Task 5: Proposed test protocol for walls of houses in extreme cold regions. Part 1: Defining exterior conditions

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Task 5: Proposed Test Protocol for Walls of Houses in Extreme Cold Regions. Part 1: Defining Exterior Conditions

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National Research Council Canada
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Task 5 Proposed Test Protocol for Walls of Houses in Extreme Cold Regions Part 1: Defining Exterior Conditions

PERD 079 PROJECT ENGINEERED BUILDING ENVELOPE TO ACCOMMODATE HIGH PERFORMANCE INSULATION WITH OUTDOOR/INDOOR CLIMATE EXTREMES

National Research Council of Canada
Institute for Research in Construction

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Task 5 Proposed Test Protocol for Walls of Houses in Extreme Cold Regions Part 1: Defining Exterior Conditions

PERD 079: "Engineered Building Envelope Systems to Accommodate High Performance Insulation with Outdoor/Indoor Climate Extremes"

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1 Summary

The objective of the experimental study of the project is to characterize the thermal response and the moisture resistance of test specimens of selected wall assemblies subjected to indoor and outdoor conditions typically encountered in the Canadian North. The data collected will provide input for a complementary study aiming at predicting hygrothermal performance under different scenarios using numerical modeling software. The accelerated testing protocol presented here is not a standard test protocol as available standard test protocols would not capture extreme climatic conditions found in the North. For this reason an accelerated test protocol has been developed, based on the research conducted in Task 3 (*Study on climate characterization)* and Task 1 (Field surveys of indoor temperature and relative humidity in homes) and keeping in mind as much as possible the feasibility of implementing complex dynamic testing scenarios in a laboratory facility. This is currently a "proposed" test protocol as its feasibility in NRC-IRC EEEF will be first assessed with a mock up test sample and adjustments necessary will be made prior to subjecting the test specimens of the study to it. The protocol for the exterior conditions imposed on the test specimens comprises four parameters: temperature, wind, atmospheric moisture and solar irradiance. An accelerated test is defined; the length of the test is 6 weeks or 42 days or 1080 hours. The test protocol is designed to capture climate conditions typical of three seasons: winter, spring or swing season and summer. Not all the parameters need to be used in the test. The most important parameter is temperature. Other parameters can be added as required.

1.1 Temperature

The temperature profile for the cold regions test protocol is shown in Figure 1.

1.1.1 Winter

Stage 1: Initial conditioning: The test specimen is gradually conditioned from lab conditions to –35ºC until the conditions are stabilized. This is expected to take about 1 week.

Stage 2: Average conditions: Hold the exterior conditions of the weather side of the test chamber at –35ºC +/- 2ºC for 1 week.

Stage 3: Typical cold conditions: The weather side of the test chamber will go down to –42ºC at a rate of –1ºC/hour. Once conditions are stabilized, the temperature is to be held at –42ºC +/- 2ºC for 1 week.

Stage 4: Extreme cold conditions: The weather side of the test chamber will go down to –50ºC at a rate of –2ºC/hour; hold at –50ºC +/- 2ºC for 36 hours.

Stage 5: Return to average conditions at –35ºC at a rate of 1ºC/hour; hold at –35ºC until the end of the 4th week.

1.1.2 Spring

Stage 6: The temperature on the weather side of the test chamber will be raised to –25ºC +/- 2ºC at a rate of 1ºC/hour. When –25ºC is reached, temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.
Stage 7: Raise the temperature from –25ºC to –15ºC +/- 2ºC at a rate of 2ºC/hour. When –15ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.
Stage 8: Raise the temperature from –15ºC to –5ºC (+/- 2ºC) at a rate of 2ºC/hour When –5ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.

1.1.3 Summer

Stage 9: Raise the temperature from –5ºC to 15ºC +/- 2ºC at a rate of 2ºC/hour. When 15ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 120 hours in total.

1.2 Wind

The suggested pressure difference across the specimen, ΔP, and heat transfer coefficient (HTC) profile for extreme cold regions protocol is given below (see Figure 2):

Winter Profile: ΔP = 50Pa; HTC = 30 $W/m^2 \cdot {}^oK$
Spring Profile: ΔP = 35Pa; HTC = 30 $W/m^2 \cdot {}^oK$
Summer Profile: ΔP = 25Pa; HTC = 30 $W/m^2 \cdot {}^oK$

1.3 Atmospheric Moisture

The suggested RH profile for cold regions protocol is given below (see Figure 3):

Winter Profile: No humidity control or maintain 70% RH.
Spring Profile: No humidity control or maintain 80% RH.
Summer Profile: No humidity control or maintain 85% RH.

1.4 Solar

The suggested solar irradiance profile is shown in Figure 4. The daily profiles for the winter, spring, and summer seasons are given in Table 1.

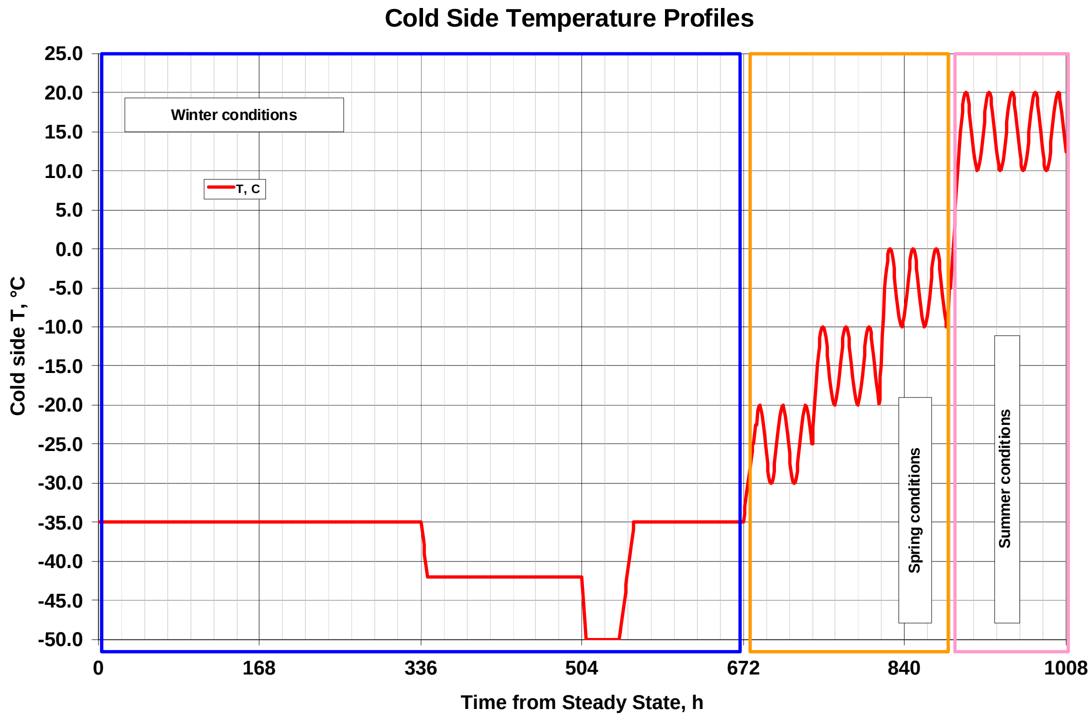

Figure 1 – The proposed temperature profile for the weather side of the test chamber, divided into 24-hour intervals.

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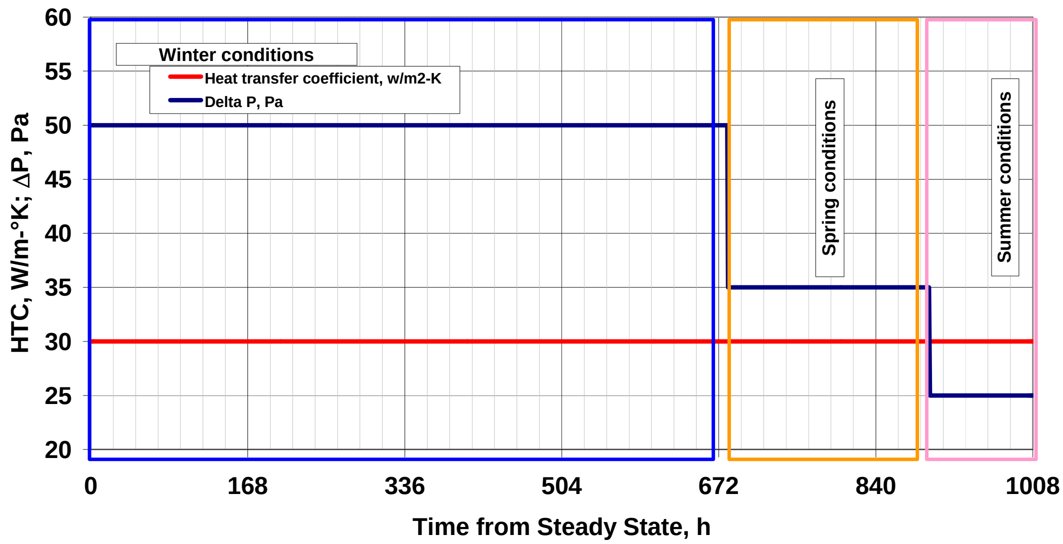


Figure 2 –Proposed pressure difference across the test specimen from outside to inside and proposed heat transfer coefficient to be maintained on the weather side of the test chamber, divided into 24-hour intervals.

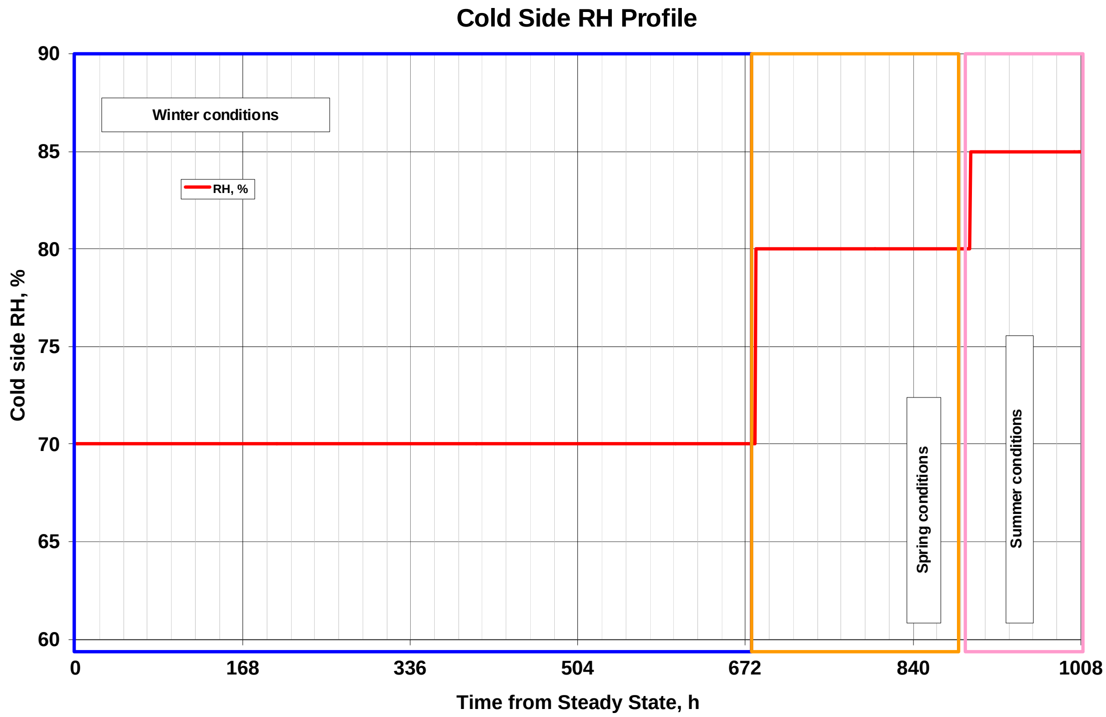


Figure 3 –Proposed relative humidity profile for the weather side of the test chamber, divided into 24-hour intervals.

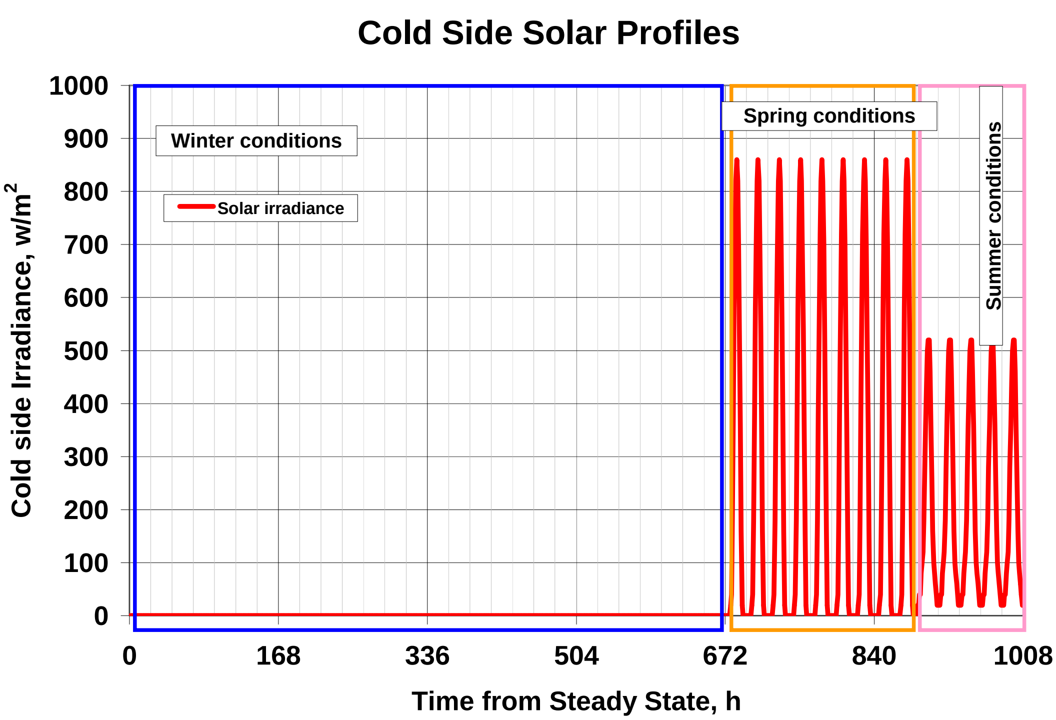


Figure 4 – Proposed solar irradiance profile for the weather side of the test chamber, divided into 24-hour intervals.

Table 1 – Recommended diurnal temperature and solar irradiance profiles for the winter, spring, and summer portions of the test protocol.

Hour	Winter	Spring	Summer	Winter	Spring	Summer
	ΔT from baseline, ºC			**Irradiance w/m²**		
1	0	–2.5	–2.5	0	0	20
2	0	–3.5	–3.5	0	0	20
3	0	–4.3	–4.3	0	0	40
4	0	–4.8	–4.8	0	0	40
5	0	–5.0	–5.0	0	0	80
6	0	–4.8	–4.8	0	20	100
7	0	–4.3	–4.3	0	40	120
8	0	–3.5	–3.5	0	180	180
9	0	–2.5	–2.5	0	380	280
10	0	–1.3	–1.3	0	580	360
11	0	0.0	0.0	0	720	440
12	0	1.3	1.3	0	820	500
13	0	2.5	2.5	0	860	520
14	0	3.5	3.5	0	820	520
15	0	4.3	4.3	0	700	460
16	0	4.8	4.8	0	540	360
17	0	5.0	5.0	0	360	260
18	0	4.8	4.8	0	160	160
19	0	4.3	4.3	0	20	100
20	0	3.5	3.5	0	0	80
21	0	2.5	2.5	0	0	60
22	0	1.3	1.3	0	0	40
23	0	0.0	0.0	0	0	20
24	0	–1.3	–1.3	0	0	20

2 Introduction

The main objective of the PERD 079 project is to develop building envelope assemblies that are energy efficient and durable under extreme outdoor and indoor climates. The approach includes an assessment of exterior wall assemblies that have minimum impact on the environment due to building construction, usage, maintenance, and future recycling at the end of its service life. Task 5A comprised the construction of mock-up walls of proposed wall assemblies and the testing of these wall specimens using indoor & outdoor climate extremes defined in Tasks 1 and 3[i]. The assessment will concentrate on performance parameters for heating and high humidity climates. The test results will also provide data to benchmark the hygrothermal model used in the computational analysis task. NRC-IRC Envelope Environmental Exposure Facility (EEEF) [1] will be used for the testing program. The proposed exterior test protocol determines the conditions on the weather side of the EEEF, the interior protocol the conditions on the room side. Two protocols have been developed for northern or cold climates, the Exterior (Weather side) Protocol and the interior (room side) protocol. This report describes the development of the weather side test protocol for walls of houses in extreme cold regions. The test protocol for the room side of the EEEF is described in a separate document [2].

3 Objective

The objective of this work was to propose a cold climate exterior or weather side protocol for the testing program to be implemented in NRC-IRC Envelope Environmental Exposure Facility (EEEF).

4 Scope

The scope of the work is summarized below:

1. Locations from which weather data were extracted shall met the extreme cold climate criteria set in the Task 3 Final Report [3],
2. The protocol will replicate characteristics of winter, spring, and summer seasons,
3. Climate indicators selected are as follows: Temperature atmospheric moisture, wind and Δp (pressure difference across the wall) and solar irradiance.
4. No account was made for increasing temperatures in the Arctic. Recently the Canadian meteorological service has made the modelling data on the Intergovernmental Panel on Climate Change 4th Assessment Report [4] scenarios available. A reassessment of the spring and summer portions of the protocols is perhaps in order to reflect future trends.

[i] A summary of the project is given in the Appendices (Appendix 1).

4.1 Outputs

The outputs are:

- Threshold values for the testing parameters, temperature, atmospheric moisture, wind speed, and solar radiation for the winter, spring, and summer seasons,
- Proposed dwell times for the threshold values, and
- Proposed testing protocol using a combination of weather parameters.

5 Defining a Representative Cold Location

The cold climate weather side protocol was developed using weather data extracted from a representative cold location. Table 2, Table 3 and Table 4 list northern Canadian locations for which climate normal data[ii] are available [5]. The Nunavik region in Quebec was not considered in this analysis since this region and other regions typically considered cold are covered by the locations considered. Also listed in the tables are NBCC 1% January dry bulb design temperature [6] and whether a Canadian Weather Energy and Engineering Data Set (CWEEDS) exists for the location. The CWEEDS files are computer data sets of hourly weather conditions recorded at Canadian locations for up to 48 years, starting as early as 1953, and ending, for most locations, in 2001 [7]. The primary purpose of these files is to provide long term weather records for use in urban planning, siting, design of wind and solar renewable energy systems and design of energy efficient buildings. In order to winnow the list of potential locations only locations meeting the cold climate criteria outlined in the Task 3 Final Report [3] were considered. The criteria are summarized below.

> "If the mean number of days where daily minimum is less than –20^{o}C is 100 or more, or if the mean number of heating degree-days above 18^{o}C is 8000 or more, then the location can be considered to be extremely cold."

Next only locations for which CWEEDS data exists were considered. The primary criterion for selecting a representative location was dry bulb temperature. The four coldest populated locations are Cambridge Bay (*Iqaluktuuttiaq*), Hall Beach (*Sanirajak*), Pond Inlet, and Resolute (*Qausuittuq*), all in Nunavut. These four locations have more than 11,000 heating degree-days above 18^{o}C and # days below –20C...However no CWEED data is available for Pond Inlet. Of the three remaining coldest locations Cambridge Bay was selected as the representative location. Cambridge Bay is not quite as cold as the other locations (Hall Beach and Resolute) on an annual basis however the winter means are similar. Resolute is primarily a military base. Cambridge Bay and Hall Beach are interchangeable. Cambridge Bay was chosen because of the greater population. Figure 5 shows the mean minimum daily temperatures for selected locations in the tables (mostly locations with associated CWEEDS data sets). Cambridge Bay however appears to have a greater seasonal range. The climate normal data for Cambridge Bay NU is given in Appendices (Appendix 2).

[ii] "Climate normals" are arithmetic calculations based on observed climate values for a given location over a specified time period and are used to describe the climatic characteristics of that location. Real-time values, such as daily temperature, are compared to the "climate normal" to determine how unusual or how large the departure from "average" they are. The current Canadian climate normals span the years 1971 to 2000.

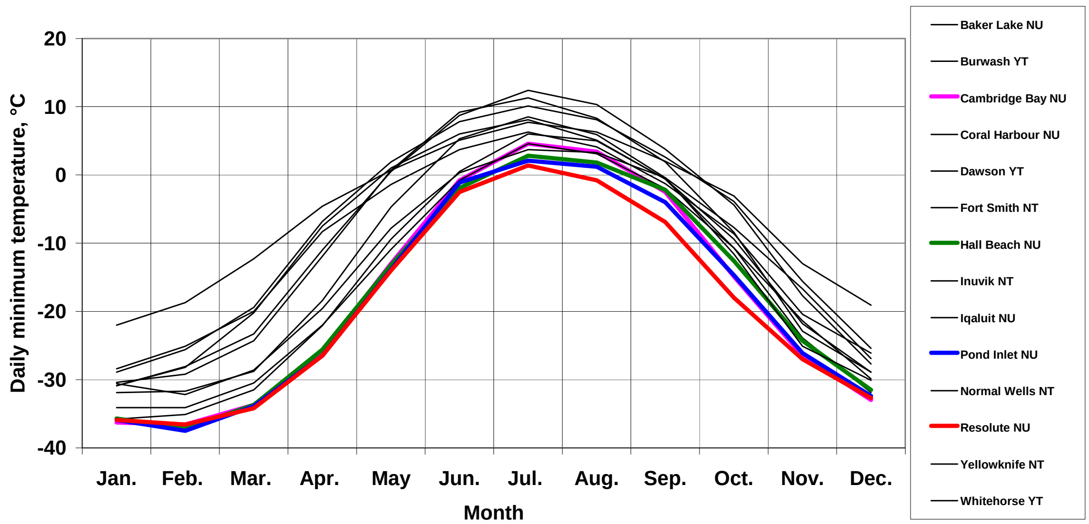


Figure 5 – Mean daily minimum temperatures for various Northern locations. Cambridge Bay, Hall Beach, Pond Inlet, and Resolute NU can be considered to be representative of very cold communities.

Table 2 – Nunavut stations with available climate normal data.

Station Name	HDD18	Days < -20 °C	Population	Mean Daily Min, °C	NBCC 1% Jan. Dry bulb	CWEEDS
Nunavut Territory						
ALERT	13105.1	205.8	75	-21.2	-45	No
BAKER LAKE A*	**10859.6**	**162.3**	**1507**	**-15.8**	**-46**	**Yes**
CAMBRIDGE BAY A	**11812.1**	**180.4**	**1309**	**-18**	**-46**	**Yes**
CAPE DORSET A	9945.8	113	1148	-12.4	-	No
CAPE DYER A	10540.8	139.4	75	-15	-	No
CAPE HOOPER	10935.5	139.6	75	-14.6	-	No
CLINTON POINT	-	145.3	0	-14	-	No
CLYDE A	11218.3	154.4	785	-16.4	-43	No
CORAL HARBOUR A	**10772.6**	**155.7**	**712**	**-15.7**	**-43**	**Yes**
DEWAR LAKES	-	156.9	-	-16.4	-	No
EUREKA	13731.8	211	75	-22.9	-48	No
FOX FIVE	10880.9	136.8	-	-14.6	-	No
HALL BEACH A	**11696.9**	**173.4**	**609**	**-17.8**	**-**	**Yes**
IGLOOLIK	-	163.1	1286	-16.5	-	No
IQALUIT A	**10117.4**	**135.2**	**5236**	**-13.6**	**-42**	**Yes**
KUGLUKTUK A	10420	155.3	1212	-14.7	-	No
LADY FRANKLIN POINT A	-	162.3	0	-15.7	-	No
LUPIN A	10759.9	153.3	0	-14.8	-	No
NANISIVIK A	-	-	77	-17.8	-	No
POND INLET A	12029.1	170.3	1220	-18.6	-	No
RANKIN INLET A	10549.4	152	2177	-14.7	-41	No
RESOLUTE CARS	**12525.6**	**182.6**	**215**	**19.5**	**-45**	**Yes**

– Bolded items indicate locations with CWEEDS data.
Shaded rows indicate the four coldest locations out of the ones meeting the temperature criterion listed in Tables 3, 4, 5

Table 3 – Northwest Territories stations with available climate normal data.

Station Name	HDD18	Days < -20	Population	Mean Daily Min, °C	NBCC 1% Jan. Dry bulb	CWEEDS
Northwest Territories						
CAPE PARRY A*	**10939.2**	**152.6**	**0**	**-14.9**	**-**	**Yes**
FORT LIARD A	7044.8	83.9	530	-6.6	-	No
FORT RELIANCE	8946.4	123.5	-	-11.2	-	No
FORT SIMPSON A	7771.5	108.7	1163	-8.8	-47	No
FORT SMITH A	**7438.9**	**93**	**2185**	**-7.9**	**-45**	**Yes**
HAY RIVER A	7647.5	95.1	3510	-7.9	-43	No
HOLMAN A	-	-	398	-15.1	-43	No
INUVIK A	**9766.9**	**144.4**	**2894**	**-13.6**	**-46**	**Yes**
MOULD BAY A	12944.9	198.4	0	-20.7	-45	No
NORMAN WELLS A	**8614.9**	**124.9**	**666**	**-10.4**	**-46**	**Yes**
SACHS HARBOUR A	11442	163.8	114	-16.6	-	No
TUKTOYAKTUK	10518.8	151.3	930	-13.9	-	No
TUKTOYAKTUK A	10389.2	155.5	930	-14.3	-	No
YELLOWKNIFE A	**8256**	**110.1**	**16541**	**-9**	**-45**	**Yes**
YELLOWKNIFE HYDRO	8669.8	118.1	16541	-11.1	-	No

* – Bolded items indicate locations with CWEEDS data

Table 4 – Yukon Territory stations with available climate normal data.

Station Name	HDD18	Days < -20	Population	Mean Daily Min, °C	NBCC 1% Jan. Dry bulb	CWEEDS
Yukon Territory						
BEAVER CREEK A	8579	125.1	88	-12	-	No
BRAEBURN	7676.7	92.8	1221	-9.9	-	No
BURWASH A*	**7937.7**	**99.3**	**68**	**-10.5**	**-**	**Yes**
DAWSON A	8165.7	107	1251	-10.6	-51	No
FARO A	7334.1	72.7	313	-7.6	-	No
JOHNSONS CROSSING	7087.6	62.2	20	-7.3	-	No
KOMAKUK BEACH A	-	151	-	-14.9	-	No
MAYO A	8236.9	89.5	366	-8.9	-	No
MAYO ROAD	-	65.5	-	-7.5	-	No
OLD CROW A	-	146.6	229	-14.2	-	No
OTTER FALLS NCPC	-	-	1221	-6.9	-	No
PELLY RANCH	7954.3	102.6	-	-10.4	-	No
SHINGLE POINT A	-	147.7	1221	-13.9	-	No
TESLIN A	6967.1	58.1	1221	-6.8	-43	No
WATSON LAKE A	7620.4	95.1	1221	-8.8	-48	No
WHITEHORSE A	**6811.3**	**56.4**	**21405**	**-5.9**	**-43**	**Yes**
WHITEHORSE RIVERDALE	6649.3	58.4	21405	-5.9	-	No

* – Bolded items indicate locations with CWEEDS data

6 Defining Exterior Temperature Test Conditions

Not surprisingly temperature was the most important testing parameter for the extreme cold regions protocol. The following analysis was made using climate normal data (see Appendices (Appendix 2) and the CWEEDS data set for Cambridge Bay NU. The temperature thresholds and profile are divided into three seasons; winter (December, January, and February), spring (March, April, and May) and summer (June, July, August).

6.1 Winter

6.1.1 Baseline winter temperatures

Threshold: Part of the objective of PERD 079 project is to investigate the performance of wall assemblies exposed to extreme climatic conditions. In determining the protocol thresholds for the winter season minimum daily temperatures were considered. Figure 6 shows the long-term daily mean temperatures for Cambridge Bay. The mean daily minimums for the winter are –33^{o}C, –36.3^{o}C, and –36.3^{o}C for December, January, and February respectively (see Table 5). The average minimum temperature for the three winter months is –35^{o}C, the suggested threshold baseline winter temperature. Depending on the testing objective the baseline temperature could be held indefinitely when simulating winter conditions.

6.1.2 Typical cold spells

Long-term mean temperatures are just that; average temperatures. Since very few climates feature temperatures that oscillate around the mean consistently it was deemed beneficial to include a “typical” cold spell in the proposed test protocol for the weather side of the EEEF.

Thresholds: The variation in temperature for the three typical cold months is shown in Figure 7. Temperatures for the typical months vary significantly however vary around the mean minimum values, around –35ºC. Not surprisingly since the selection process was biased towards the long-term minimum. There are significant periods where the temperatures are below –40ºC. A threshold temperature of –42ºC is adequate to cover typical cold spells. From Figure 7 typical cold spells seem to last about 1 week.

Table 5 – Mean daily mean minimum temperatures, average monthly minimum for specific months, and the difference from the long-term mean.

Year	Month	Mean Monthly Min, ºC	Monthly Min ºC	% Abs Diff from Mean
		Typical months		
1996	Dec	–33.0	–32.98	0.05
1969	Jan	–36.3	–36.25	0.14
1993	Feb	–36.6	–36.81	0.58
		Extreme months		
1957	Dec	–33.0	–37.06	12.3
1966	Jan	–36.3	–41.67	14.8
1958	Feb	–36.6	–42.17	15.2

6.1.3 Extreme cold spells

In order to examine extreme cold spells months with the coldest average minimum temperature were selected (see Table 5).

Thresholds: Temperatures for the extreme months vary significantly (see Figure 8). There is a significant period in February where the temperatures are below –46ºC, the winter design temperature (1% January dry bulb temperature). During these periods the heating systems in building may not be able to maintain the design temperature. In order to simulate extreme cold spells a threshold temperature of –50ºC is suggested. A period of 36 hours at –50ºC will capture some of extreme cold periods.

6.1.4 Winter heating and cooling rates

Most of the rates of temperature change rate in winter seem to fall between 0 and 2ºC/hour (see Figure 9).

6.1.5 Diurnal cycling – winter

It seems clear from Figure 7 and Figure 8 that there is no regular pattern of diurnal temperature cycling during the winter season as compared to the spring and summer seasons (see Figure 10 and Figure 14). The predominate cause of daily temperature change appears to be advection of air masses[iii]. Changes due to solar radiation, low in the winter, are small and overwhelmed with the irregular temperature changes caused by moving air masses. It is recommended that there be no diurnal temperature cycling for the winter months of the extreme cold regions protocol.

6.1.6 Suggested winter profile

The suggested winter temperature profile for the extreme cold regions protocol is given below.

Stage 1: Initial conditioning: The test specimen is gradually conditioned from lab conditions to –35ºC until the conditions are stabilized. This is expected to take about 1 week.
Stage 2: Average conditions: Hold the exterior conditions of the weather side of the test chamber at –35ºC +/- 2ºC for 1 week.
Stage 3: Typical cold conditions: The weather side of the test chamber will go down to –42ºC at a rate of –1ºC/hour. Once conditions are stabilized, the temperature is to be held at –42ºC +/- 2ºC for 1 week.
Stage 4: Extreme cold conditions: The weather side of the test chamber will go down to –50ºC at a rate of –2ºC/hour; hold at –50ºC +/- 2ºC for 36 hours.
Stage 5: Return to average conditions at –35ºC at a rate of 1ºC/hour; hold at –35ºC until the end of the 4th week.

[iii] See Appendices (Appendix 3)

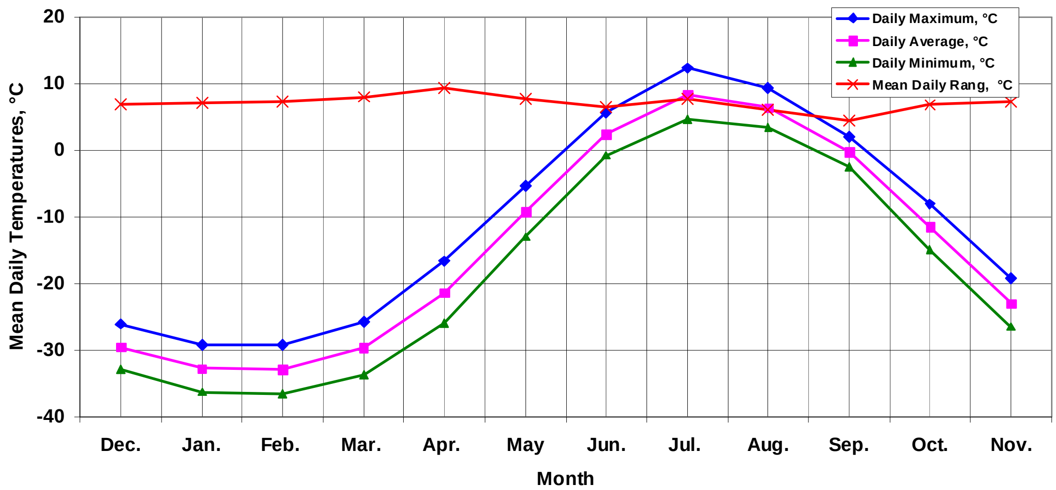


Figure 6 – Daily mean maximum, average, and minimum for 12 months for Cambridge Bay NU. The average minimum for the winter months is near –35ºC. The mean daily temperature swing is shown as well.

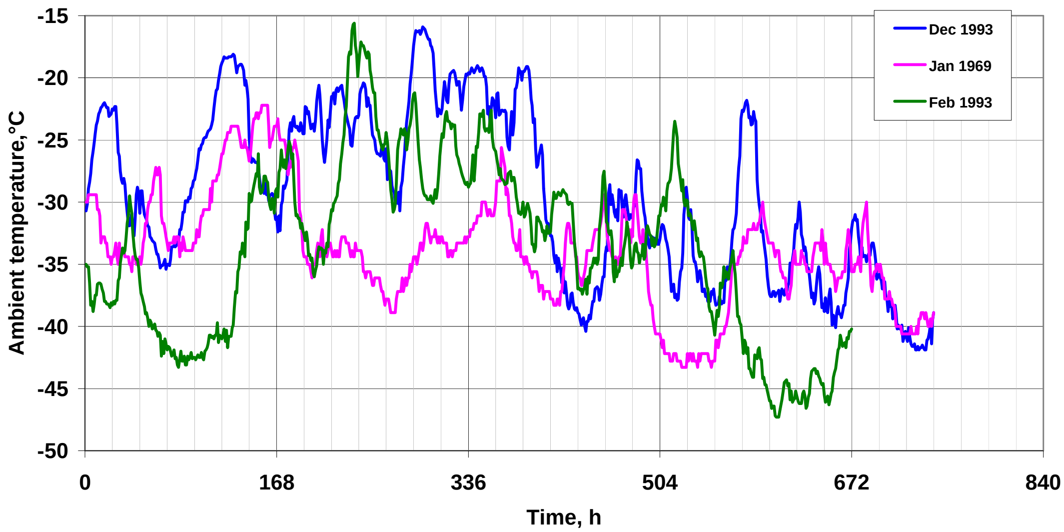


Figure 7 – Temperatures for the typical cold winter months for Cambridge Bay NU. Note the occurrence of temperatures at or below the 1% winter design temperature (–46ºC) [iv].

[iv] 1 week = 168 hours

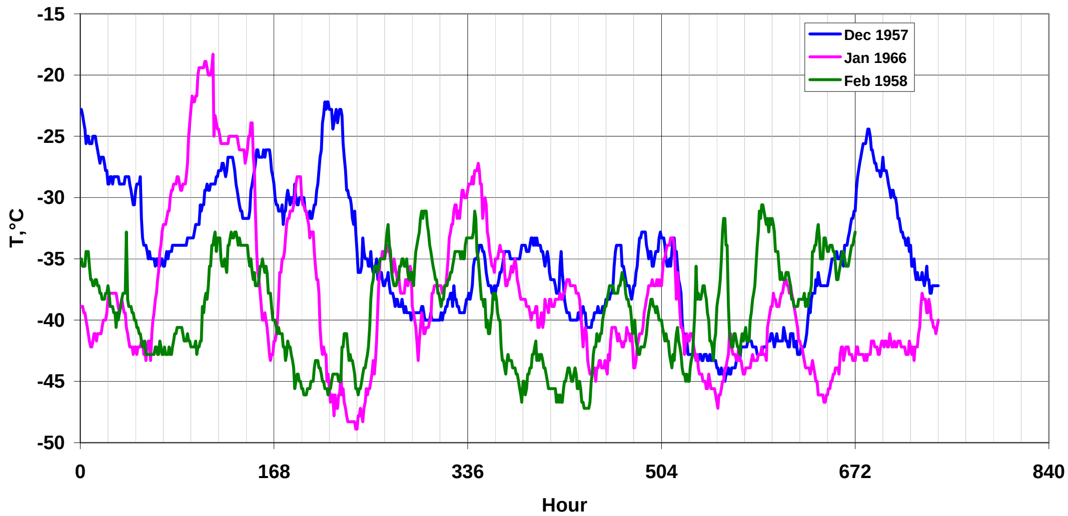
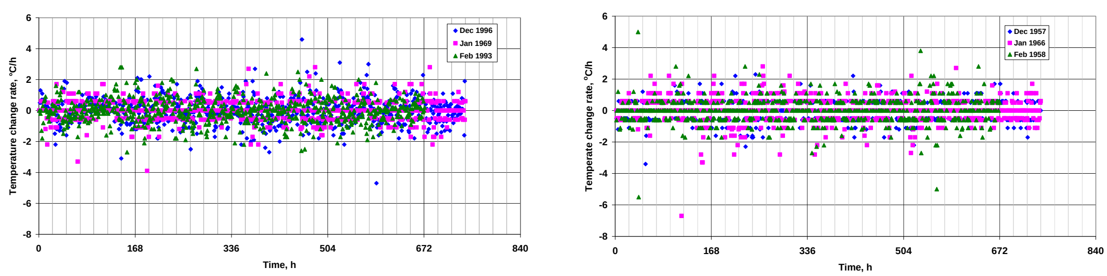


Figure 8 – Temperatures for the extreme cold months for Cambridge Bay NU.



(a) (b)

Figure 9 – Rates of temperature change during the winter months, a) months close to the mean daily minimum and b) extreme cold months for Cambridge Bay NU.

6.2 Spring

There is a rapid warming during the spring season. Large diurnal cycles can permit the melting and refreezing of accumulated moisture in the cavity. Instead of using minimum temperatures the daily mean maximum temperatures were used as the basis of the spring season profile to increase the possibility of freeze/thaws cycles in the cavity.

6.2.1 Baseline spring temperatures

Threshold: In determining the protocol thresholds for the spring season daily mean maximum temperatures were considered. Figure 6 shows the long-term daily mean temperatures for Cambridge Bay. The mean daily maximums for the spring are –25.7^{o}C (Mar), –16.7^{o}C (Apr), and –5.3^{o}C (May); see Table 6. The threshold for the typical or baseline spring temperatures for extreme cold climates are –25^{o}C, –15^{o}C, and –5^{o}C; in steps of 10^{o}C.

Table 6 – Daily mean maximum temperatures, average monthly minimum for specific months, and the difference from the long-term mean.

Year	Month	Mean Monthly Max, ºC	Monthly Max ºC	% Abs Diff from Mean
		Spring		
1984	Mar	–25.7	–25.7	0
1991	Apr	–16.7	–16.6	0.379242
1991	May	–5.3	–5.4	2.251978
		Summer		
1990	Jun	5.6	5.5	1.309524
1983	Jul	12.3	12.3	0.262261
2001	Aug	9.4	9.5	1.544269

Dwell Time: Depending on the testing objective the baseline temperatures should be progressively increased towards the summer time thresholds moving through the spring thresholds at intervals of about one week.

6.2.2 Typical spring warm spells

Typical warm spring months were selected from the CWEEDS data set by calculating the mean maximum temperature for each month and choosing the months where the calculated mean was closest to the long-term mean. These months are given in Table 6 and hourly temperature progression shown in *Figure 10*. Temperatures for the typical spring months vary significantly around the mean value. There is a steady warming trend observed. Suggested steps are at –25ºC for March, –15ºC for April, and –5ºC for May, the same as the baseline recommendations.

6.2.3 Spring heating and cooling rates

There is considerably more variation in heating and cooling rates as the sun tracks further north. The rates of temperature change in spring seem to fall between 0 and 4ºC/hour (see Figure 11), however most of the values fall between 0 and 2ºC/hour.

6.2.4 Diurnal cycling – spring

The spring months show a clear pattern of diurnal cycling due to solar effect (see Figure 10). The effect of air mass advection is still apparent however. For the spring and summer months the mean variation in daily temperature is 7.8ºC with a standard deviation of 2.6ºC (see Figure 12). To maximize the effect springtime variation it is recommended that a 10ºC[v] 24-hour diurnal swing around the base line temperatures be incorporated into the spring season profile. The peak temperature should occur at 16:00 hours (see Figure 13).

6.2.5 Proposed spring profile

Continuing from the proposed winter temperature profile the spring profile for extreme cold regions protocol is given below. Note that the temperature steps where shortened to 72 hours so as to allow the protocol to be fit into a six-week schedule.

[v] The mean plus standard deviation is approximately equal to 10ºC.

Stage 6: The temperature on the weather side of the test chamber will be raised to –25ºC +/- 2ºC at a rate of 1ºC/hour. When –25ºC is reached, temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.
Stage 7: Raise the temperature from –25ºC to –15ºC +/- 2ºC at a rate of 2ºC/hour. When –15ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.
Stage 8: Raise the temperature from –15ºC to –5ºC (+/- 2ºC) at a rate of 2ºC/hour When –5ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.

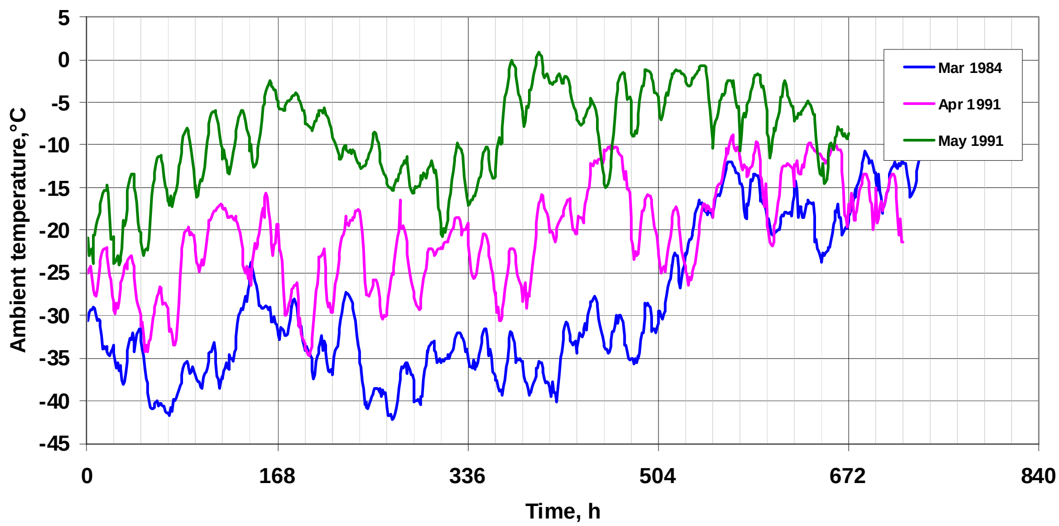


Figure 10 – Temperatures for the typical warm spring months for Cambridge Bay NU.

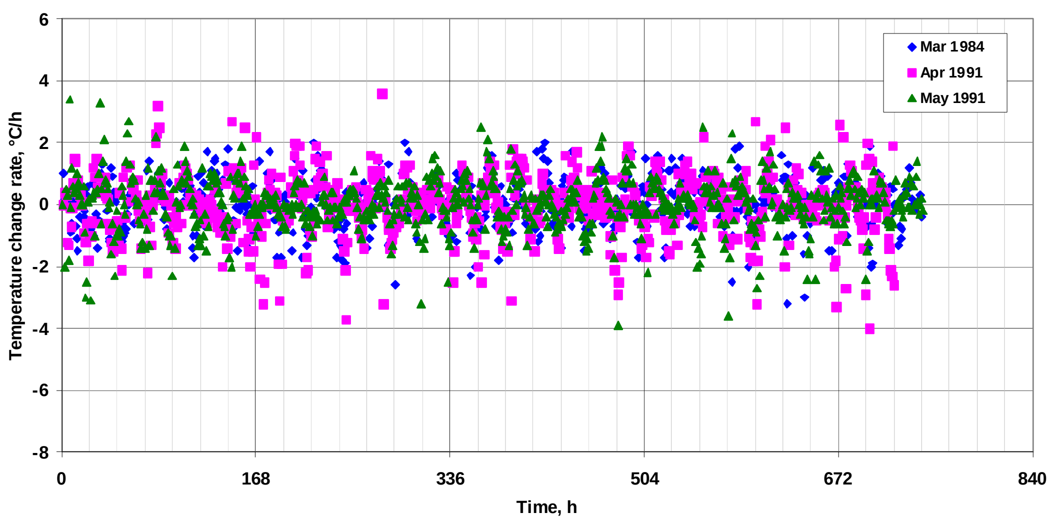


Figure 11 – Rates of temperature change during warm spring months.

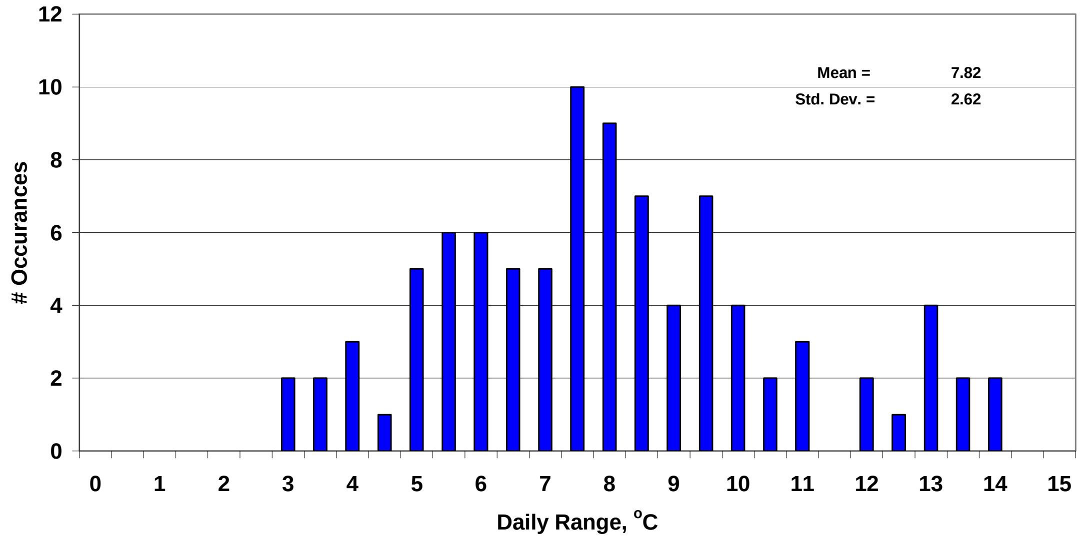


Figure 12 – Histogram of daily temperature ranges for warm spring and summer months in Cambridge Bay NU.

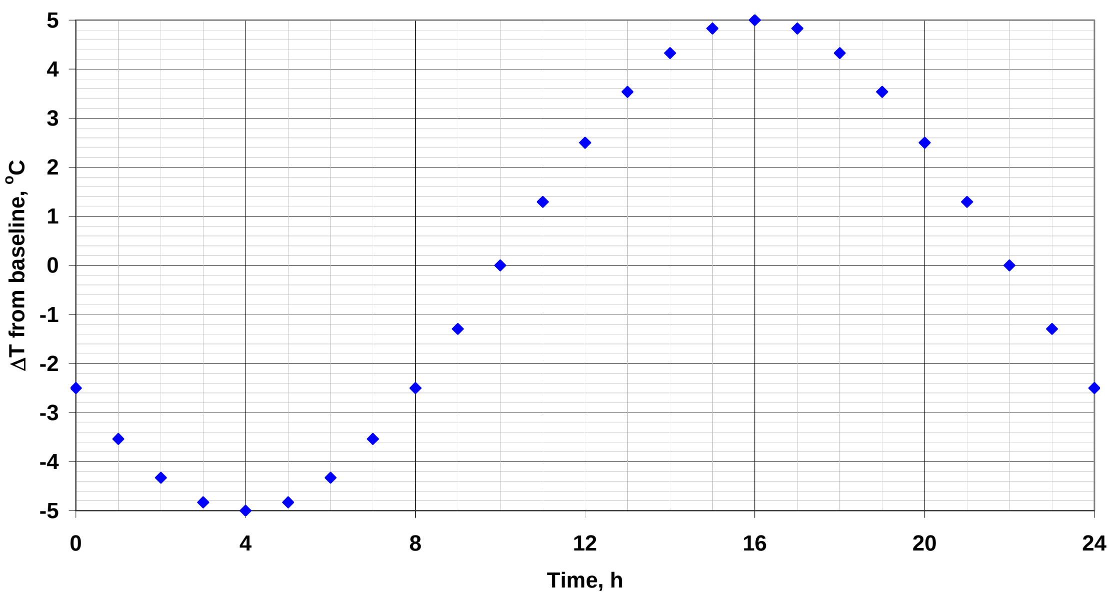


Figure 13 – ΔT variation around a baseline temperature to simulate solar driven diurnal temperature cycling.

6.3 Summer

During the summer months there is a progressive warming, an increase in mean daily temperatures due to increased amounts of insolation. Large regular diurnal cycles can raise the temperature of exterior building envelope elements leading to heat damage or premature aging of the components. Instead of using minimum temperatures the daily mean maximum temperatures were used as the basis of the summer season profile.

6.3.1 Baseline summer temperatures

Threshold: In determining the protocol thresholds for the summer season maximum temperatures were considered. The mean daily maximums for the summer are 5.6°C (Jun), 12.3°C (Jul), and 9.4°C (Aug); see Table 6 and Figure 6. The thresholds for the typical or baseline spring temperatures for extreme cold climates are 5°C, 15°C, and 10°C in steps.

Dwell Time: Depending on the testing objective the baseline temperatures could be progressively move through the summer time thresholds moving one week at a time.

6.3.2 Typical summer months

Typical warm summer months were selected from the CWEEDS data set by calculating the mean maximum temperature for each month and choosing the months where the calculated mean was closest to the long-term mean. These months are given in Table 6 and hourly temperature progression shown in Figure 14. Temperatures for the typical summer months vary more narrowly than in spring around the mean value showing a progressive warming as the amount of insolation increases. There is about a one-month delay from the month with maximum solar irradiation, the hottest month being July. By August temperatures are beginning to cool, as the radiation balance is negative. One step representing the summer is suggested, 15ºC.

6.3.3 Summer heating and cooling rates

There is less variation in heating and cooling rates than in the spring. This is expected due to the prolonged daylight periods. Most of the rates of temperature change in summer seem to fall between 0 and 2ºC/hour (very similar to spring) although there are excursions around 8ºC/hour (see Figure 15).

6.3.4 Diurnal cycling – summer

The summer months show a strong pattern of diurnal cycling due to solar irradiance (see Figure 14. The effect of air mass advection is not apparent in the months selected. For the summer months the mean variation in daily temperature is 7.9ºC with a standard deviation of 2.6ºC (see Figure 12). To maximize the effects summertime variation it is it recommended that a 10ºC[vi] 24-hour diurnal swing around the base line temperatures be incorporated into summer season profile. The peak temperature should occur at 16:00 hours (see Figure 13).

6.3.5 Suggested summer profile

Continuing from the suggested spring and winter temperature profiles the summer profile for extreme cold regions protocol is given below:

> **Stage 9**: Raise the temperature from –5ºC to 15ºC +/- 2ºC at a rate of 2ºC/hour. When 15ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 120 hours in total.

[vi] The mean plus standard deviation is approximately equal to 10ºC.

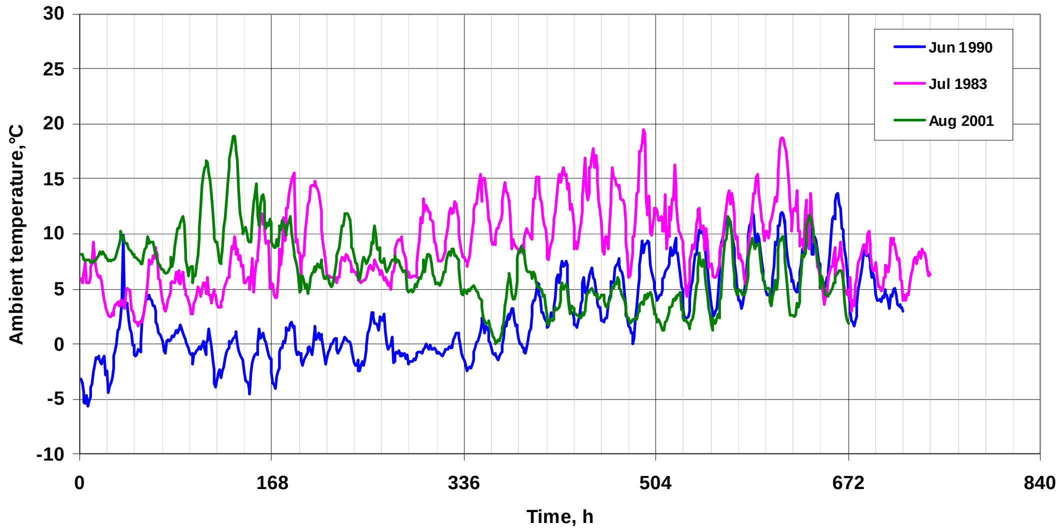


Figure 14 – Temperatures for the typical warm summer months for Cambridge Bay NU.

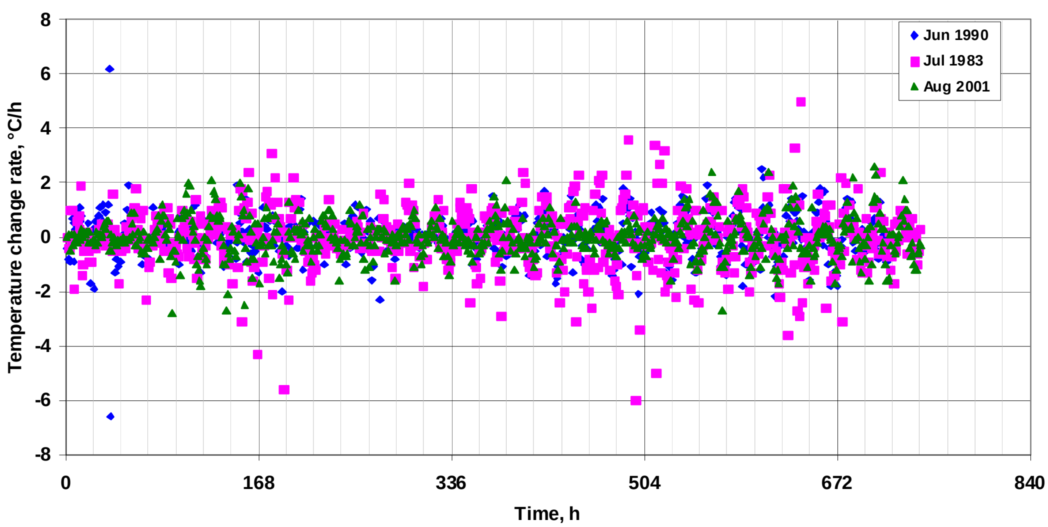


Figure 15 – Rates of temperature change during warm summer months.

6.4 Summary of Proposed Temperature Profile

6.4.1 Winter

Stage 1: Initial conditioning: The test specimen is gradually conditioned from lab conditions to –35ºC until the conditions are stabilized. This is expected to take about 1 week.
Stage 2: Average conditions: Hold the exterior conditions of the weather side of the test chamber at –35ºC +/- 2ºC for 1 week.
Stage 3: Typical cold conditions: The weather side of the test chamber will go down to –42ºC at a rate of –1ºC/hour. Once conditions are stabilized, the temperature is to be held at –42ºC +/- 2ºC for 1 week.
Stage 4: Extreme cold conditions: The weather side of the test chamber will go down to –50ºC at a rate of –2ºC/hour; hold at –50ºC +/- 2ºC for 36 hours.
Stage 5: Return to average conditions at –35ºC at a rate of 1ºC/hour; hold at –35ºC until the end of the 4^{th} week.

6.4.2 Spring

Stage 6: The temperature on the weather side of the test chamber will be raised to –25ºC +/- 2ºC at a rate of 1ºC/hour. When –25ºC is reached, temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.
Stage 7: Raise the temperature from –25ºC to –15ºC +/- 2ºC at a rate of 2ºC/hour. When –15ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.
Stage 8: Raise the temperature from –15ºC to –5ºC (+/- 2ºC) at a rate of 2ºC/hour When –5ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 72 hours in total.

6.4.3 Summer

Stage 9: Raise the temperature from –5ºC to 15ºC +/- 2ºC at a rate of 2ºC/hour. When 15ºC is reached the temperature will be cycled according to the 10ºC diurnal cycle proposed (see Table 1). The length of this cycle is 120 hours in total.

7 Defining Air Pressure Test Conditions

Wind is the second most important climate parameter in determining the hygrothermal performance of exterior envelopes in extreme cold climates. Wind affects buildings in many ways; exerting forces on structures, causing snow drifting and snow infiltration, and creating pressure regimes around buildings. The last of these is important since the pressure regime around a building can, combined with the stack effect, cause significant amounts of air movement through the envelope either by infiltration or exfiltration. The Canadian arctic can be divided roughly into two regions; the Eastern and Western Arctic, the Eastern Arctic being the windier of the two (see Figure 16). Comparing various

Northern communities Cambridge Bay can again be used as a representative location for windy locations (see Figure 17). Mean monthly wind speeds for Cambridge Bay are given in Table 7. The range is fairly narrow while the direction is consistent from the North.

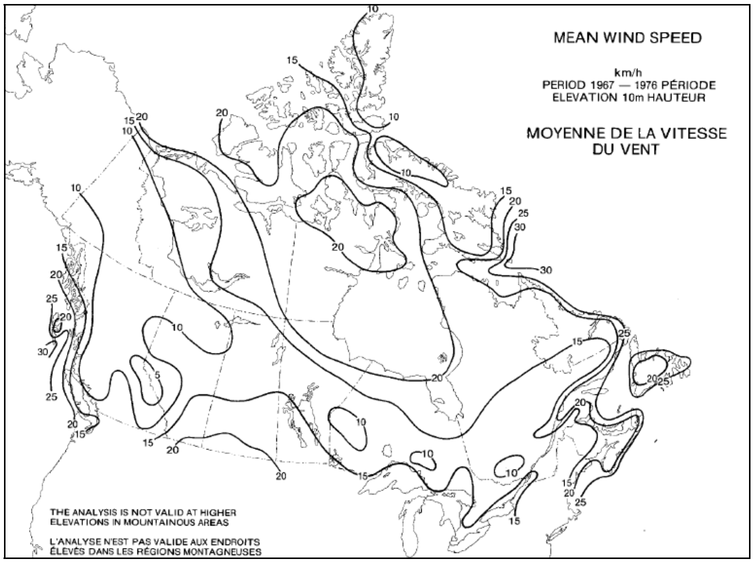


Figure 16 – Mean wind speeds across Canada. Note the higher mean wind speeds in the Eastern Arctic [8].

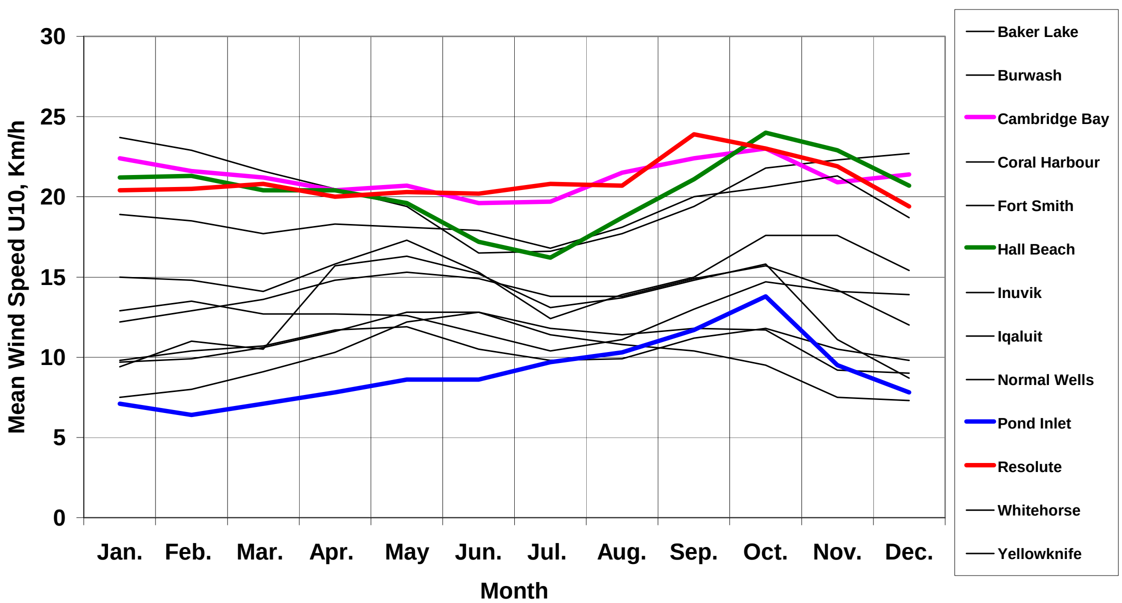


Figure 17 – Mean wind speeds for various Northern locations. Cambridge Bay, Hall Beach, and Resolute NU can be considered to be representative of windy communities. Pond Inlet is relatively sheltered.

Table 7 – Mean and maximum hourly wind speeds for Cambridge Bay NU.

Cambridge Bay NU	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Speed (km/h)	22.4	21.6	21.2	20.4	20.7	19.6	19.7	21.5	22.4	23	20.9	21.4	21.2
Most Frequent Direction	NW	NW	NW	NE	NE	NE	N	W	NW	NW	NW	NW	NW
Maximum Hourly Speed	89	89	84	80	80	93	71	79	87	101	82	97	

Two alternatives present themselves. The first alternative is to assume that the wind velocity is constant around the mean wind speed, 22 km/h or 6.1 m/s. There is not much variation in mean wind speeds throughout the year. The second alternative is to use an extreme hourly wind speed, 90 km/h, and use this during the test. Coincident wind speeds during the months selected as representative are around 20 km/h or less, the means being around between 15 and 20 km/h. It is proposed that a wind speed near the annual mean wind speed, 22 km/h (6.1 m/s), be used for the test protocol since this is the baseline condition.

In order to simulate the effect of wind (positive or negative) in the test chamber a pressure difference should be maintained across the sample. As well a heat transfer coefficient on the exterior surface of the test specimen should be selected in order to simulate the effect of heat removal (or heat gain). In order to convert wind speed into applied pressure difference, ΔP, across the test specimen, the following assumptions were made about the buildings included in the study, aiming for a worst-case scenario of air exfiltration resulting in higher risk of interstitial condensation:

1. The building height is 6m (i.e. low-rise construction up to 2 storeys)
2. The location of the Neutral Pressure Plane (NPP) is at grade or 0m (i.e. the building is pressurized all around). That is very unlikely in practice - stack, and wind will bring cold air infiltration at the base of the walls and ground floor
3. The barometric pressure is 101.325kPa
4. The indoor temperature is 25ºC
5. The wind pressure coefficient on the leeward side, C_s is 1.0
6. The stack and wind pressures are added to maximize exfiltration.(i.e. a worst-case scenario for interstitial condensation)

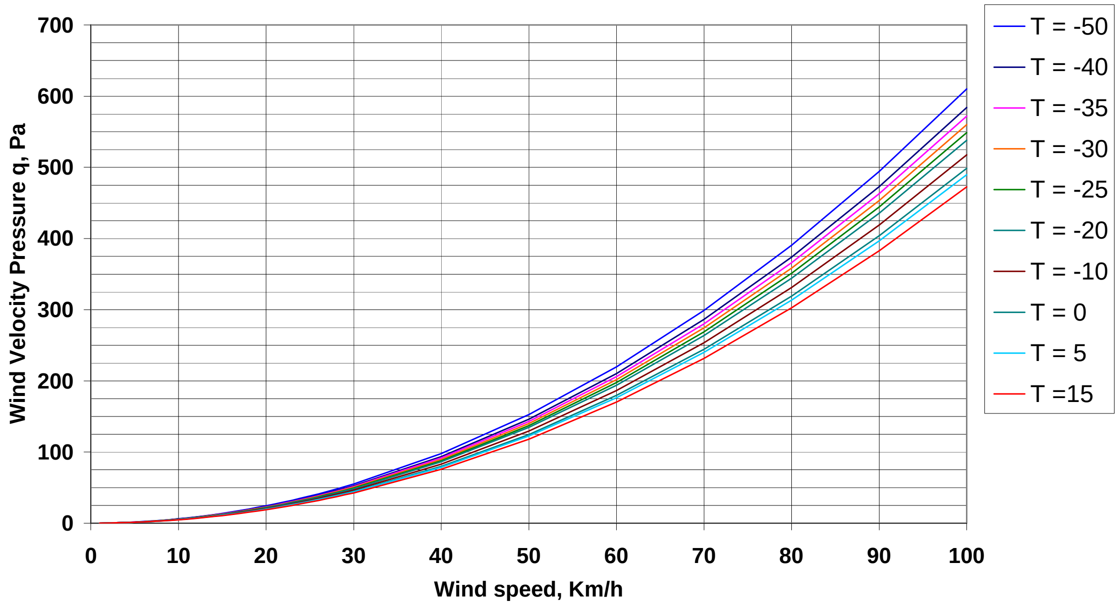


Figure 18 – Variation of wind velocity pressure, q, with wind speed at various exterior temperatures.

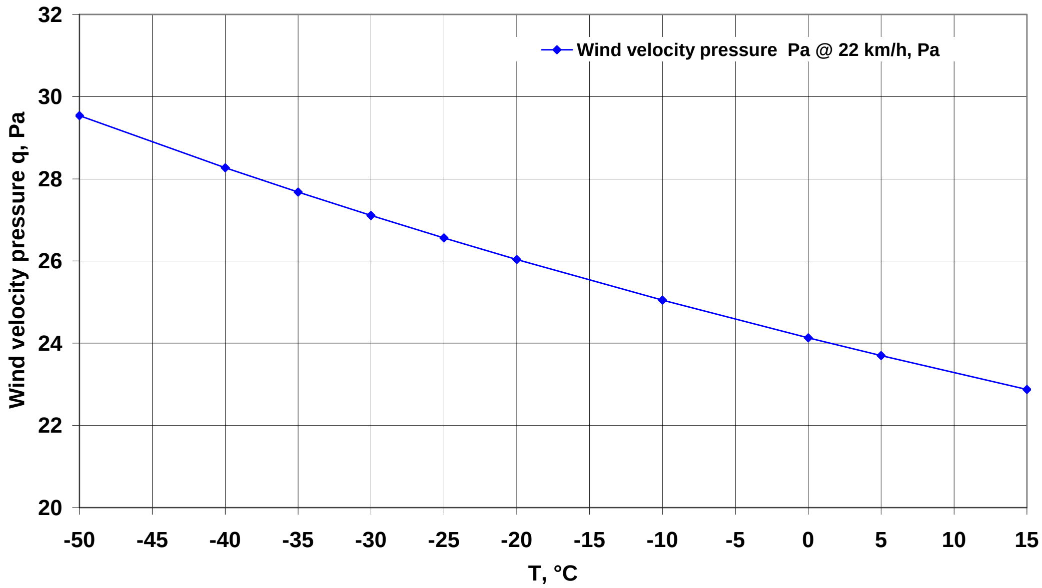


Figure 19 – Variation of wind velocity pressure, q, with temperature at a mean wind speed of 22 km/h.

7.0.1 Wind velocity pressure

The wind velocity pressure at various wind speeds and air temperatures is shown in Figure 18. For wind speeds of 90 km/h the wind velocity pressures are in a range between 450 and 600Pa. For the cold climate test protocol it is recommended that instead of extreme hourly wind speeds a wind speed near the annual mean wind speed be used since this is the condition. Thus for the test protocol it is suggested that a wind speed of 22 km/h (6.1 m/s) be used. Wind velocity pressures at this speed range from 23 to 30Pa, depending on temperature (see Figure 19).

Wind velocity pressure = $\frac{1}{2} \rho_{air} v^2$, Pa

Where: ρ_{air} is the density of air, kg/m^3
v is the velocity of the wind, m/s.

7.0.2 Stack pressure

The absolute stack pressure for various temperature differences, $|T_{out} - T_{in}|$ is shown below. The worst-case scenario for exfiltration is a ΔT of –75ºC, with the NPP at grade. The stack pressure in this case is ~ 23Pa. For the spring and summer time conditions the stack pressure is much reduced, ~ 5Pa. This is shown in Figure 20.

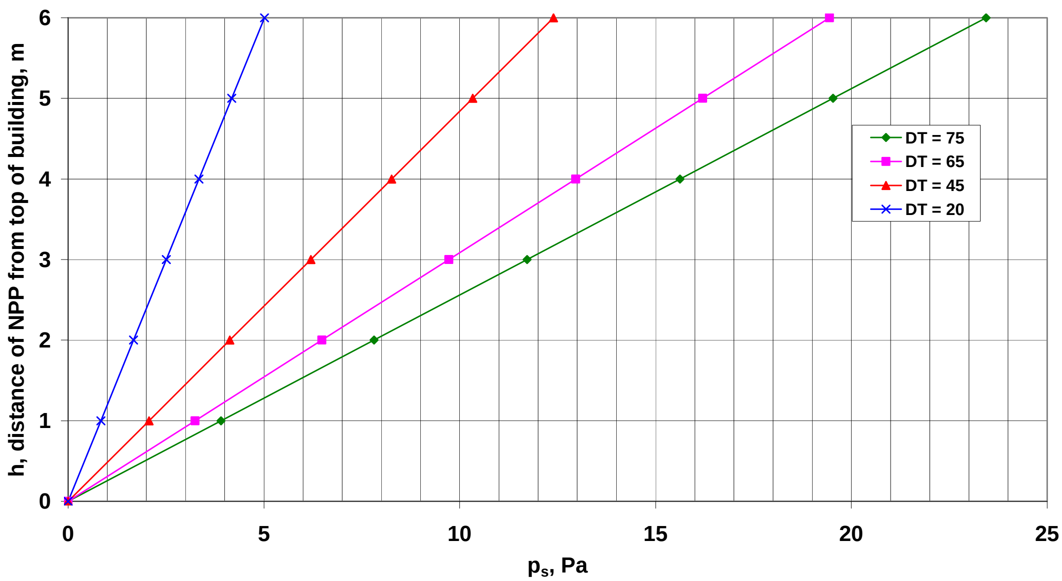


Figure 20 – Variation of stack pressure with distance from the NPP for various temperature differences.

The stack pressure was calculated from the formula found in Hutcheon [9].

$$p_s = 0.0342 h P_{Tot} \left(\frac{1}{T_{out}} - \frac{1}{T_{in}} \right) \qquad \text{(Pa)}$$

7.0.3 Heat Transfer Coefficient

The variation of Heat Transfer Coefficient (HTC) using the ASHRAE Handbook of Fundamentals, Chapter 3 formula [10] shows that the heat transfer coefficient should be in the range of 30 W/m^2·ºK, for mean wind speeds, to 100 W/m^2·ºK, for maximum hourly sustained speeds. This is shown in Figure 21. The recommendation is to keep the heat transfer coefficient at 30 W/m^2·ºK throughout the test in keeping with the assumed 22 km/h wind speed. The HTCs were calculated from McAdams [11] and ASHRAE [10].

$$h_c \begin{cases} 5.82 + 3.96V & V \le 5m/s \\ 7.68V^{0.75} & V \succ 5m/s \end{cases}$$

Where V is the wind speed near the surface of the building in m/s.

7.0.4 Combined wind and stack pressure

For exfiltration and infiltration cases the wind velocity pressure and stack pressure should be added to give the worst case.

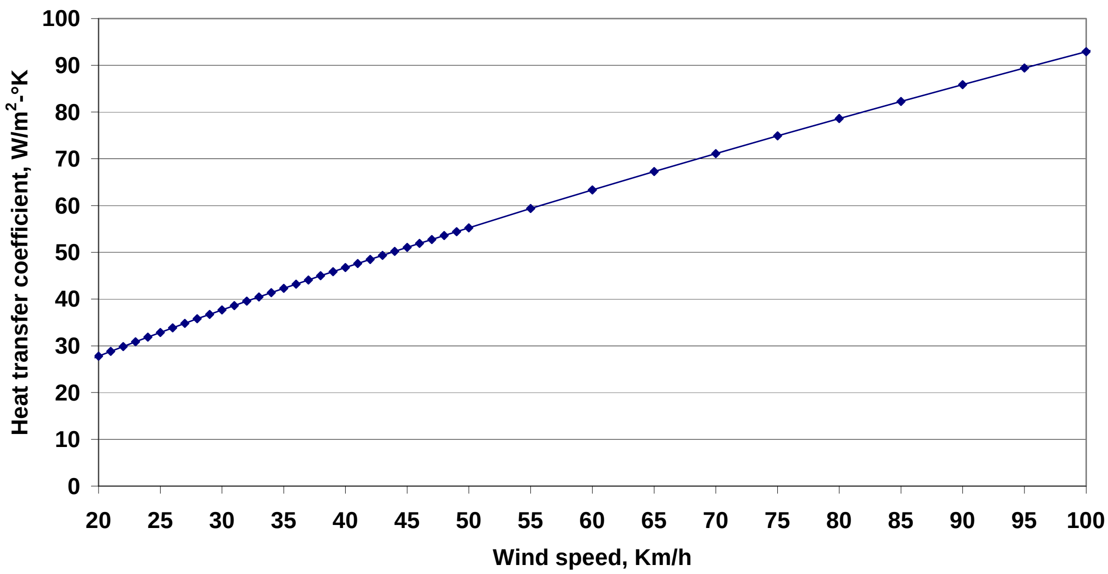


Figure 21 – Relationship between HTC and wind speed.

7.1 Winter

For the winter profile assuming an ambient temperature of –35ºC, the long-term mean, the wind velocity pressure is approximately 27Pa. The stack pressure at this temperature is approximately 17Pa. The combined pressure is 44Pa. Rounding up the recommended pressure difference across the envelope is 50Pa or 45 Pa. The heat transfer coefficient recommended is 30 W/m^2·ºK or greater.

7.2 Spring

For the spring profile assuming an ambient temperature of –15ºC, the long-term mean, the wind velocity pressure is approximately 26Pa. The stack pressure at this temperature is approximately 10Pa. The combined pressure is 36Pa. Rounding down the recommended pressure difference across the envelope is 35Pa. The heat transfer coefficient recommended is 30 W/m^2·ºK.

7.3 Summer

For the spring profile an ambient temperature of 15ºC, the long-term mean is assumed. At this temperature the wind velocity pressure is approximately 23Pa. The stack pressure at this temperature is approximately 2Pa. The combined pressure is 25Pa. The heat transfer coefficient recommended is 30 W/m^2·ºK.

7.4 Summary on Proposed Air Pressure Profile

The suggested pressure difference, *ΔP*, and heat transfer coefficient (HTC) profile for extreme cold regions protocol is given below:

Winter Profile: *ΔP* = 50Pa positive pressure; HTC = 30 W/m^2·ºK
Spring Profile: *ΔP* = 35Pa positive pressure; HTC = 30 W/m^2·ºK
Summer Profile: *ΔP* = 25Pa positive pressure; HTC = 30 W/m^2·ºK

8 Defining Atmospheric Moisture Test Conditions

Atmospheric moisture in the extreme cold regions does not directly play a large role in the performance of the building envelope. Temperatures are too cold throughout most of the year for the atmosphere to hold significant amounts of moisture. Of more consequence is the difference between the interior and exterior vapour pressures. Generally the exterior vapour can be considered to be close to zero. Consequently this parameter is less important than temperature, wind and solar radiation.

Table 8 – Long-term mean values for atmospheric moisture in Cambridge Bay NU.

Cambridge Bay NU	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Vapour Pressure (kPa)			0.1	0.1	0.3	0.6	0.9	0.8	0.6	0.3	0.1	0.1
Average Relative Humidity – 0600LST (%)			71.6	77.8	87.4	87.6	85.2	88.9	90.6	87.4	78.9	72.6
Average Relative Humidity – 1500LST (%)			73.7	79.4	85.2	76.6	68.6	73.4	82.9	86.2	78.5	71.9

8.1 Winter

During the winter months the amount of water vapour in the atmosphere is very low. The average humidity ratio is about 0.6 g water vapour /kg dry air (100Pa vapour pressure). These are shown in Table 8. For the temperatures specified for the winter portion of the protocol the saturation humidity ratios are less 0.14 g/kg (22Pa). Compare these values with typical values for indoor air moisture content, which vary between 2 and 4 g/kg (350 to 650Pa) during the winter period. Control of humidity on the cold side of the test chamber is not crucial during the winter portion of the test protocol. If humidity control is desired and possible it is proposed to hold the RH level around 70%. The targets correspond to humidity ratios of 0.10, 0.04, and 0.02 g/kg (16, 7 and 4Pa) at –35ºC, –42ºC, –50ºC respectively, also given in Table 9.

Table 9 – Suggested atmospheric moisture profile if desired and possible.

Temperature, ºC	RH, %	Vapour pressure, Pa	Humidity ratio, g/kg
Winter Profile			
–35	70	16	0.10
–42	70	7	0.04
–50	70	4	0.02
Spring Profile			
–25	80	51	0.21
–15	80	132	0.81
–15	80	321	1.98
Summer Profile			
15	85	1465	9.15

8.2 Spring

During the spring months the amount of water vapour in the atmosphere is low. The average humidity ratio is about 1.0 g water vapour /kg dry air (150Pa vapour pressure). These are shown in Table 8. If humidity control is desired and possible it suggested that the target RH be held around 80% for the spring portion of the test. The values begin to be come close to range of the indoor values. The targets correspond to humidity ratios of 0.21, 0.81 and 1.98 g/Kg (51, 132, and 312 Pa) at –25ºC, –15ºC, –5ºC respectively, also given in Table 9.

8.3 Summer

In the summer months the average humidity ratio is about 5.0 g water vapour /kg dry air (800 Pa vapour pressure). This is much more significant than in the winter and spring periods. These are shown in Table 8. The suggested target RH is 85% for the summer portion of the test. The corresponding humidity ratio is 9.13 g/Kg (1465 Pa) at 15ºC given in Table 9.

8.4 Proposed RH profile

The suggested RH profile for extreme cold regions protocol is given below:

Winter Profile: No humidity control or maintain 70% RH.
Spring Profile: No humidity control or maintain 80% RH.
Summer Profile: Maintain 85% RH.

9 Defining Solar Radiation Test Conditions

The proposal to include solar radiation was based on questions and anecdotal evidence obtained during the community consultation task of the PERD 079 Project. It was reported by the community that solar driven moisture was considered a major climatic consideration affecting performance [12]. Temperatures inside the wall cavity could be elevated, to 35ºC and were reported to be especially problematic in the transition season (spring). The southwest exposure of the building, especially on the dark surfaces, tended to show damage first.

Global horizontal irradiance is the total of direct and diffuse radiant energy received on a horizontal surface by a pyranometer over a period of time. The direct normal irradiance is the portion of the radiant energy received by a pyranometer directly from the sun whereas the diffuse horizontal irradiance is the portion of the radiant energy received on a horizontal surface by a pyranometer indirectly from the sky. Figure 22 shows the daily means of global, direct and diffuse irradiance for Cambridge Bay NU. The pattern of global radiation shows a sharp rise in the spring months and a sharp fall off in the autumn with a slight double peak. The direct irradiance pattern follows the same pattern but shows a more pronounced double peak. The diffuse radiation reaches a peak on the longest day of the year. The pattern on a vertical surface however is somewhat different. The orientation that receives the most radiation in Cambridge Bay is south (actually about 13º East of South). The pattern for direct normal radiation on a south facing vertical surface and the total irradiance is also shown in Figure 22. The peaks occur around the end of March or beginning of April. Therefore it appears that the peak solar load received on a southern exposure occurs during spring swing season as suggested by the participants of the community consultation. In the following analysis the irradiance on a vertical surface orientated towards the south was considered.

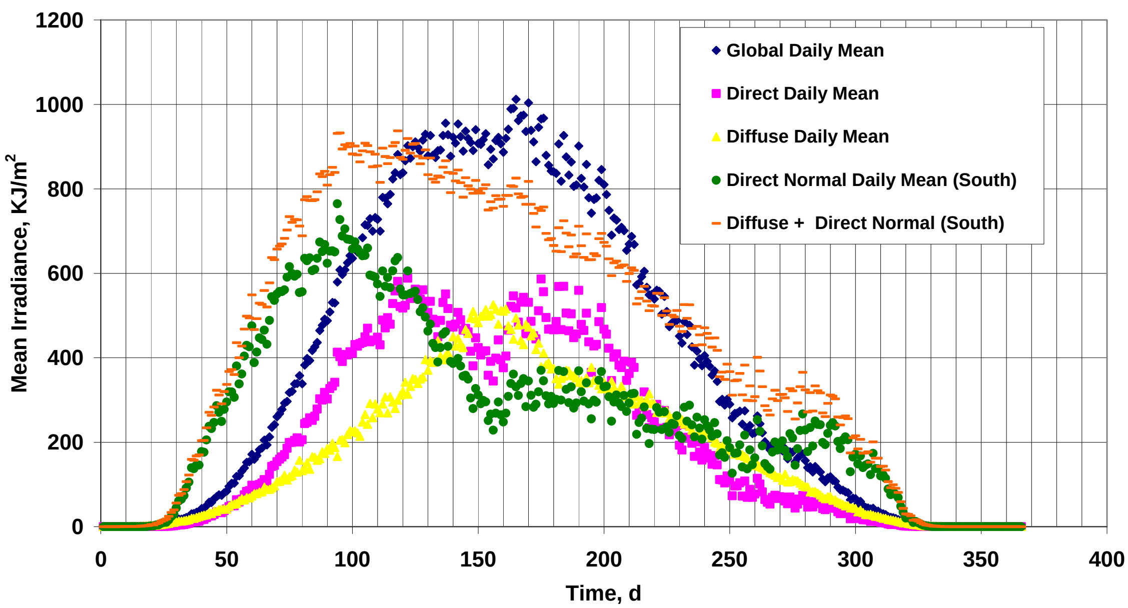


Figure 22 – Mean daily irradiance values for Cambridge Bay NU.

9.1 Winter

Figure 23 shows the mean hourly irradiance on vertical surface facing south in Cambridge Bay NU. From the Figure 22 and Figure 23 it is clear that irradiance values for the winter months are low to zero. There is however a steep increase in irradiance during the month of February increasing to a peak by the end of March. The recommended irradiance is 0 W/m^2 for the winter portion of the cold regions test protocol.

9.2 Spring

Figure 22 and Figure 23 show that during the spring swing season there is a rapid increase in solar irradiance the peak occurring around Day 94 or the 3rd of April[vii]. The peak mean total irradiance corresponds with the peak mean hourly irradiance as well. Day 81 is the vernal equinox. Day 94 is suggested for the solar profile for the spring portion of the cold regions test protocol. The hourly irradiance values, direct normal plus diffuse, rounded to the nearest 20 w/m^2 are given in Table 10.

9.3 Summer

Direct solar irradiance on a vertical surface is less in the summer months than the spring swing season. Diffuse radiation is high however due to the longer daylight hours. The peak values occur towards the beginning of June. Since there is almost constant daylight for the summer months the profiles are all similar. The suggested daily profile for the cold regions test protocol is the summer solstice, the longest day of the year (June 21st or Day 173). The hourly irradiance values, direct normal plus diffuse, rounded to the nearest 20 w/m^2 are given in Table 10.

9.4 Proposed Solar Radiation Profile

The days selected as typical for the testing protocol are: January 1st, April 3rd, and June 21st. The irradiance profiles for these days are shown in Figure 24. The values shown are direct normal radiation on a south facing vertical surface plus the diffuse radiation. The mean values are plotted. The hourly irradiance values for the typical days, rounded to the nearest 20 w/m^2, are given in Table 10.

10 Test Protocol Alternative

An alternative to the test protocol proposed is to use the actual weather data for the representative months identified in the test protocol. The advantages of using real weather data obviously that real weather data is been being used for the test. In some cases, such a numerical modeling, it is useful to apply measured data. The disadvantages however are that the combination of severe or prolonged conditions may not appear in any one particular weather file. For the winter portion of the test January 1966 should be used (see Table 5). Note that although the coldest month February 1959 is colder than January there is a rapid increase in solar irradiance in the month of February.

For the spring of swing season the month April 1991 should be used. Solar irradiance for the month of April is high (it peaks on south facing walls). July 1983 should be used for the summer month. The months are given in Table 11

[vii] Note that number includes a leap day; i.e. there are 366 days in the year.

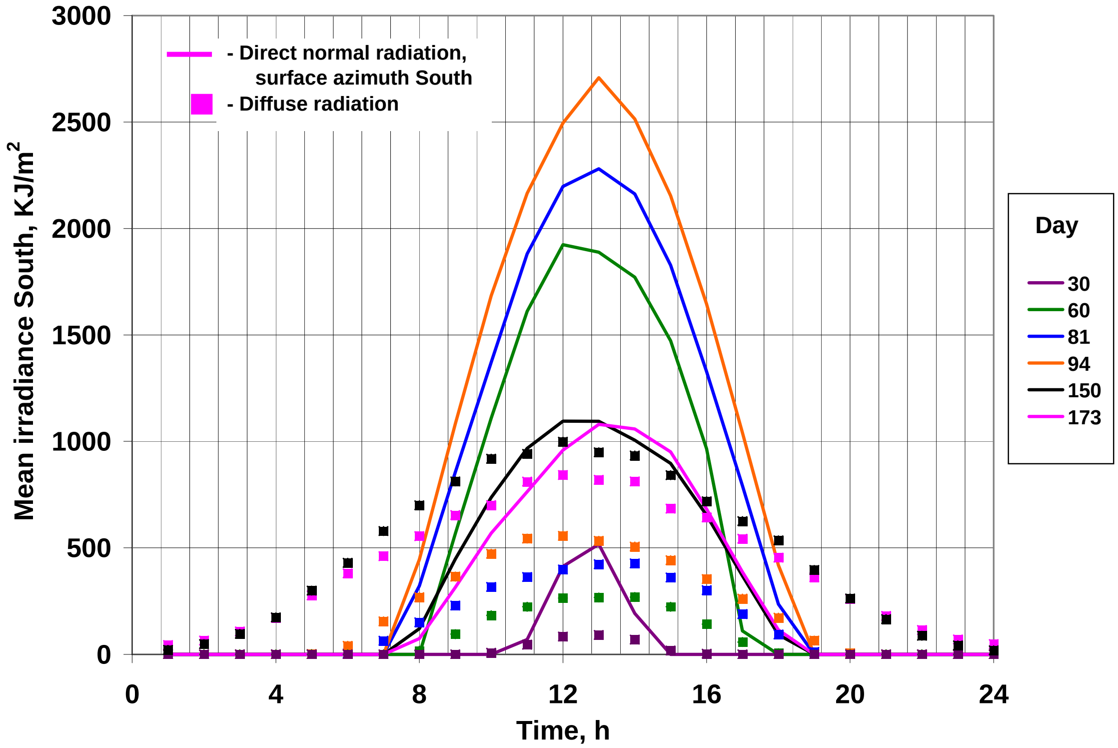


Figure 23 – Mean hourly irradiance on a vertical surface facing south for selected days of the year in Cambridge Bay NU.

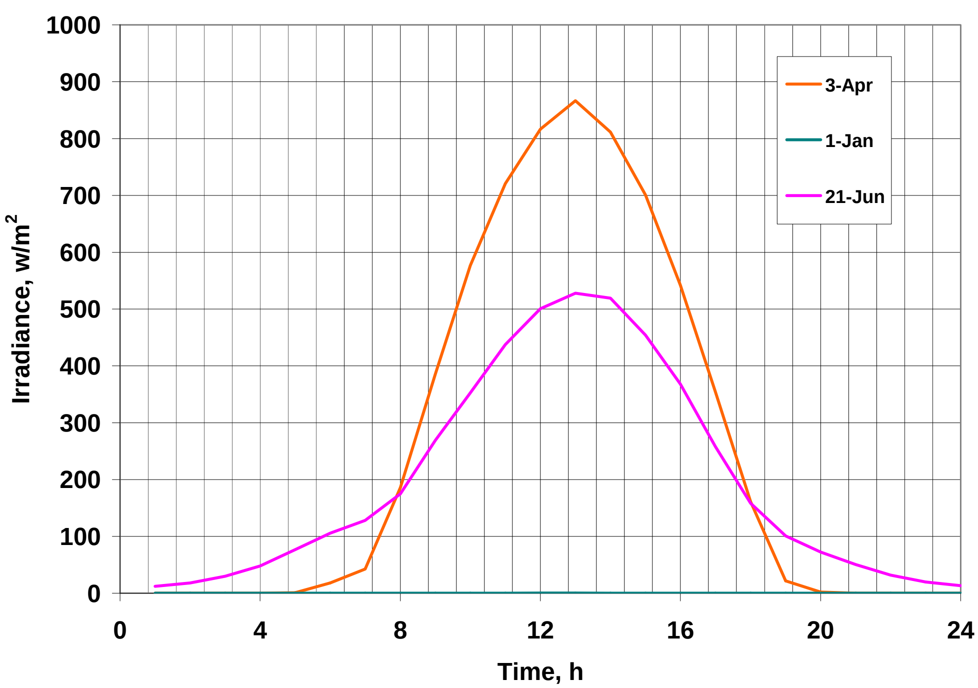


Figure 24 – Mean total irradiance (Direct plus diffuse) for selected days of the year for a south face vertical surface in Cambridge Bay NU.

Table 10 – Recommended hourly irradiance values for the winter, spring, and summer portion of the test protocol.

	Winter Jan. 1st	**Spring Apr. 3rd**	**Summer Jun. 21st**
Hour	**Irradiance w/m^2**	**Irradiance w/m^2**	**Irradiance w/m^2**
1	0	0	20
2	0	0	20
3	0	0	40
4	0	0	40
5	0	0	80
6	0	20	100
7	0	40	120
8	0	180	180
9	0	380	280
10	0	580	360
11	0	720	440
12	0	820	500
13	0	860	520
14	0	820	520
15	0	700	460
16	0	540	360
17	0	360	260
18	0	160	160
19	0	20	100
20	0	0	80
21	0	0	60
22	0	0	40
23	0	0	20
24	0	0	20

Table 11 – Alternative protocol: Selected months from the Cambridge Bay weather record for alternative protocol.

Season	**Year**	**Month**
Winter	1966	January
Spring	1991	April
Summer	1983	July

The data for these months can be obtained from the Cambridge Bay NU data set (WBAN 26005). The data is published by Environment Canada as part of the CWEEDS data set [7]. The parameters required are: direct normal irradiance (element 103), diffuse horizontal irradiance (element 104), station pressure (element 205), dry bulb temperature (element 206), dew point temperature (element 207), wind direction (element 208), and wind speed (element 209).

Direct normal solar irradiance will have to be translated to a vertical surface. This can be done using the equations given in the ASHRAE Handbook of Fundamentals Chapter 31 in the section on determining incident solar flux (pages 31.13 – 31.16) [10]. A south facing wall will be subjected to peak solar irradiance in Cambridge Bay NU.

The relative humidity or equivalent measure of atmospheric moisture can be calculated using the equations give in Chapter 6, Pyschrometrics, of the ASHRAE Handbook of Fundamentals [10], from the station pressure and the dry bulb and dew point temperatures.

If a specific orientation is required that the pressure coefficient, C_s, used to determined the wind velocity pressure can be calculated using the ASHRAE Handbook of Fundamentals Chapter 16, in the section on Surfaced-Averaged Wall Pressure (page 16.4) [10].

Appendices

1. Summary of the PERD 079 Project

PERD 079 Overview
“Engineered Building Envelope Systems to Accommodate High Performance Insulation with Outdoor/Indoor Climate Extremes”

Objective

The main objective of this project is to develop building envelope assemblies that are energy efficient and durable under extreme outdoor and indoor climates. The focus will be on the hygrothermal performance of building envelope systems in climate extremes in the northern and humid northern-coastal areas. The approach will include assessment of building envelope assemblies that have minimum impact on the environment due to building construction, usage, maintenance, and future recycling at the end of its service life.

Tasks

1. **Survey**: Conduct a survey to identify example indoor & concurrent outdoor conditions (both average & extreme) in northern and northern-coastal communities to guide the design and hygrothermal performance analysis tasks. The survey will be contracted out to consultants through CMHC. IRC in collaboration with CMHC will design the questionnaire and analyze the survey results.

2. **Literature review & Community consultation**:
   A) Literature review: With focus on extreme northern & northern-coastal climates, review literature on Building Envelope (BE) systems, indoor climate, and sustainable BE approaches.

   B) Community consultation: Consult with northern and northern-coastal communities and professionals to identify and review building issues and community needs. The RCMP and DND housing authority will also be approached for input regarding their buildings in these communities.

3. **Climate characterization: Determine northern and northern-coastal climate** extremes with focus on temperature, humidity, and precipitation (snow & rain fall). Available weather data from various sources such as Environment Canada and DND will be used. The objective is to provide climate data for the hygrothermal performance analysis tasks.

4. **Review work plan & Select wall assemblies:**
   A) Refine work plan & Select wall assemblies: Review and refine project tasks based on the investigation results of Tasks 1-3. Select wall assemblies for hygrothermal, energy, and environmental assessment.

Present, for discussion and approval, refined tasks and proposed building envelope assemblies to partners and collaborators including CMHC, NRCan, and possible Alberta & Territorial public works & housing authorities.

B) Workshop: to discuss progress to date and approve wall assemblies for hygrothermal, energy, and environmental assessment.

5. **Hygrothermal assessment of proposed wall assemblies:**
   Construct mock-up walls of proposed building envelope assemblies for testing at IRC laboratory facilities using indoor & outdoor climate extremes defined in Tasks 1 and 3. The assessment will concentrate on performance parameters for heating and high humidity climates. The tests will also provide data to benchmark the hygrothermal model used in the computation analysis. The following facilities will be used:

   A) Laboratory testing - EEEF: Assess the hygrothermal performance of the mock-up wall assemblies in the Extreme Environmental Exposure Facility (EEEF).

   B) Hygrothermal computation analysis: Conduct a parametric study to assess the hygrothermal performance of the selected building envelope assemblies. Computational studies will be coordinated with the laboratory testing studies in order to obtain data to benchmark computation as well as provide data for the design of the laboratory testing. This task will determine required material properties for the computations and coordinate their measurement at IRC laboratory.

   C) Workshop: to discuss progress to date.

6. **Energy & Environment impact analysis**:
   This task will be conducted in collaboration with NRCan

   A) Energy analysis: Conduct parametric assessments of energy usage budget of the selected building envelope assemblies.

   B) Environmental impact analysis: assess impact on the environment of the selected building envelope assemblies.

   C) Workshop: to discuss progress to date.

7. **Final project report & Seminar Tour:**
   A) **Final Report**: Prepare a summary report of the project finding from all tasks. This report is in addition to task-reports. At the completion of every task, a report will be prepared to document the task's investigation approach and finding.
   B) **Seminar tour**: Organize seminar tour in major northern and northern-coastal centres to present the project results to the target communities.

Tasks not included in the PERD project but might be included in the strategic project BES2003:

5-D) **Field testing:** Conduct long-term monitoring of hygrothermal performance of preferably 2-buildings in NWT and 2-buildings in a BC northern coastal community. This task will depend on funding and assistance from partners/collaborators, including NWT, Alberta, and BC provincial authorities and possible involvement of RCMP, DND, CMHC, and NRCan.

6-D) **Sustainable Energy technologies:** Assess sustainable energy technologies for northern climates (Ground source heat pump, Photovoltaic cells, Wind, etc.). (Collaborator NRCan)

2. Climate normal data for Cambridge Bay NU.

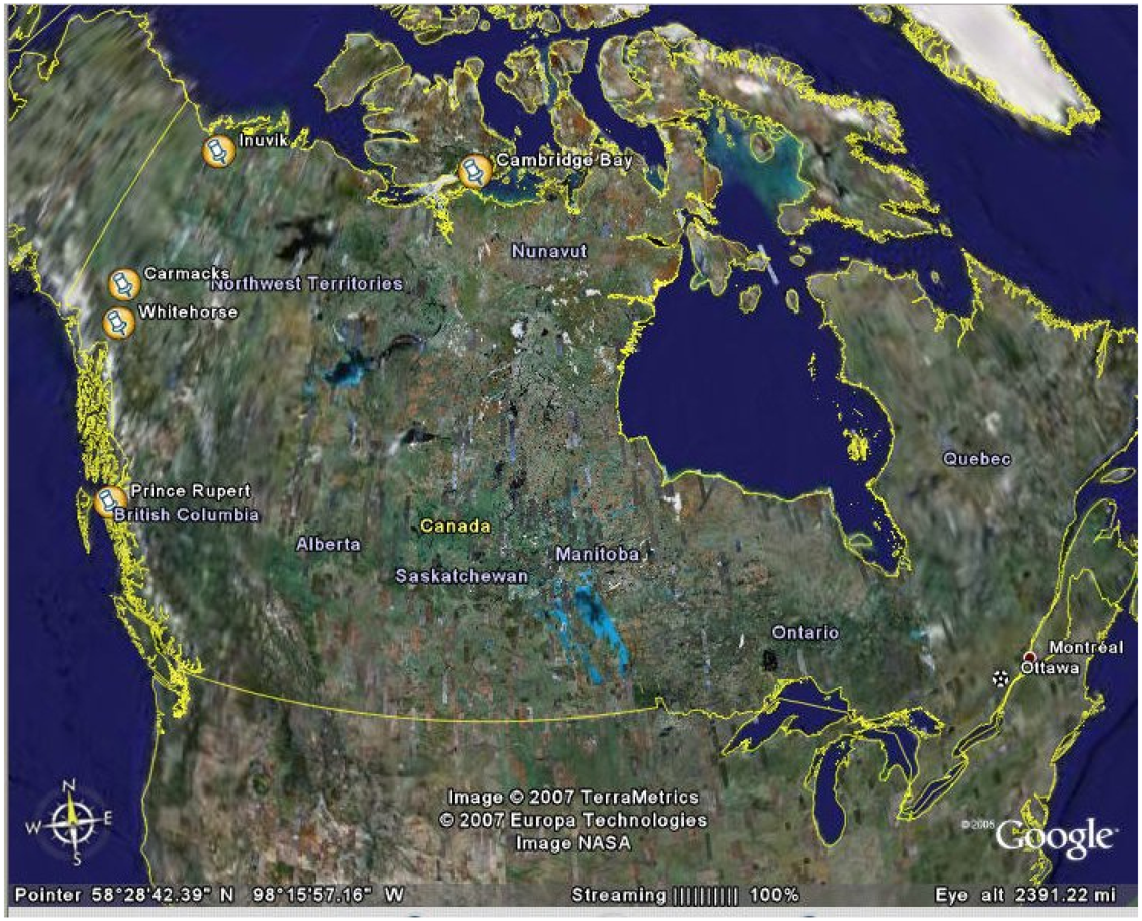


Figure A 1 – Cambridge Bay NU. Latitude 69°06' N; Longitude –105°08'; Elevation 27 m.

Table A 1 – Climate normal data for Cambridge Bay, NU; Airport; Latitude 69°06' N; Longitude –105°08'; Elevation 27 m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Temperature														
Daily Average (°C)	-32.8	-33.0	-29.7	-21.4	-9.2	2.4	8.4	6.4	-0.3	-11.5	-23.0	-29.6	-14.4	A
Standard Deviation	2.6	3.2	2.4	3.0	2.6	2.3	1.6	1.6	1.9	2.9	3.3	2.8	1.2	A
Daily Maximum (°C)	-29.3	-29.3	-25.7	-16.7	-5.3	5.6	12.3	9.4	1.9	-8.1	-19.3	-26.1	-10.9	A
Daily Minimum (°C)	-36.3	-36.6	-33.7	-26.0	-13.0	-0.8	4.6	3.4	-2.5	-14.9	-26.5	-33.0	-18.0	A
Extreme Maximum (°C)	7.8	-9.4	-6.1	6.2	13.0	23.3	**28.9**	26.1	15.6	6.9	0.0	-4.8		
Date (yyyy/dd)	1948/19	1941/05+	1955/20	1995/30	1993/03	1996/27	**1930/01**	1991/04	1957/06	1988/05	1931/01	1983/24		
Extreme Minimum (°C)	**-52.8**	-50.6	-48.3	-42.8	-35.0	-17.8	-1.7	-8.9	-17.2	-33.0	-42.2	-49.4		
Date (yyyy/dd)	**1935/03**	1955/27	1936/02+	1972/03	1935/13	1974/02	1978/01	1952/30	1965/30	1978/29	1941/25	1934/31		
Precipitation	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rainfall (mm)	0.0	0.0	0.0	0.1	1.6	9.8	21.7	24.5	11.4	0.4	0.0	0.0	69.6	A
Snowfall (cm)	5.6	6.4	7.4	7.5	9.3	2.8	0.0	2.2	8.9	16.2	9.3	6.3	82.1	A
Precipitation (mm)	4.6	5.1	6.0	6.5	9.4	12.5	21.7	26.7	19.3	14.6	7.2	5.3	138.8	A
Average Snow Depth (cm)	21	24	28	31	30	7	0	0	1	7	14	18	15	A
Median Snow Depth (cm)	21	24	28	31	30	4	0	0	0	8	14	18	15	A
Snow Depth at Mon.-end (cm)	22	26	30	32	22	0	0	0	2	12	16	20	15	A
Extreme Daily Rainfall (mm)	0.2	0.0	0.0	3.8	6.8	19.4	**35.8**	30.7	28.2	10.4	0.3	0.0		
Date (yyyy/dd)	1993/14	1929/01+	1929/01+	1975/28	1990/29	1997/02	**1988/24**	1949/18	1988/06	1963/16	1968/09	1930/01+		
Extreme Daily Snowfall (cm)	11.9	11.6	10.2	12.7	15.7	17.8	1.5	15.8	10.2	**20.8**	15.2	10.2		
Date (yyyy/dd)	1944/25	1991/06	1965/03	1941/12	1972/23	1929/19	1956/21	1996/21	1997/08	**1962/08**	1940/13	1940/12		
Extreme Daily Precip. (mm)	11.9	5.6	10.2	12.7	13.5	21.1	**35.8**	30.7	28.2	20.8	15.2	10.2		
Date (yyyy/dd)	1944/25	1956/14	1965/03	1941/12	1965/05+	1969/02	**1988/24**	1949/18	1988/06	1962/08	1940/13	1940/12		
Extreme Snow Depth (cm)	48.0	50.0	56.0	58.0	**59.0**	57.0	1.0	4.0	10.0	38.0	48.0	47.0		
Date (yyyy/dd)	1993/02+	1983/22+	1958/27+	1958/29+	**1993/09**	2001/01	1978/01	1994/31	1960/26+	1992/17	1992/08+	1992/20+		

Table A 1 – Climate normal data for Cambridge Bay, NU; Airport; Latitude 69°06' N; Longitude –105°08'; Elevation 27 m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Days with Max. Temperature														
<= 0 °C	31.0	28.3	31.0	29.7	25.6	3.6	0.0	0.0	9.3	29.2	30.0	31.0	248.6	A
> 0 °C	0.0	0.0	0.0	0.30	5.4	26.4	31.0	31.0	20.7	1.8	0.0	0.0	116.7	A
> 10 °C	0.0	0.0	0.0	0.0	0.07	5.9	21.0	12.3	0.87	0.0	0.0	0.0	40.2	A
> 20 °C	0.0	0.0	0.0	0.0	0.0	0.27	1.3	0.24	0.0	0.0	0.0	0.0	1.8	A
> 30 °C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	A
> 35 °C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	A
Days with Min. Temperature														
> 0 °C	0.0	0.0	0.0	0.0	0.20	13.7	30.6	26.6	8.0	0.07	0.0	0.0	79.2	A
<= 2 °C	31.0	28.3	31.0	30.0	31.0	24.2	4.3	10.3	27.0	31.0	30.0	31.0	309.1	A
<= 0 °C	31.0	28.3	31.0	30.0	30.8	16.3	0.40	4.4	22.0	30.9	30.0	31.0	286.1	A
< -2 °C	31.0	28.3	31.0	30.0	29.5	8.1	0.0	0.69	14.3	30.1	30.0	31.0	264.0	A
< -10 °C	31.0	28.3	31.0	29.2	20.1	0.83	0.0	0.0	1.8	22.6	29.7	31.0	225.6	A
< -20 °C	30.7	28.0	30.2	23.7	5.5	0.0	0.0	0.0	0.0	7.5	24.8	30.0	180.4	A
< - 30 °C	27.5	24.8	24.0	9.4	0.07	0.0	0.0	0.0	0.0	0.37	10.0	23.6	119.7	A
Days with Rainfall														
>= 0.2 mm	0.03	0.0	0.0	0.03	1.1	5.1	10.1	12.1	7.1	0.45	0.03	0.0	36.0	A
>= 5 mm	0.0	0.0	0.0	0.0	0.03	0.40	1.1	1.2	0.43	0.0	0.0	0.0	3.1	A
>= 10 mm	0.0	0.0	0.0	0.0	0.0	0.13	0.20	0.31	0.10	0.0	0.0	0.0	0.74	A
>= 25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.07	0.0	0.03	0.0	0.0	0.0	0.10	A
Days With Snowfall														
>= 0.2 cm	6.5	6.8	8.1	7.2	8.0	2.5	0.07	1.6	6.8	12.5	9.1	7.7	76.8	A
>= 5 cm	0.03	0.13	0.13	0.17	0.30	0.07	0.0	0.07	0.30	0.43	0.21	0.13	2.0	A
>= 10 cm	0.0	0.03	0.0	0.0	0.03	0.03	0.0	0.03	0.03	0.03	0.03	0.0	0.21	A
>= 25 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	A

Table A 1 – Climate normal data for Cambridge Bay, NU; Airport; Latitude 69°06' N; Longitude –105°08'; Elevation 27 m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Days with Precip.														
>= 0.2 mm	6.3	6.5	7.3	6.6	7.8	6.8	10.2	13.1	12.2	11.8	8.4	7.2	104.1	A
>= 5 mm	0.03	0.07	0.13	0.23	0.37	0.57	1.1	1.3	0.77	0.41	0.07	0.07	5.1	A
>= 10 mm	0.0	0.0	0.0	0.0	0.07	0.17	0.20	0.38	0.13	0.03	0.0	0.0	0.98	A
>= 25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.07	0.0	0.03	0.0	0.0	0.0	0.10	A
Days with Snow Depth														
>= 1 cm	31.0	28.3	31.0	30.0	31.0	15.7	0.03	0.17	6.6	28.6	30.0	31.0	263.4	A
>= 5 cm	31.0	28.3	31.0	30.0	30.6	11.7	0.0	0.0	1.7	19.3	28.8	31.0	243.5	A
>= 10	30.3	28.3	31.0	30.0	29.1	8.2	0.0	0.0	0.03	9.5	22.8	27.2	216.4	A
>= 20	15.6	19.0	25.9	26.9	23.8	4.0	0.0	0.0	0.0	1.1	5.1	10.8	132.4	A
Wind														
Spd. (km/h)	22.4	21.6	21.2	20.4	20.7	19.6	19.7	21.5	22.4	23.0	20.9	21.4	21.2	A
Most Frequent Direction	NW	NW	NW	NE	NE	NE	N	W	NW	NW	NW	NW	NW	A
Maximum Hourly Spd.	89.0	89.0	84.0	80.0	80.0	93.0	71.0	79.0	87.0	**101.0**	82.0	97.0		
Date (yyyy/dd)	1959/19+	1972/22	1970/20	1986/09+	1977/15	1978/18	1976/01	1976/02	1974/26+	**1974/03**	1959/03	1976/24		
Direction of Max. Hourly Spd.	N	NW	NW	NE	NW	NW	SE	NW	NW	NE	NW	NW		
Maximum Gust Spd.	108.0	109.0	97.0	102.0	102.0	120.0	93.0	109.0	116.0	121.0	102.0	**122.0**		
Date (yyyy/dd)	1963/09	1972/22	1970/20	1986/09	1977/15	1978/18	1976/01	1971/13	1975/08	1974/07	1977/12+	**1976/23**		
Direction of Maximum Gust	NW	NW	NW	N	NW	NW	SE	W	NE	NE	E	NW		
Days with Winds >= 52 km/hr	5.1	3.8	4.0	3.2	3.4	2.5	2.0	3.8	3.7	5.4	4.1	3.4	44.3	C
Days with Winds >= 63 km/hr	2.0	1.2	1.2	0.92	1.3	0.65	0.46	0.67	1.1	1.7	1.5	1.0	13.8	C

Table A 1 – Climate normal data for Cambridge Bay, NU; Airport; Latitude 69°06' N; Longitude –105°08'; Elevation 27 m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Degree Days														
Above 24 °C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	A
Above 18 °C	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	A
Above 15 °C	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.2	0.0	0.0	0.0	0.0	1.3	A
Above 10 °C	0.0	0.0	0.0	0.0	0.0	2.7	19.3	8.8	0.0	0.0	0.0	0.0	30.7	A
Above 5 °C	0.0	0.0	0.0	0.0	0.0	22.7	110.0	65.6	3.6	0.0	0.0	0.0	202.0	A
Above 0 °C	0.0	0.0	0.0	0.0	1.4	96.3	261.2	197.7	42.5	0.6	0.0	0.0	599.6	A
Below 0 °C	1017.0	932.2	920.3	641.2	285.4	24.2	0.0	0.4	52.0	357.8	688.8	917.7	5836.8	A
Below 5 °C	1172.0	1073.5	1075.3	791.2	439.0	100.6	3.8	23.4	163.2	512.2	838.8	1072.7	7265.5	A
Below 10 °C	1327.0	1214.8	1230.3	941.2	594.0	230.6	68.1	121.5	309.5	667.2	988.8	1227.7	8920.6	A
Below 15 °C	1482.0	1356.2	1385.3	1091.2	749.0	377.9	205.0	267.9	459.5	822.2	1138.8	1382.7	10717.5	A
Below 18 °C	1575.0	1441.0	1478.3	1181.2	842.0	467.9	296.9	360.7	549.5	915.2	1228.8	1475.7	11812.1	A
Bright Sunshine														
Total Hours		66.3	174.3	268.1	250.8	300.6	328.8	189.2	71.1	55.6	14.9			
Days with measurable		16.6	27.0	27.7	27.4	27.7	29.7	28.1	21.1	15.7	6.5			
% of possible daylight hours		31.8	48.3	56.0	37.5	41.8	45.2	34.1	17.7	19.5	11.4			
Extreme Daily	4.3	8.6	11.2	17.1	24.0	24.0	24.0	19.4	14.3	8.9	6.0	0.0		A
Date (yyyy/dd)	1985/31	1975/28	1996/29+	1991/29	**1973/29+**	**1972/28+**	**1978/02+**	1989/03	1980/01	1979/09+	1980/01	1971/01+		
Humidex														
Extreme Humidex	-5.0	-9.7	-5.6	3.9	10.5	25.3	**30.8**	28.6	16.3	5.8	-1.4	-5.0		
Date (yyyy/dd)	1987/09	1989/04	1955/20	1975/27	1994/27	1973/27	**1989/17**	1991/04	1957/06	1988/05	1994/12	1983/24		
Days with Humidex >= 30			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Days with Humidex >= 35			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Days with Humidex >= 40			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Wind Chill														
Extreme Wind Chill	**-73.4**	-72.6	-69.8	-60.1	-43.2	-29.2	-7.9	-13.1	-28.6	-49.4	-60.7	-66.3		
Date (yyyy/dd)	**1975/12**	1979/11	1979/04	1964/10	1961/07	1972/02	1978/05	1986/30	1974/29	1978/28	1968/26	1979/17		
Days with Wind Chill < -20	31.0	28.3	31.0	28.8	16.6	0.5	0.0	0.0	1.3	20.1	29.4	31.0	217.9	A
Days with Wind Chill < -30	30.7	28.0	30.3	23.7	4.6	0.0	0.0	0.0	0.0	7.3	24.8	30.0	179.3	A
Days with Wind Chill < -40	28.7	26.0	26.1	13.0	0.2	0.0	0.0	0.0	0.0	1.2	14.1	25.9	135.3	A

Table A 1 – Climate normal data for Cambridge Bay, NU; Airport; Latitude 69°06' N; Longitude –105°08'; Elevation 27 m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Humidity														
Avg. Vapour Pressure (kPa)			0.1	0.1	0.3	0.6	0.9	0.8	0.6	0.3	0.1	0.1		
Avg. RH - 0600LST (%)			71.6	77.8	87.4	87.6	85.2	88.9	90.6	87.4	78.9	72.6		
Avg. RH- 1500LST (%)			73.7	79.4	85.2	76.6	68.6	73.4	82.9	86.2	78.5	71.9		
Pressure														
Avg. Station Pressure (kPa)	101.2	101.4	101.5	101.8	101.6	101.2	100.9	100.8	100.9	101.0	101.2	101.2	101.2	A
Avg. Sea Level Pressure (kPa)	101.6	101.8	101.9	102.1	101.9	101.5	101.3	101.2	101.3	101.4	101.5	101.5	101.6	A
Radiation														
Global (RF1)												0.1		
Extreme Global (RF1)	0.8	4.7	13.6	23.7	31.3	**32.2**	30.4	23.3	14.0	7.3	1.9	0.1		
Date (yyyy/dd)	1972/30	1972/28	1972/31	1982/30	1972/29	**1974/06**	1978/02	1991/01	1976/02	1972/06	1977/01	1990/02+		
Visibility (hours with)														
< 1 km	49.2	47.0	39.0	23.8	34.0	15.0	11.6	9.5	22.7	33.9	26.0	31.0	342.7	C
1 to 9 km	184.7	189.8	163.9	121.3	109.5	42.4	27.4	35.3	87.6	146.8	136.4	174.3	1419.5	C
> 9 km	510.1	441.0	541.0	575.0	600.5	662.6	705.0	699.2	609.7	563.3	557.5	538.8	7003.6	C
Cloud Amount (hours with)														
0 to 2 tenths	370.8	313.6	349.4	342.8	166.8	134.8	130.2	90.1	59.2	158.2	283.1	340.6	2739.5	C
3 to 7 tenths	148.6	135.0	142.4	121.8	108.0	131.4	173.0	130.0	88.3	104.6	120.2	150.2	1553.6	C
8 to 10 tenths	224.7	229.1	252.2	255.4	469.2	453.8	440.8	523.9	572.5	481.3	316.7	253.3	4472.7	C

3. Diurnal cycling

The application of a simple model for modeling daily temperatures based on the daily minimum and maximum temperatures to the typical winter and summer months shows good correspondence in the summer months and less correspondence for the winter months. The model is given below. The model assumes a simple symmetric cosine variation around the daily mean temperature, shifted to accommodate the daily peak.

$$\Delta T = \left(\frac{Max_{Daily} - Min_{Daily}}{2} \right) \cos(\alpha) \qquad (^{o}\mathrm{C})$$

$$\alpha = \frac{2\pi}{24}(Hour + Shift_{peak}) \qquad (\mathrm{Radians})$$

Where:

Max_{Daily}	= Daily maximum temperature, ºC
Min_{Daily}	= Daily minimum temperature, ºC
α	= Hour angle, Radians
$Hour$	= Time of day, h
$Shift_{peak}$	= Shift parameter to move peak daily temperature, h

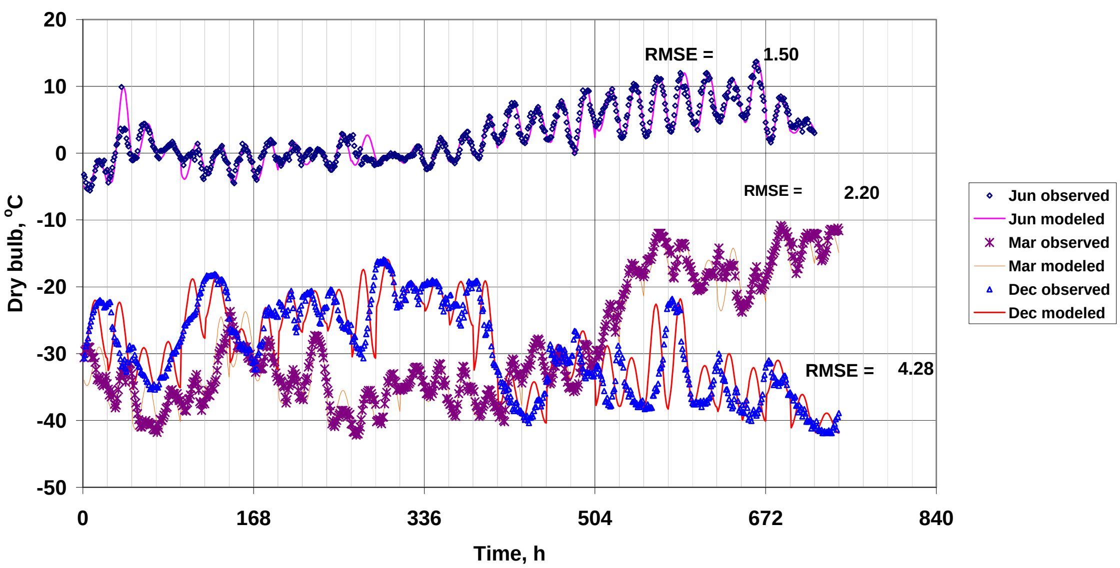


Figure A 2 – Comparison of a simple daily diurnal model to daily temperatures. The results indicate that diurnal cycling is the main driving force in the spring and summer months and less so in the winter months.

Table A 2 – Errors between simple model predictions and daily average temperatures. The errors are larger for the winter months indicating that temperature changes are caused by advection of air masses rather than solar irradiance.

Month	**RMSE**	$\rho_{x,y}$
Dec	4.28	0.797247
Jan	2.42	0.853376
Feb	3.30	0.895217
Mar	2.20	0.969299
Apr	3.00	0.87865
May	1.90	0.945581
Jun	1.32	0.947258
Jul	1.72	0.89575
Aug	1.50	0.898933

$\rho_{x,y}$ – correlation coefficient

Applying the simple model to determine to spring and summer diurnal cycles using the following parameters, [$Max_{Daily} – Min_{Daily}$] = 10, and $Shift_{Peak}$ = 8 (Daily peak at 16:00 hours) gives the daily profile given below.

Table A 3 – Daily diurnal profile to be used in the test protocol.

Hour	**ΔT from Daily Mean, ºC**
0	–2.5
1	–3.5
2	–4.3
3	–4.8
4	–5.0
5	–4.8
6	–4.3
7	–3.5
8	–2.5
9	–1.3
10	0.0
11	1.3
12	2.5
13	3.5
14	4.3
15	4.8
16	5.0
17	4.8
18	4.3
19	3.5
20	2.5
21	1.3
22	0.0
23	–1.3
24	–2.5

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