Solar Domestic Hot Water System Sizing for Whitehorse, YT, and Dawson, YT

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1 Introduction

The Yukon Housing Corporation is exploring the possibility of installing solar domestic hot water systems at two residences in Whitehorse (latitude 60.72N) and Dawson (latitude 64.04N). The residences in question are 3-bedroom duplexes with roughly 1,200 ft^2 on each side. This report documents the solar resource in Whitehorse and Dawson, and explores possible system designs (type of collector, size of collector, size of tank, and slope of collector) for the two locations.

2 Solar Resource in Whitehorse and Dawson

2.1 CWEEDS

The solar resource can be assessed from a number of sources. The best source for Whitehorse is the Canadian Weather Energy and Engineering Data Sets (CWEEDS) (Environment Canada, 2005). The CWEEDS file covers the period 1953 to 2005. Most of the solar radiation data over that period are *measured*, which guarantees a relatively accurate estimation of solar radiation.

Similar files are available for Dawson, YT, but for that site no solar radiation measurement is available; instead, solar radiation is estimated by a model using earth-sun geometry and cloud cover information.

The average solar radiation data for Whitehorse and Dawson, from the CWEEDS files, are summarized in Table 1.

2.2 PV Maps

Another source is the Photovoltaic Potential and Solar Resource Maps of Canada (PV Maps), developed by the Canadian Forest Service (Great Lakes Forestry Centre). These maps were produced in collaboration with the CANMET Energy Technology Centre (CETC-Varennes) Photovoltaic Systems Group (NRCan, 2008). PV Maps and the CWEEDS files are derived from a common source, so the two sources agree generally well, as shown in Table 1.

2.3 NASA SSE

Finally solar radiation estimates, derived from satellite data, are available from NASA's Surface Meteorology and Solar Energy Data Set (NASA, 2008). Values from that service are also given in Table 1. This source is usually considered less reliable than ground data, but it provides better spatial coverage, particularly for remote locations.

2.4 Comparison

Table 1 provides a comparison between all three sources. All sources agree that solar radiation is around 2.8 kWh/m2/day in Whitehorse and slightly lower around 2.6 kWh/m2/day in Dawson. Figure 1 and Figure 2 provide a comparison in graphical form. In the rest of the study, CWEEDS averages will be used as they usually constitute the current reference to use in Canada.

Table 1 – Monthly mean daily solar radiation in Whitehorse and Dawson, according to various sources. All data in kWh/m2/day.

	Whitehorse			**Dawson**		
	CWEEDS	PV Maps	NASA SSE	CWEEDS	PV Maps	NASA SSE
Jan	0.35	0.4	0.36	0.15	0.2	0.15
Feb	1.11	1.1	1.12	0.83	0.8	0.79
Mar	2.56	2.6	2.42	2.38	2.3	2.13
Apr	4.34	4.4	4.19	4.23	4.4	3.98
May	5.24	5.4	5.52	5.12	5.4	5.25
Jun	5.71	5.7	6	5.61	5.7	5.99
Jul	5.16	5.2	5.48	5.15	4.9	5.41
Aug	4.12	4.1	4.37	4.08	3.7	4.05
Sep	2.52	2.6	2.73	2.35	2.2	2.56
Oct	1.24	1.2	1.44	0.94	1	1.17
Nov	0.46	0.5	0.55	0.27	0.3	0.3
Dec	0.2	0.2	0.21	0.05	0.1	0.04
Annual	2.75	2.78	2.87	2.60	2.58	2.65

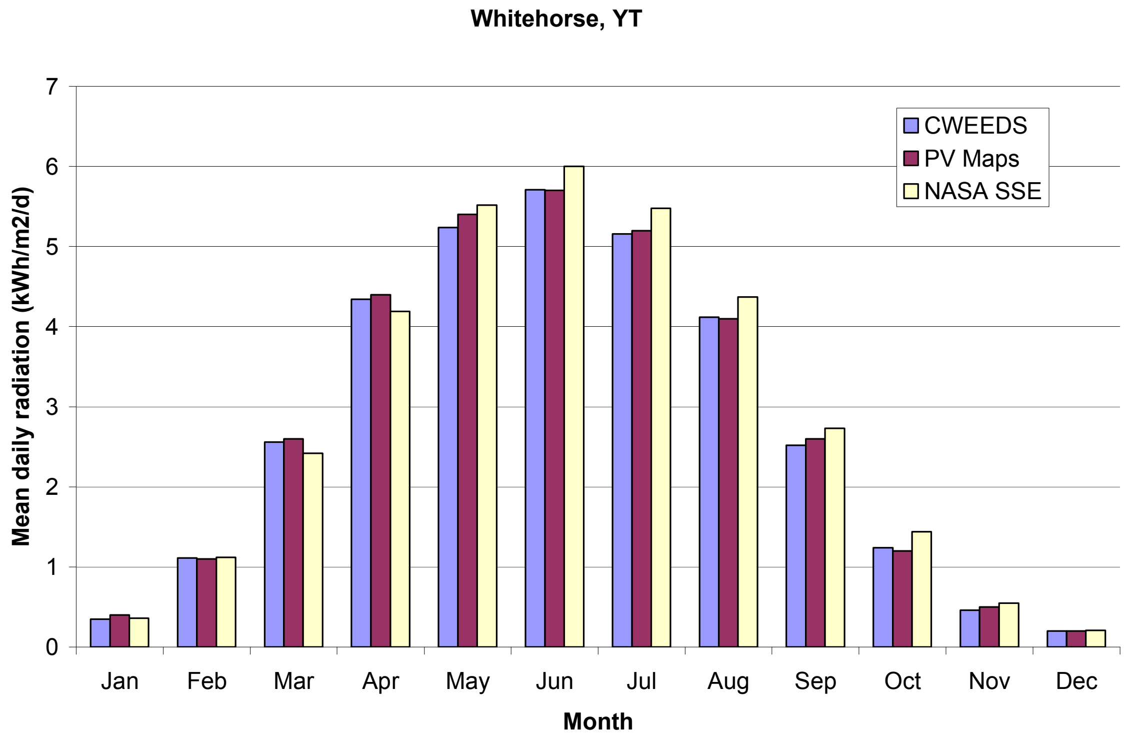

Figure 1 – Evaluation of solar resource in Whitehorse, YT.

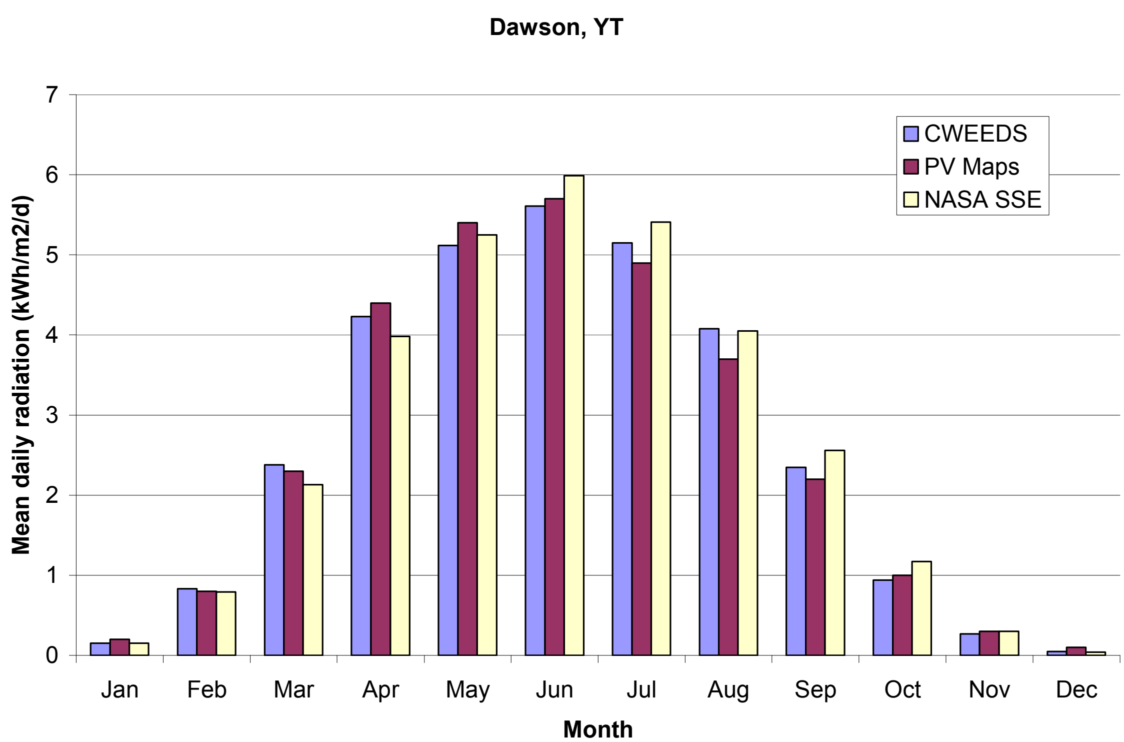

Figure 2 – Evaluation of solar resource in Dawson, YT.

2.5 Temperature

Ambient temperature is another parameter of importance for the evaluation of solar domestic hot water systems. Monthly averages were obtained from the Canadian Normals (Environment Canada, 2008) and are summarized in Table 2.

Table 2 – Average temperatures (°C) in Whitehorse and Dawson.

	Whitehorse	Dawson
Jan	-17.7	-26.7
Feb	-13.7	-22.4
Mar	-6.6	-11.9
Apr	0.9	0.1
May	6.9	8.3
Jun	11.8	13.7
Jul	14.1	15.6
Aug	12.5	12.5
Sep	7.1	5.9
Oct	0.6	-5.0
Nov	-9.4	-17.9
Dec	-14.9	-24.7
Annual	-0.7	-4.4

3 Solar Domestic Hot Water Equipment Suitable for Whitehorse and Dawson

There are dozens, if not hundreds, of solar domestic hot water systems currently on the market. Broadly speaking, they fall into three categories: unglazed collectors, glazed collectors, and evacuated tube collectors. Unglazed collectors are not suitable for year-round domestic hot water heating applications in the Yukon because of the generally cold ambient temperatures and consequently, high thermal losses from the collector to the environment. Glazed and evacuated tube collectors are appropriate, as long as they are protected from potential freezing with a glycol solution. Two well known Canadian manufacturers of flat-plate collectors are Thermo-Dynamics (Dartmouth, NS) and EnerWorks (Dorchester, ON). There is no Canadian manufacturer of evacuated tube collectors, but two well-known makes are the Thermomax and Sunda collectors.

There is no definite argument for choosing either kind of collector for the Yukon. Evacuated tube collectors have a reputation for performing better under cold and cloudy conditions, but may not be as robust as flat-plate collectors and may be more expensive. Both kinds of collectors will be considered in section 5.

Most manufacturers now provide not only collectors, but whole systems including tank, pump, heat exchanger, and controller. It is a good idea to consider such systems as they take the guesswork out of matching components from different manufacturers, and give a better chance that the system as a whole will work as intended. Some systems may even be certified to standard CAN/CSA-F379.1-88 *Solar Domestic Hot Water Systems* which applies to packaged systems designed for single-family dwellings.

Antifreeze protection is necessary; the type and concentration of the antifreeze used in the system is usually recommended by the manufacturer, so no particular make is suggested here. The system should be protected at least to the minima encountered in the locations considered, that is, -52.2 °C in Whitehorse and -55.8 °C in Dawson (Environment Canada, 2008).

A typical system schematic is shown in Figure 3. The figure shows the solar collector, connected to the preheat tank through a heat exchanger. The purpose of the heat exchanger is to separate the collector loop, filled with glycol, from the tank, which contains ordinary water delivered to the load. Many Canadian systems use a natural convection heat exchanger located near the bottom of the preheat tank. In this type of heat exchanger the motion of the fluid on the tank side of the exchanger happens only by natural convection, because of the buoyancy generated by the temperature rise inside the exchanger. It should also be noted that in most Canadian systems, the preheat tank comes *in addition* to the regular hot water tank, thereby creating a two-tank system. For cost reasons, a regular electric water heater is often used as the preheat tank, but without connecting its heating element to any power source. The preheat tank works together with the solar collector and the heat exchanger to collect solar energy. It then delivers preheated water to the auxiliary tank/heater. On bright sunny days, the temperature of the preheated water may be sufficiently high that the auxiliary heater does not need to turn on. On overcast days, the solar heater contributes only a small fraction of the temperature rise, the bulk being provided by the auxiliary heater.

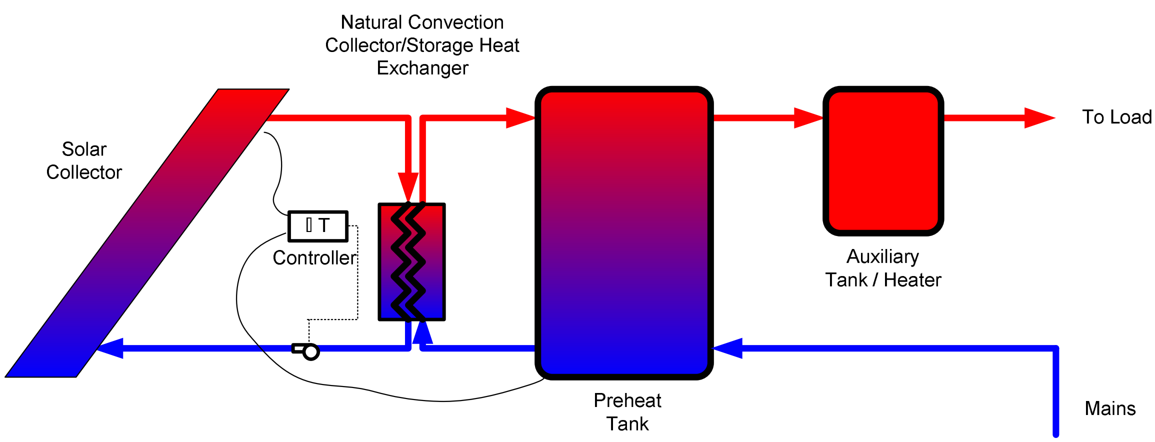

Figure 3 – Typical solar domestic water heating system.

4 List of Potential Suppliers

4.1 Evacuated Tubes

Canadian Solar Technologies Inc.
8459 110A Street
Delta, British Columbia
Canada V4C 2K5
Phone: 604.721.6565
Fax: 604.507.9671
Web: http://www.canadiansolartechnologies.ca/

Contact: Wendy Maver, B.Eng., P.Eng.

Canadian Solar Technologies does not have a distributor in the Yukon, however they have dealt with individual contractors in the past.

Thermomax Industries Ltd.
3181 Kingsley Street
Victoria, BC
Canada V8P 4J5
Phone: (250) 721-4360
Fax: (250) 721-4329
Toll Free Fax & Messaging: 1-888-923-9443
Web: http://www.solarthermal.com/

Contact: Patrick Spearing, patrick@solarthermal.com

4.2 Flat-plate Collector Systems

Thermo Dynamics Ltd.
101 Frazee Avenue
Dartmouth, Nova Scotia
Canada, B3B-1Z4
tel: +1 (902) 468-1001
fax: +1 (902) 468-1002
Web: http://www.thermo-dynamics.com/

Thermo-Dynamics was contacted and referred to Sow's Ears Builders as their distributor in the Yukon:

Sow's Ears Builders
Box 31825
Whitehorse, Yukon

Y1A-6L3
(867) 334-2076
Contact: Cory Gorden

EnerWorks Inc.
252 Hamilton Crescent
Dorchester, ON. Canada
NOL 1G4
Tel: 519.268.6500
Fax: 519.268.6292
Sales: 1-877-268-6502

EnerWorks was contacted and could not refer to an installer in the Yukon.

4.3 Other Possible Systems

Other collectors may be appropriate for this project (e.g. Viessmann, Apricus). A list of collectors accepted by the EcoEnergy program can be found at http://www.ecoaction.gc.ca/ecoenergy-ecoenergie/heat-chauffage/collectors-capteurs-eng.cfm.

5 System Sizing

The system is sized for a duplex. ASHRAE (2007, Ch. 49) suggests that 159.2 L of hot water at 60 °C is typically used daily by each apartment in such buildings (ASHRAE, 2007, Ch. 49, Table 7). The annual load would therefore be 7.96 MWh. However from Yukon Housing Corp's experience this figure is too high, possibly because of the use of water saving fixtures. Based on figures provided by Yukon Housing, an annual load of 21,350 MJ (5.93 MWh) was used, which corresponds to an average hot water use of 120 L/day for each apartment.

The RETScreen program (NRCan, 2005), version 3.1, was used to size the system. Of particular interest were the type of collector, the number of collectors, the size of the tank, and the slope of the collectors. Other assumptions were: heat exchanger with 80% efficiency, 3% piping and solar tank losses, 5% losses due to snow and dirt. Collectors are assumed to face due South. The default collector used in sections 5.1 to 5.3 is a Thermo-Dynamics S32 collector. This collector is characterized by a 2.96m^2 gross area, a 2.78 m^2 aperture area; the Y intercept of the efficiency curve is 0.64 and its slope is -4.65 $W/m^2/°C$. Sizing for Whitehorse is presented first in sections 5.1 to 5.4. Section 5.5 summarizes sizing results for Dawson.

5.1 Number of Collectors

For this calculation, collector slope was set at latitude and tank size was set at 454 L. Results, shown in Table 3 and Figure 4, reveal that 3 collectors will be sufficient to achieve 50% solar fraction[1]. This is more than the default system proposed by Thermo-Dynamics (two collectors) due to the somewhat low solar availability and cold temperatures in Whitehorse.

Table 3 – Influence of number of collectors on yearly energy delivered.

# of collectors	Yearly energy delivered (MWh)	Solar fraction (%)
1	1.41	24
2	2.34	39
3	2.98	50
4	3.42	58
5	3.72	63

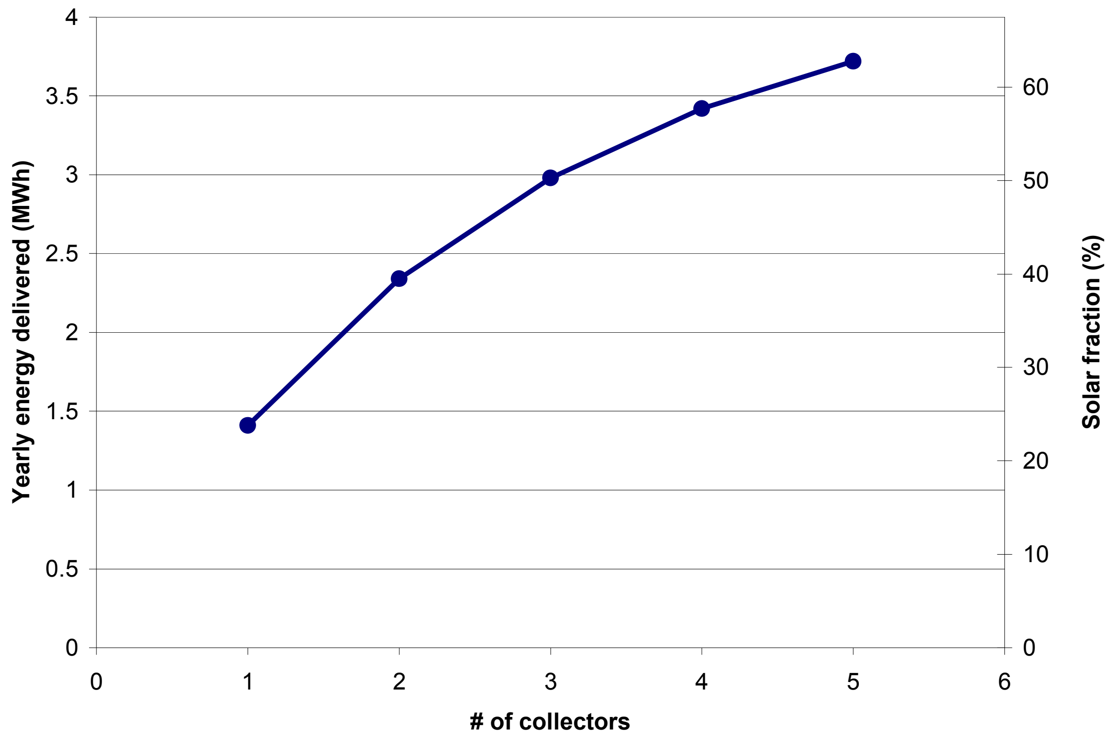

Figure 4 – Influence of number of collectors on yearly energy delivered.

[1] The solar fraction is the fraction of the load met by the solar energy system.

5.2 Size of Preheat Tank

For this calculation, the slope of the collector is set to latitude and the number of collectors is set to 3. Results are summarized in Table 4 and Figure 5. These results show that preheat (storage) tank size has only a limited influence; an increase from 300 to 900 L results only in a 10% increase in the amount of energy delivered. It is suggested to stay with a 454 L tank (120 US gal) as this is a fairly standard and practical tank size.

Table 4 – Influence of storage tank size on yearly energy delivered.

Storage size (L)	Yearly energy delivered (MWh)
300	2.84
400	2.94
454	2.98
500	3.01
600	3.07
700	3.12
800	3.16
900	3.2

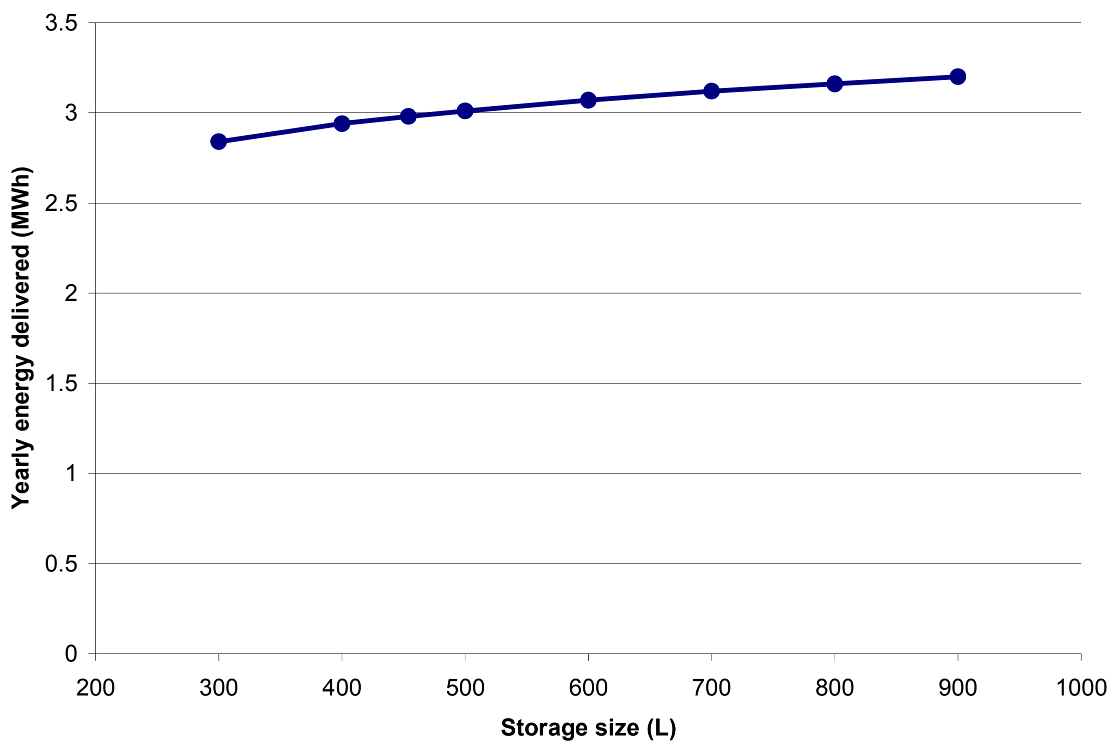

Figure 5 – Influence of storage tank size on yearly energy delivered.

Tank size is often determined relative to collector area. Ratio of tank size to collector area less than 37.5 L/m^2 are generally not recommended as they do not provide enough ‘buffer’ to accumulate energy during sunny days and deliver it during overcast days. 300 L is the smallest tank size corresponding to that ratio with a 3-collector system.

5.3 Slope of Collectors

For this calculation, the number of collectors is set to 3 and the storage size is set to 454 L. Results are summarized in Table 5 and in Figure 6. These results show that the optimal slope of the collector is close to the latitude; this high slope is also advantageous in helping snow slide off the collectors in the winter, although higher slopes would be even more beneficial. The results also show that it is possible to mount the collectors vertically, however there is a slight penalty (-18%) in doing so. If a vertical mount is chosen, for esthetical or space reasons, this penalty can be easily overcome by adding one extra collector.

Table 5 – Influence of slope on yearly energy delivered.

Slope (degrees)	Yearly energy delivered (MWh)
50	3.01
60	2.99
70	2.89
80	2.71
90	2.46

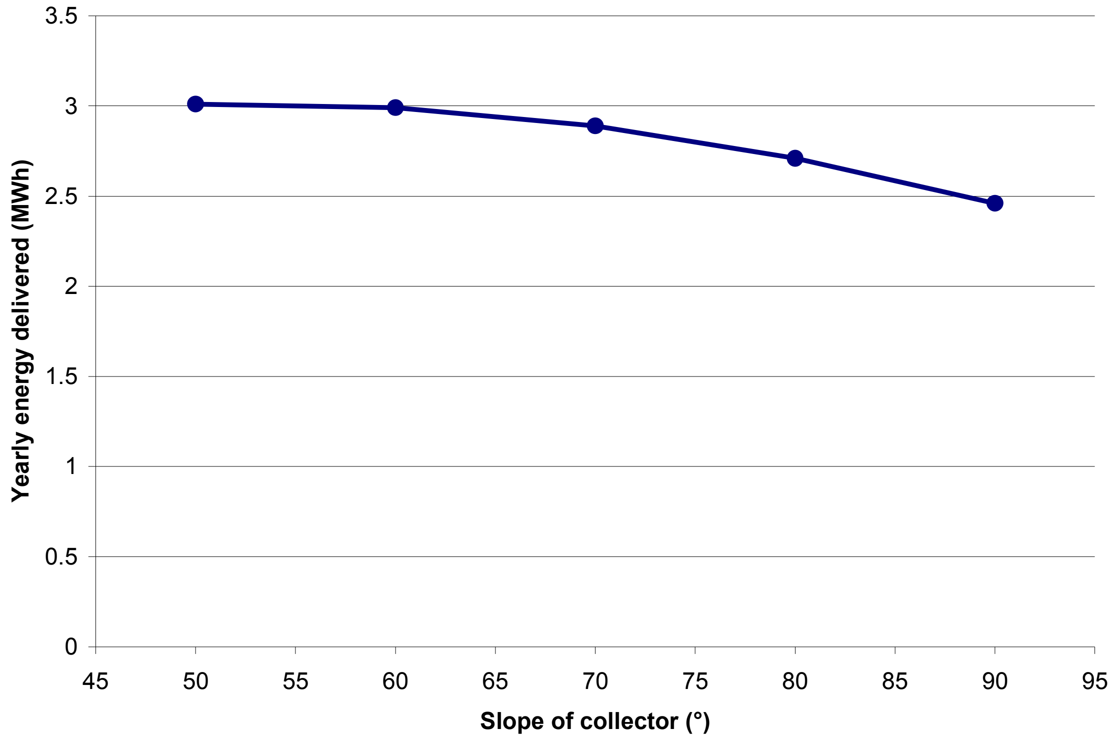

Figure 6 – Influence of slope on yearly energy delivered.

5.4 Type of Collector

In this last set of calculations, the storage tank size is set to 454 L, the slope of the collectors is set to 60.7°, and an evacuated tube collector is used. The model chosen is a Sunda Seido1-16, although similar results would be obtained with other collectors of this type. Collector gross area is 3.994 m^2, aperture area is 3.619 m^2, the Y intercept of the efficiency curve is 0.529 and its slope is -1.697 $W/m^2/°C$. With 2 collectors installed (8 m^2 total), yearly energy delivered is 3.23 MWh leading to a 54% solar fraction. This is better than what is predicted for a slightly larger size flat-plate collector (2.98 MWh delivered yearly with a 3-collector or 9 m^2 system, as per section 5.1). This is an interesting result which suggests that because of the type of climate in Whitehorse – low solar radiation, low temperature – the use of evacuated tube collectors can prove beneficial.

Table 6 provides a comparative summary of results for Whitehorse, for two collector slopes and two types of collectors.

Table 6 – Summary of results for Whitehorse.

Collector type	Slope (°)	Yearly energy delivered (MWh)	Solar fraction (%)
Thermodynamics	60.72	2.98	50
Thermodynamics	90	2.46	41
Sunda	60.72	3.23	54
Sunda	90	2.77	47

5.5 System Sizing for Dawson

Climatic conditions in Dawson are not that different from those in Whitehorse, as shown in section 1, so the sizing exercise will lead to the same kind of system. Calculation results with Dawson's climatic data are summarized in Table 7 (tank size: 454 L; 3 Thermodynamics collectors or 2 Sunda collectors). Note that compared to Table 6 the results are slightly lower, due to the lower solar resource and colder temperatures in Dawson.

Table 7 – Summary of results for Dawson.

Collector type	Slope (°)	Yearly energy delivered (MWh)	Solar fraction (%)
Thermodynamics	64.04	2.88	48
Thermodynamics	90	2.42	40
Sunda	64.04	3.04	51
Sunda	90	2.64	44

6 Fact Sheets

See the end of this report for fact sheets about two proposed configurations: a 2-collector vertical Sunda system for Whitehorse, and a 4-collector vertical Thermodynamics system for Dawson. Both systems have a solar fraction close to 50%. The choice of a flat-plate vs. an evacuated tube system for either location is somewhat arbitrary – for the same surface of collector, the results above show that evacuated tube systems would outperform flat-plate systems for both locations. The proposed configurations enable the two systems to perform almost similarly under different climates (but with a larger collector for the flat-plate system).

7 References

ASHRAE (2007). ASHRAE Handbook – Applications. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

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Environment Canada (2008) Canadian Climate Normals or Averages 1971-2000. http://climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

NASA (2008) Surface Meteorology and Solar Energy Data Set, version 6.0. http://eosweb.larc.nasa.gov/sse/

NRCan (2005) RETScreen International – Clean Energy Project Analysis Software. www.retscreen.net.

NRCan (2008) Photovoltaic potential and solar resource maps of Canada. https://glfc.cfsnet.nfis.org/mapserver/pv/index.php?lang=e

Fact Sheet:
Evacuated tube system for Whitehorse, YT

Dwelling:	Duplex
Location:	Whitehorse, YT
Assumed load:	240 L/day of hot water at 60 °C (120 L/day per apartment)
Proposed system:	
Collector:	Sunda Seido1-16
Type:	Evacuated tube collector
Orientation:	Vertical facing south
Number of collectors:	2
Total collector area:	8.0 m^2
Heat exchanger:	Natural convection
Preheat tank:	Conventional 454 L tank
Energy delivered:	2.77 MWh
Solar fraction:	47%

Fact Sheet
Flat-plate collector system for Dawson, YT

Dwelling:	Duplex
Location:	Dawson, YT
Assumed load:	240 L/day of hot water at 60 °C (120 L/day per apartment)
Proposed system:	
Collector:	Thermo-Dynamics S32
Type:	Flat-plate collector
Orientation:	Vertical facing south
Number of collectors:	4
Total collector area:	11.84 m^2
Heat exchanger:	Natural convection
Preheat tank:	Conventional 454 L tank
Energy delivered:	2.84 MWh
Solar fraction:	47%