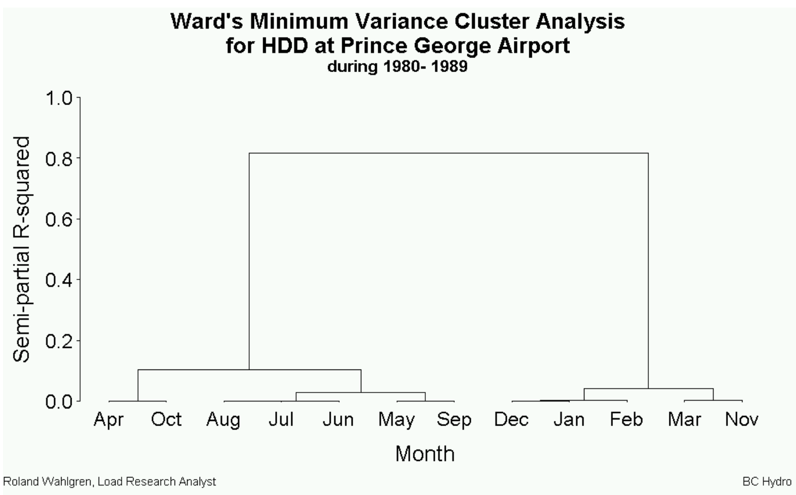

Figure A-2-38: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

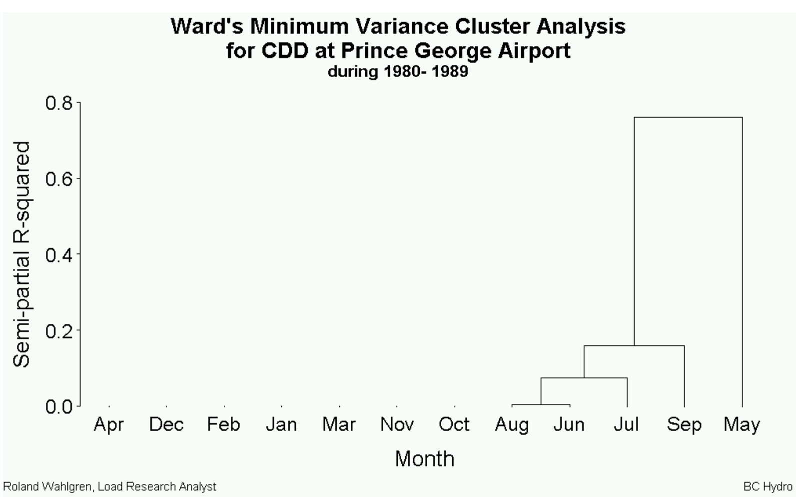

Figure A-2-39: Cooling degree days occur in May, June, July, August, and September

Table A-2-20: Results from EC data set for Prince George 1990 to 1999

Prince George Airport			
Month	**HDD**	**CDD**	**Season**
April	382		Shoulder
May	221	5	Summer
June	129	8	Summer
July	73	12	Summer
August	93	15	Summer
September	224	1	Summer
October	427		Shoulder
November	617		Winter
December	748		Winter
January	832		Winter
February	669		Winter
March	553		Winter

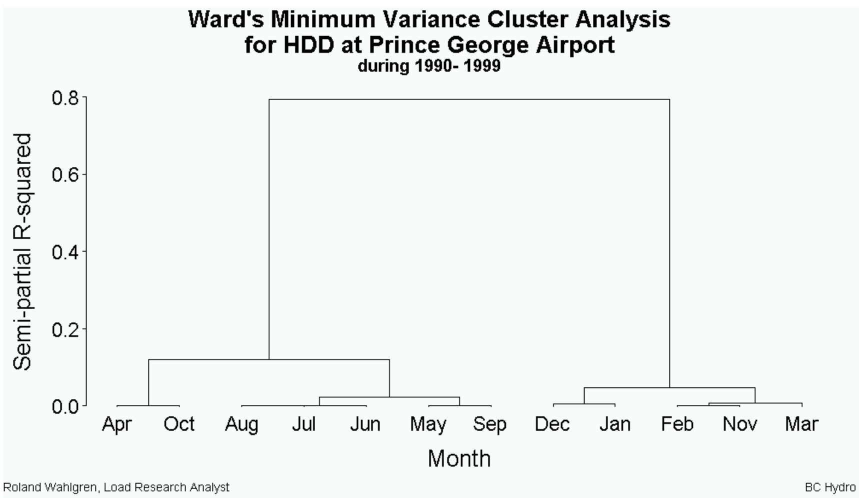

Figure A-2-40: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

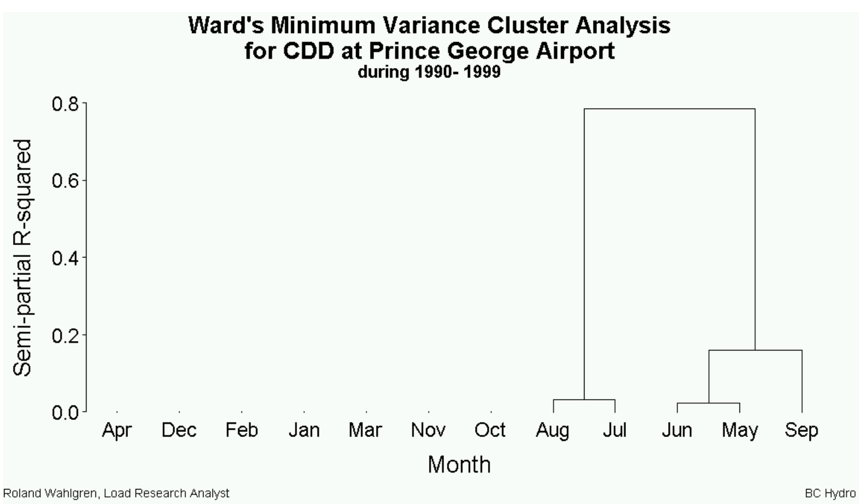

Figure A-2-41: Cooling degree days occur in May, June, July, August, and September

Table A-2-21: Results from EC data set for Prince George 2000 to 2008

Prince George Airport			
Month	**HDD**	**CDD**	**Season**
April	406		Shoulder
May	245	3	Summer
June	124	8	Summer
July	80	15	Summer
August	112	10	Summer
September	253	1	Summer
October	416		Shoulder
November	595		Winter
December	737		Winter
January	759		Winter
February	702		Winter
March	567		Winter

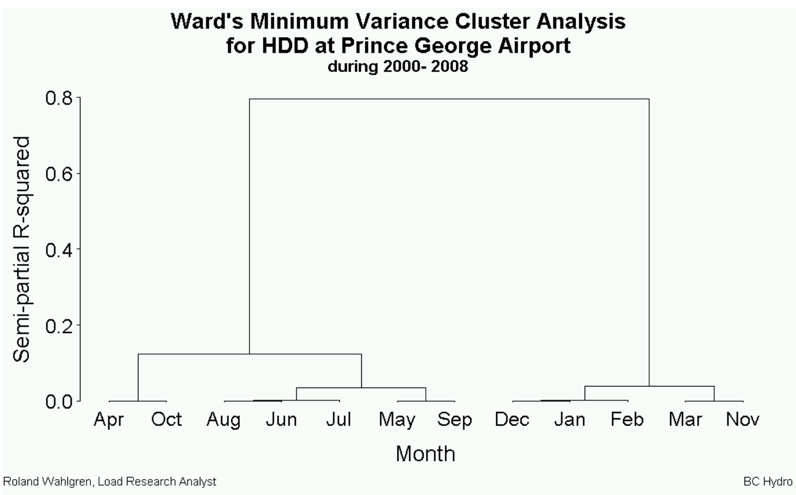

Figure A-2-42: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

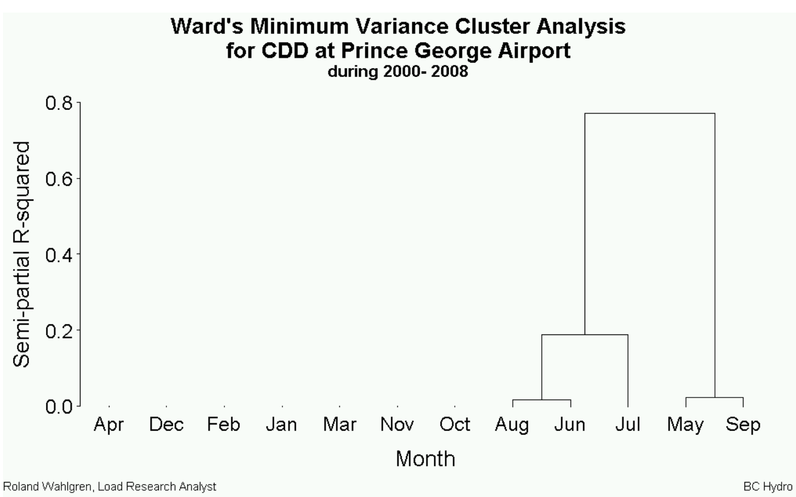

Figure A-2-43: Cooling degree days occur in May, June, July, August, and September

Table A-2-22: Results from EC data set for Kelowna 1960 to 2004

Kelowna Airport			
Month	**HDD**	**CDD**	**Season**
April	271	2	Shoulder
May	134	14	Summer
June	46	52	Summer
July	16	102	Summer
August	23	84	Summer
September	128	13	Summer
October	310	1	Shoulder
November	496		Winter
December	619		Winter
January	658		Winter
February	568		Winter
March	430		Winter

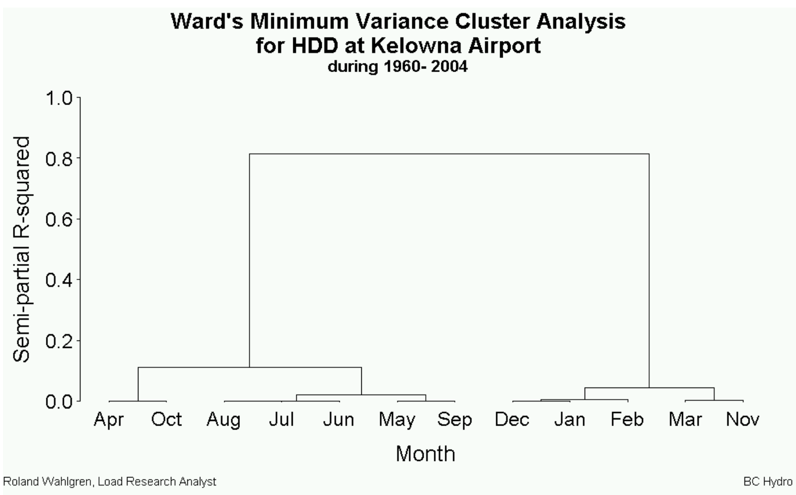

Figure A-2-44: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

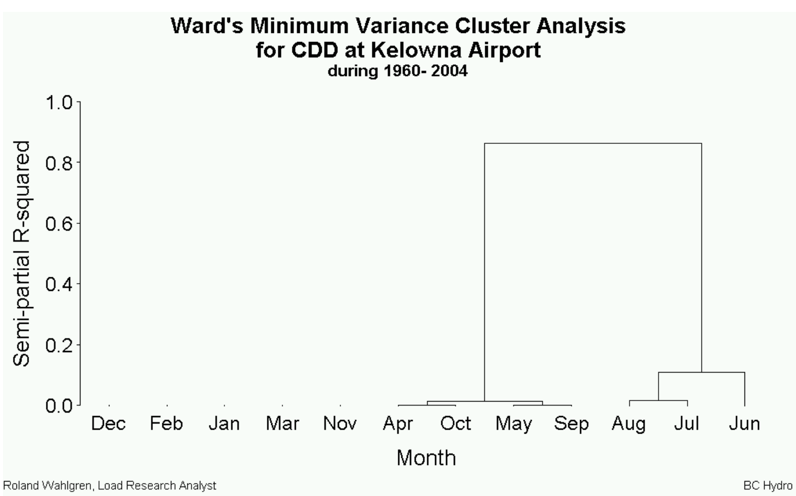

Figure A-2-45: Cooling degree days occur in April, May, June, July, August, September, and October

Table A-2-23: Results from EC data set for Kelowna 1960 to 1969

Kelowna Airport			
Month	**HDD**	**CDD**	**Season**
April	232	2	Shoulder
May	91	24	Summer
June	20	92	Summer
July	7	157	Summer
August	16	132	Summer
September	84	30	Summer
October	259	1	Shoulder
November	465		Winter
December	595		Winter
January	653		Winter
February	529		Winter
March	408		Winter

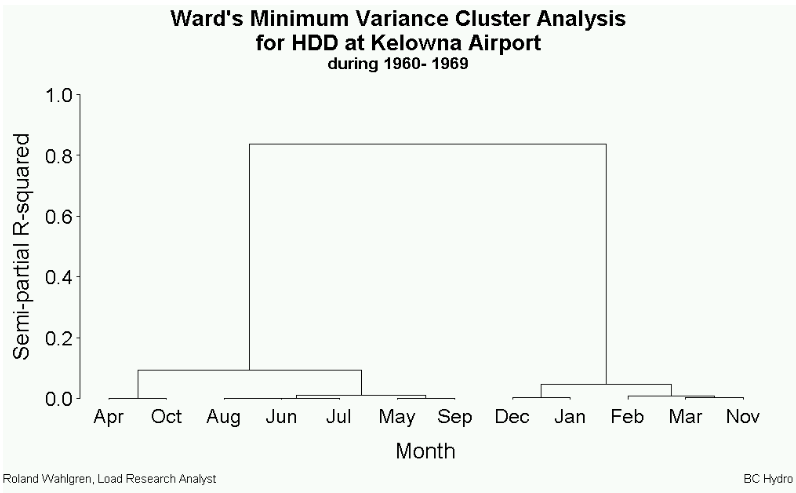

Figure A-2-46: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October

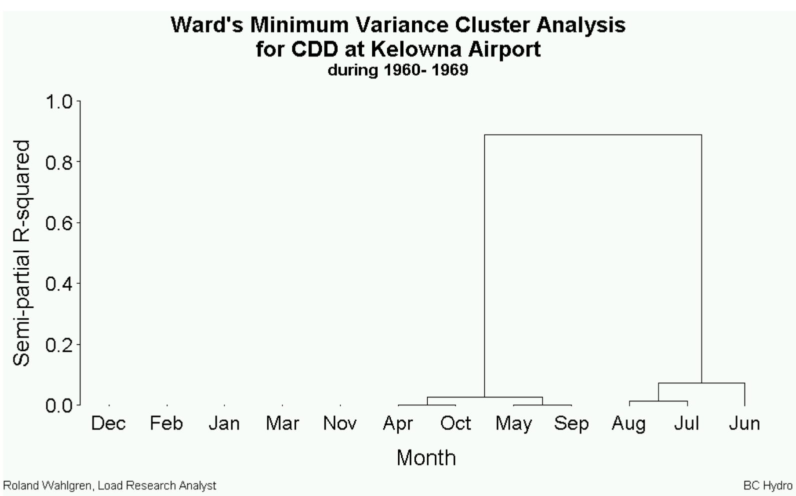

Figure A-2-47: Cooling degree days occur in April, May, June, July, August, September, and October

Table A-2-24: Results from EC data set for Kelowna 1970 to 1979

Kelowna Airport			
Month	**HDD**	**CDD**	**Season**
April	311		Shoulder
May	170	4	Summer
June	63	28	Summer
July	21	78	Summer
August	32	62	Summer
September	158	2	Summer
October	345		Shoulder
November	520		Shoulder
December	634		Winter
January	711		Winter
February	597		Winter
March	468		Shoulder

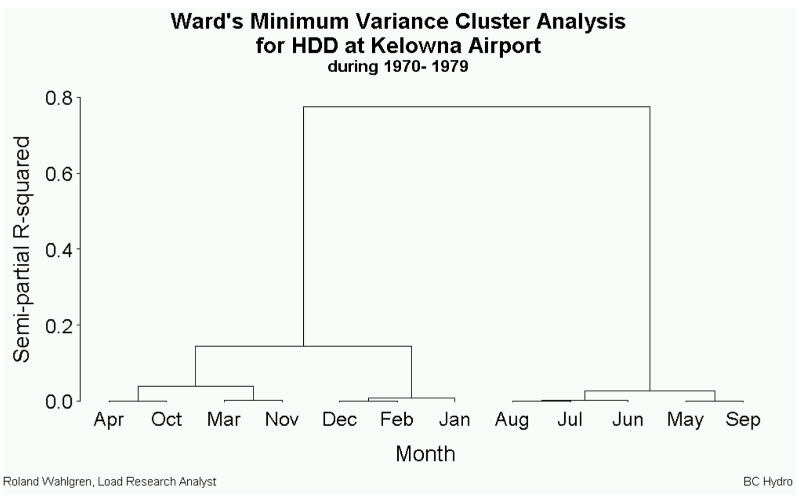

Figure A-2-48: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (December, January, February); and Shoulder months (March, April, October, November)

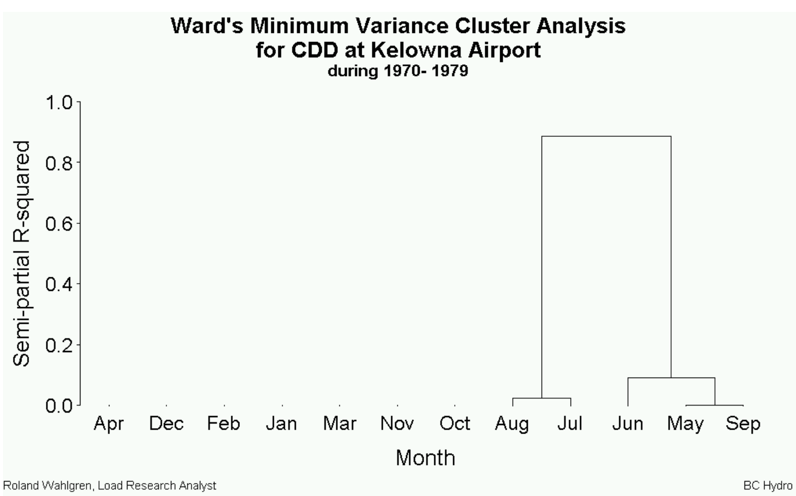

Figure A-2-49: Cooling degree days occur in May, June, July, August, and September

Table A-2-25: Results from EC data set for Kelowna 1980 to 1989

Kelowna Airport			
Month	HDD	CDD	Season
April	272		Shoulder
May	136	9	Summer
June	51	44	Summer
July	22	82	Summer
August	20	62	Summer
September	144	9	Summer
October	321		Shoulder
November	503		Shoulder
December	639		Winter
January	630		Winter
February	582		Winter
March	416		Shoulder

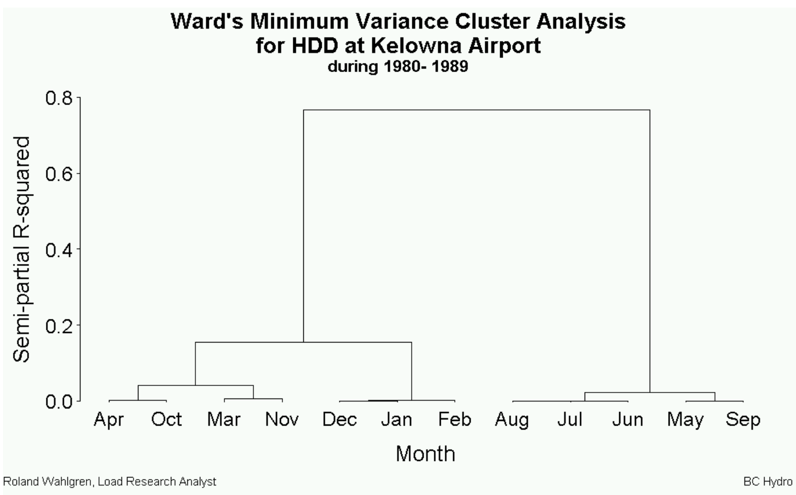

Figure A-2-50: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (December, January, February); and Shoulder months (March, April, October, November)

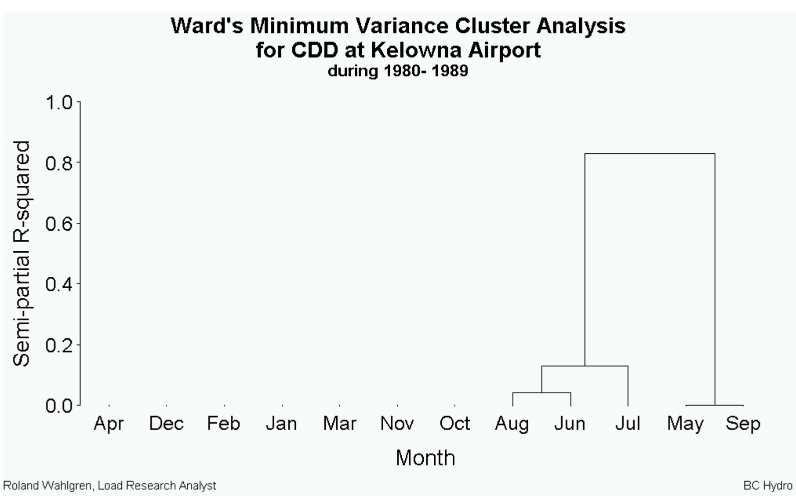

Figure A-2-51: Cooling degree days occur in May, June, July, August, and September

Table A-2-26: Results from EC data set for Kelowna 1990 to 1999

Kelowna Airport			
Month	**HDD**	**CDD**	**Season**
April	250		Shoulder
May	114	22	Summer
June	48	45	Summer
July	13	82	Summer
August	21	91	Summer
September	103	8	Summer
October	310		Shoulder
November	498		Winter
December	641		Winter
January	657		Winter
February	553		Winter
March	408		Winter

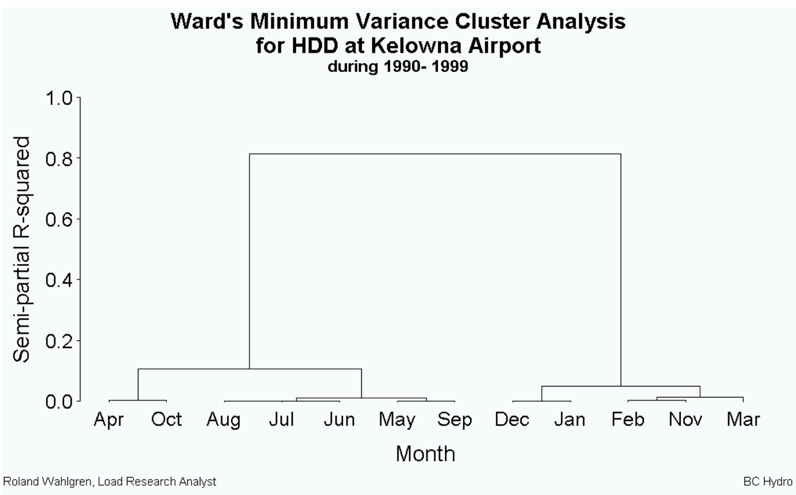

Figure A-2-52: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

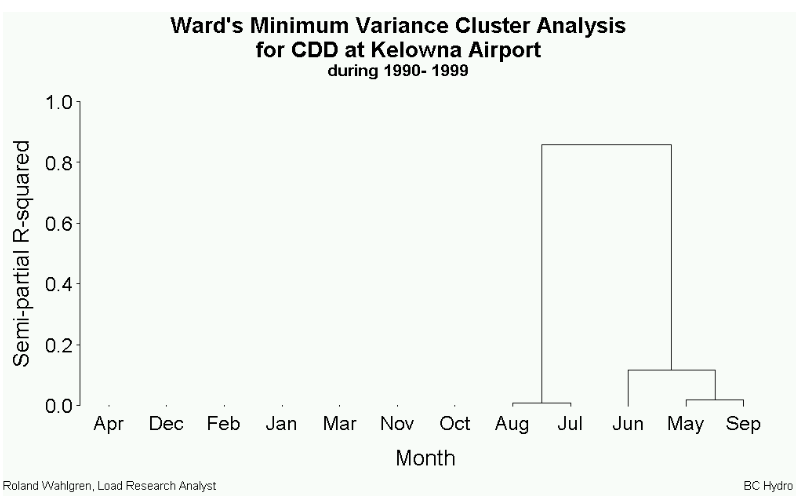

Figure A-2-53: Cooling degree days occur in May, June, July, August, and September

Table A-2-27: Results from EC data set for Kelowna 2000 to 2004

Kelowna Airport			
Month	**HDD**	**CDD**	**Season**
April	285		Shoulder
May	169	1	Summer
June	43	45	Summer
July	7	109	Summer
August	18	70	Summer
September	143	7	Summer
October	329		Shoulder
November	509		Winter
December	556		Winter
January	595		Winter
February	565		Winter
March	446		Winter

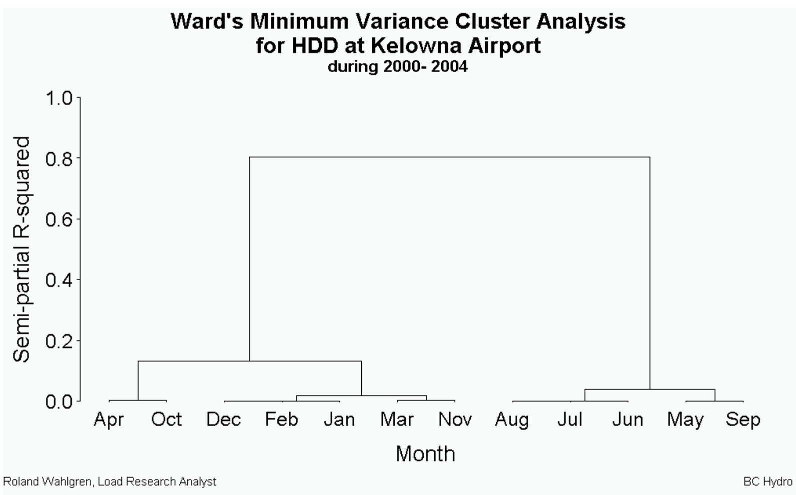

Figure A-2-52: Cluster analysis result: Summer months (May, June, July, August, September); Winter months (November, December, January, February, March); and Shoulder months (April, October)

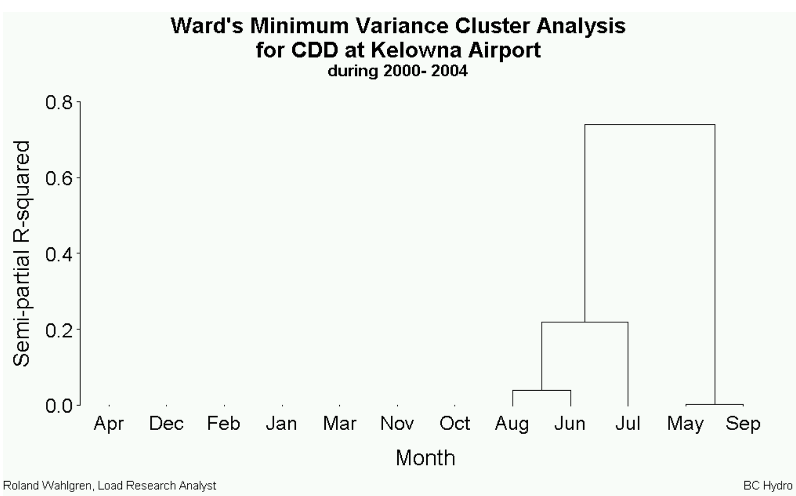

Figure A-2-53: Cooling degree days occur in May, June, July, August, and September