Benchmarking of Solar-Thermal Technologies in B.C.'s Agricultural and Agri-Food Operations

July 2012

B.C. Ministry of Agriculture

Agricultural and Agri-Food Renewable Energy Feasibility Studies Project

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DISCLAIMER

All readers should note a solar-thermal system project is highly site-specific. As such, all information presented here is subject to interpretation and re-evaluation by the reader. Prior to commencing with the development of a solar-thermal system, an experienced solar consultant should be engaged to ensure soundness of project assumptions and parameters.

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DEFINITIONS AND ABBREVIATIONS

Aperture area
The aperture area is the area through which the solar energy enters the collector. The aperture area is used to size a solar-thermal system. Average value used for flat plate collector is 2.32 square metres.

ASHRAE
American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Btu/h
A British thermal unit per hour is an unit of energy.

C
Celsius is a metric measure of temperature.

Chabot Profitability Index
The net present value of the sum of the discounted energy bills over \( n \) years of operation divided by the present value of the total installed costs.

cfm
A cubic feet per minute is an imperial measure of flow rate.

COP
The coefficient of performance is a value used to determine the efficiency of a refrigeration device. It is equal to the energy output divided by the energy input.

F
Fahrenheit is an imperial measure of temperature.

GJ
A gigajoule is equal to one billion joules. A joule is a metric measure of heat energy.

Gross area of collector
Simply the length times the width of the collector.

Heat transfer fluid
A fluid used to transfer the heat produced by one device to another device.

kWh
The kilowatt-hour is an unit of energy.

Net present value
Is the sum of the present values of the individual cash flows.

Potable water
Refers to drinking water.

Process air
Outdoor air that is introduced into a space for process reasons, not associated with people or animals.

Process water
Hot or cold water used in agricultural processes.

Propylene glycol
A low toxic fluid, when mixed with water gives water freeze protection.

Renewable heat incentive
A renewable heat incentive is a payment, usually paid by government, for renewable generation of heat to encourage a switch from fossil fuels and contribute towards carbon reduction.
**RETSscreen**
A free software program used to determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects.

**Simple payback**
The amount of time needed for energy savings to equal installed cost.

**Thermal energy**
A form of internal energy usually associated with temperature. A high temperature fluid has high thermal energy, whereas a low temperature fluid has low thermal energy.

**Transpired solar**
A solar collector that is usually wall mounted to capture the low angle rays of the sun in winter to preheat supply air for a building (either ventilation air or process air).

**Solar-thermal technologies**
Solar-thermal technologies collect heat from the sun onto a collector and transfer the heat energy to a working medium (water or air) that is circulated through the collector.

**Ventilation air**
Outdoor air that is introduced into a space for air quality reasons, usually associated with people or animals.

**UNIT CONVERSIONS**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Multiply By</th>
<th>Equivalent Unit</th>
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<tbody>
<tr>
<td>Celsius</td>
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<td>Fahrenheit</td>
</tr>
<tr>
<td>US-gallon</td>
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<td>litres</td>
</tr>
<tr>
<td>Ton refrigeration</td>
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<td>kW</td>
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<td>GJ</td>
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<td>kWh</td>
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<td>Btu/h</td>
</tr>
<tr>
<td>GJ</td>
<td>947,820</td>
<td>Btu</td>
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1 EXECUTIVE SUMMARY

B.C.'s agricultural sector consumes significant quantities of energy. Renewable energy from the sun present agricultural operators with an opportunity to decrease their utility costs, become more energy independent and reduce the environmental impacts of their operations.

This study was undertaken to evaluate the potential of using solar-thermal technologies (namely hot water, chilled water and heated air) at five agricultural sites in the province including a dairy farm, floriculture greenhouse, cherry orchard and packing facility, co-operative farm and boutique winery. These sites were chosen to be representative of the diverse agricultural operations in B.C.

Using information gathered from these sites, this study looked at the solar-thermal potential at each site and the applicable technologies for each type of agricultural operation. Where there was a potential use for a given technology a model was designed. This model included determining what energy tariffs or funding amounts would be necessary in order to make the given technology financially viable given today's local energy prices.

From the five sites evaluated in this study, solar hot water seems to have the most potential in B.C.'s agricultural sector.

Solar hot water
Of the five sites participating in this study, two had hot water loads that warranted investigation. Farm #1 had an estimated load of 3,300 litres of water at 82 C per day; and Farm #5 had an estimated load of 9,080 litres of water at 60 C per day (both use natural gas to heat water).

Due to the average low price of natural gas in B.C. of $9.23/GJ this study concludes that to make a solar hot water system financially viable, one of the following conditions must be met:

- The price of natural gas would need to increase to between $21.50/GJ to $25.00/GJ based on a 10 per cent return on investment; or
- A one-time capital cost rebate of between $800 to $825 per square metre of installed flat plate collector (about 45 per cent of total cost of installation) would be needed based on a 5 per cent return on investment; or
- A renewable heat incentive of $0.045/kWh to $0.054/kWh of heat energy produced over a 25-year period would be needed based on a 10 per cent return on investment.

Furthermore, this study concludes that for agricultural or agri-food operations who currently meet their daily hot water demand using either electricity or propane, it is financially viable today to install a solar hot water system based on the average price of electricity and propane in B.C. of $0.087/kWh and $0.55/L respectively. In other words, no capital cost rebate or renewable heat incentive would be required for these situations.

Solar chilled water
Of the five sites participating in this study, three had chilled water loads. Farm #1 had a temperature demand of 2.2 C; Farm #3 had three different temperature demands of 8 to 10 C, 4 to 7 C and 0 to 2 C; and Farm #5 had a temperature demand of –3 to –10 C. Solar chilled water systems are limited to delivering down to a temperature of 7 C; therefore this type of system is suitable for one of the above applications.

Farm #3's chilled water demand of 8 to 10 C warranted investigation. However, upon analysis, this study concludes that due to the capital cost of $470,000 for the proposed system and a maximum savings of $1,000 per year that this is not a financially viable option.

Consequently, this study found no suitable applications for solar chilled water at any of the participating five sites. Suitability will largely depend on agricultural sites meeting the following system requirements:
- Minimum cooling load of 35 kW (10 ton), based on current equipment available on the market;
- Chilled water temperature demand at or above 7°C, due to current technology limitations; and
- Chilled water demand during July and August, with a preheat hot water demand for the other 10 months of the year.

Even if all of the above operating parameters are met, solar chilled water may still not be a viable solution for agricultural and agri-food operations in B.C. because there is not as much solar radiation available in Canada as there is in the southern United States where most of these systems have been installed. For example, Sante Fe, New Mexico, has about 42 per cent more annual solar radiation than Vancouver and about 78 per cent more annual solar radiation than Abbotsford. Most of the solar chilled water installations have been in the southern United States for office buildings for air-conditioning. We found no examples of solar chilled water systems being used in the agricultural sector in North America. So while the system might seem promising it has its limitations here in Canada.

**Solar heated air**

Of the five sites participating in this study, one had an application for solar heated air. Farm #5 had a preheated ventilation air demand of 830 cubic feet per minute. However, upon analysis, this study concludes that due to the capital cost of $5,700 for the proposed system and a maximum savings of $272 per year that this is not a financially viable option.

Solar heated air systems have been used extensively in the agricultural sector for livestock ventilation of poultry and hog barns, in Quebec and Ontario. Other agricultural sectors that might benefit from solar heated air are crop-drying facilities. For example, solar heated air systems have been used in other countries for drying herbs, nuts, fruit, coffee, tea, cocoa and rice. The systems heat the incoming ventilation air for the fuel-fired dryers. Solar heated air systems are credited with decreasing the use of traditional fuels by up to 30 per cent.

**Barriers**

This study found several barriers to the development of solar-thermal systems in B.C.’s agricultural sector.

One of the barriers is the lack of experienced consultants, contractors and authorities having jurisdiction who are familiar with solar-thermal technology. A barrier that will likely be addressed over time as the industry grows. In the meantime, as long as the market remains small, there will only be a few individuals willing to put the time and effort into the required learning.

Another barrier to the implementation of solar-thermal systems in B.C.’s agricultural sector is the seasonal nature of energy demand at these operations. For example, in one of the case studies, the agricultural operation only had an energy demand for 8 weeks of the year, during the summer. Outside of this window of opportunity, there was little, if any, heating or cooling demand, and therefore, limited opportunity to take advantage of solar-thermal technologies.

A common feature of profitable solar-thermal systems is a long duration temperature demand. This is because these systems can only generate a return on the capital investment when operating. Short duration temperature demand is the least profitable because the equipment will only operate for a limited number of hours per year, and therefore, cannot produce enough savings to overcome the installation cost. The estimated cost for installing a solar hot water system is $1,800 per square metre of flat plate collector; the estimated cost for installing a solar chilled water system is $2,350 per square metre of flat plate collector; and the estimated cost for installing a solar heated air system is $300 per square metre of collector.

Another barrier to the implementation of solar-thermal systems in B.C.’s agricultural sector is the load temperature requirements at agricultural operations. For example, in three of the case studies, the required chilled temperature demands were beyond the capabilities of the solar-thermal system. In another case study, the required high temperature demand was during winter when output of a solar-
thermal system is at its lowest, necessitating a system so large it became impractical and financially unviable.

About 70 per cent of the annual energy output of a solar collector is generated over the period April to October. In other words, for a given load, a solar-thermal system that only operates in the winter will need twice as many collectors as compared to a solar-thermal system that operates year-round to meet the same load demand.

Solar collectors can only capture so much energy, and the amount depends on location, time of year and climatic conditions. For example, in Abbotsford the energy input to a square metre of south-facing collector is about 1,447 kWh annually; in Kelowna the energy input to a square metre of south-facing collector is about 1,526 kWh annually; and on Salt Spring Island the energy input to a square metre of south-facing collector is about 1,378 kWh annually.

This study concludes that solar-thermal hot water systems have the highest performance potential for agricultural and agri-food operations where hot water loads exist on a consistent, daily basis all year-round. On the other hand, solar chilled water systems do not offer the same performance potential because the available solar radiation in B.C. during the fall, winter and spring season is not sufficient to drive the absorption chiller used in these types of systems. Solar heated air likely has potential for B.C. agricultural operations such as poultry and hog barns, and crop-drying facilities, however we were not able to evaluate the feasibility of this technology within a local context due to lack of study participants.

Budget estimates provided in this study are generalized costs. The above findings are based on current figures and current industry practices and as such can change with time, with location and with physical on-site findings. Hence, these findings may prove to be more or less viable upon a detailed engineering design and competitive pricing.
2 ABOUT THIS STUDY

This study was undertaken to develop benchmarks to help individuals and groups in B.C.’s agricultural sector to make informed decisions regarding the use of solar-thermal systems (namely hot water, chilled water and heated air) for agricultural and agri-food operations. Benchmarks have been developed based on the analysis and summation of feasibility studies of five agricultural operations in B.C. The five sites were selected with the intention of representing different types of operations and geographic locations in B.C.

The goals of this solar-thermal benchmarking study are to:

1) Provide a thorough understanding to each individual participating agricultural operator regarding the feasibility of using solar-thermal systems for heating and cooling applications;

2) To inform the B.C. Ministry of Agriculture and other stakeholders regarding the wider opportunity for solar-thermal technology in the agricultural sector; and

3) To develop technical, logistic and financial benchmarks that will help other B.C. agricultural and agri-food operators to conduct their own high-level preliminary feasibility assessment for the adoption of solar-thermal systems.

This study was completed under the B.C. Ministry of Agriculture’s climate action plan and is funded by Growing Forward, a federal-provincial-territorial initiative. This study aims to provide new information about actions that agricultural and agri-food operators can take to reduce greenhouse gas emissions and encourage climate change adaptation by the sector.

This work was guided by a Project Steering Committee comprised of representatives from the B.C. Ministry of Agriculture; B.C. Ministry of Energy and Mines; Agriculture and Agri-Food Canada; and B.C. Agricultural Research and Development Corporation.

2.1 INTENDED AUDIENCE

This study is intended for:

1) Agricultural and agri-food producers;

2) Individuals with an interest in the agricultural and agri-food industry and who are interested in the potential suitability of solar-thermal technologies for agricultural operations; and

3) Government and/or private sector professionals looking for an introduction to the current financial viability of solar-thermal technologies for agricultural operations.

2.2 HOW TO USE THIS STUDY

This study contains background information on solar-thermal technology, detailed technical and financial feasibility assessments, benchmarks conditions required for viability, and a guide to self-assessment of potential solar-thermal applications. It is not intended for all readers to read all sections.

1) Chapter 3 provides a review of solar fundamentals. It may be beneficial for all readers to review this chapter either as a refresher or as an introduction.

2) Chapter 4 provides an introduction to the various solar-thermal technologies reviewed in this study (namely hot water, chilled water and heated air). It may be beneficial for all readers to review this chapter either as a refresher or as an introduction.

3) Chapter 5 provides a brief description of the five participating sites.
4) Chapter 6 discusses fuel prices and incentives (energy tariffs and grants) that would be required to make solar-thermal technologies financially viable in B.C. This chapter may be of interest to all readers as an indicator of the current state of solar economics.

5) Chapter 7 provides a self-assessment guide for agricultural operators so that they might perform their own, independent site assessment of potential solar-thermal technologies at their operation. For readers who are considering adopting solar-thermal technology, this would be a beneficial chapter.

6) Appendix A provides detail on each of the five sites that participated in this study. Readers who have sites similar to those profiled may find the case studies useful.

2.3 PROCESS OF SELECTING PARTICIPANTS

Agricultural and agri-food operations were chosen to participate in this study based on meeting the following goals:

1) To represent as broad a geographic region of B.C. as possible;

2) To represent B.C.’s diverse agricultural sector;

3) To select agricultural operations with a sound technical opportunity for the application of at least one solar-thermal technology; and

4) To select operations that were in a position to act on technically and financially viable solar-thermal opportunities identified in this study.

A total of seven applications were received. Upon review, five were selected for participation in this study and cover the following geographic areas:

- Three participants in the Okanagan/Interior;
- One participant in the Fraser Valley; and
- One participant on Vancouver Island/Gulf Islands.

The five sites chosen represent the following agricultural sectors (see Figure 1 for geographic location of each participating site):

1) Dairy operation;

2) Greenhouse rose production;

3) Cherry orchard and packing facility;

4) Co-operative produce/poultry/dairy farm; and

5) Boutique winery.
One of the goals of this study was to present financial benchmarks for the development of on-site agricultural solar-thermal systems. Certain assumptions had to be made to develop these benchmarks and may or may not be applicable to all agricultural or agri-food operations. While we have tried to make our assumptions based on typical installations, readers must keep in mind each installation is site-specific. Therefore, readers should use this study and its findings as a preliminary guide only. If a decision is made to proceed with the development of a solar-thermal system, an experienced solar consultant should be engaged to ensure soundness of project assumptions and parameters.

Capital costs used in this study are estimates only, based on Stantec’s past experience with similar projects and information provided by other parties. The capital costs stated in this study include the supply and installation of the solar-thermal system only and assume a backup system is in place. For many days of the year, even the best solar-thermal system cannot meet all temperature requirements. As a result, it will always be necessary to retain a backup system, which in winter may need to provide 100 per cent of heat required, and which may not be needed at all on some summer days.

Maintenance cost estimates assume regular maintenance is carried out by a contractor rather than by the agricultural owner/operator. In practice, this estimate may be on the high side, as agricultural operators tend to be self-reliant and may elect to carry out their own regular maintenance.

Energy costs used in this study are based on April 2012 energy utility provider rates in areas covered by the five studies and are shown in Table 1.
Table 1. Local Fuel Costs as of April 2012

<table>
<thead>
<tr>
<th>Location</th>
<th>Natural Gas</th>
<th>Electricity</th>
<th>Propane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraser Valley</td>
<td>9.94 $/GJ</td>
<td>0.090 $/kWh</td>
<td>0.55 $/L</td>
</tr>
<tr>
<td>Central Okanagan</td>
<td>8.87 $/GJ</td>
<td>0.084 $/kWh</td>
<td>0.55 $/L</td>
</tr>
<tr>
<td>Vancouver/Gulf Islands</td>
<td>n/a</td>
<td>0.088 $/kWh</td>
<td>0.55 $/L</td>
</tr>
<tr>
<td>North Okanagan</td>
<td>8.87 $/GJ</td>
<td>0.084 $/kWh</td>
<td>0.55 $/L</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>9.23 $/GJ</td>
<td>0.086 $/kWh</td>
<td>0.55 $/L</td>
</tr>
</tbody>
</table>

2.5 SOLAR-THERMAL SYSTEM SIZE CONSTRAINT

From a technical standpoint, the size of any solar-thermal system is limited to the physical constraints of the particular site. For example, a dairy farm operation with 50 square metres of un-shaded space is limited to a maximum installation of about 20 solar collectors for a solar hot water system (50 square metres divided by flat plate collector size of 2.5 square metres). Similarly, a poultry farm operation with 150 square metres of south-facing wall is limited to a maximum solar heated air system of 150 square metres.
3 SOLAR FUNDAMENTALS

Solar energy is the energy that sustains life on Earth. The energy output of the sun is virtually constant and can be measured at the top of our atmosphere. This energy, known as the solar constant, is equal to 1,367 watts per square metre. To get to Earth, this energy must travel through the Earth’s atmosphere where some of this energy is lost due to reflection, absorption and scatter.

Solar-thermal technologies collect the sun's energy via collectors and transform this energy into heat. A solar-thermal system is only as good as the amount of energy it can collect. The amount of sun energy we can collect on Earth depends on three things:

1) Air mass factor,
2) Cloud cover, and
3) Orientation.

3.1 AIR MASS FACTOR

Figure 2 shows how the angle of the sun affects the depth of atmosphere the sun's energy must travel through. This depth is known as the air mass factor and is measured in atmospheres. For example, when the sun is directly overhead, the sun’s energy only has to travel through 1 atmosphere. Late in the day, when the sun is close to the horizon at an angle of 30 degrees, the sun’s energy must travel through about 2 atmospheres before it reaches Earth. In other words, a solar-thermal collector will generate more heat at noon than at 4 p.m. Travelling through 4 atmospheres can reduce the sun’s energy by as much as 65 to 70 per cent.
3.2 CLOUD COVER

On a clear day the sun's energy can be felt on your face as heat, and on a cloudy day the sun's energy feels less intense on your face. This is because clouds reflect, absorb and scatter the sun's energy. Figure 3 shows how different sky conditions affect the sun's energy we receive, which is known as irradiated power and is measured in watts per square metre. For example, on a clear day the irradiated power we receive from the sun is about 800 to 1,000 watts per square metre, while on a partly cloudy day the irradiated power we receive from the sun is about 350 to 800 watts per square metre. On a cloudy day the irradiated power we receive from the sun is about 100 to 350 watts per square metre. In other words, a solar-thermal collector will generate more heat on a sunny day than on a cloudy day.

Figure 3. Incoming Solar Energy in Different Sky Conditions

3.3 ORIENTATION

The sun changes position in the sky from summer to winter. For example, in summer the sun traces a path high overhead in the sky. In winter, the sun traces a path closer to the horizon. This change in solar altitude, the position of the sun with respect to the horizon, means in summer the sun's energy travels through fewer atmospheres than in winter. In other words, a solar-thermal collector will generate more heat in summer than in winter.

The position of the sun in the sky also varies with latitude because of the relative position of the Earth's axis in relation to the sun. For example, at a dairy farm in the Fraser Valley the sun will be higher in the sky at noon than it will be at a grain farm in the Peace River Valley on the same day.

The number of daylight hours also varies with latitude because of the change in relative position of the Earth's axis in relation to the sun. In summer northern B.C. has more daylight hours than southern B.C., and in winter northern B.C. has fewer daylight hours than southern B.C.

In other words, the amount of solar energy available on any given day will be different depending on where your agricultural or agri-food operation is located in B.C.

3.4 SOLAR POTENTIAL IN B.C.

As discussed in this chapter, the amount of energy solar-thermal collectors can capture from the sun depends on site location, time of year and the climatic conditions. Figure 4 shows the summer and winter solar-thermal potential in B.C. (measured in megajoules per square metre).
From the map we can see in summer northern B.C. has the most solar-thermal potential. That is because in summer there are more daylight hours the further you travel north.

Contrary to what you might expect, in winter northern and eastern B.C. have the most solar-thermal potential. That is mainly because these areas of the province have more sunny days in winter than the rest of the province.

The map also shows us there is more solar-thermal potential in summer than in winter. In fact, about 70 per cent of the annual energy input from the sun to a south-facing collector is received over the period April to October.

Figure 4. Solar Resource Potential in B.C.
This study was undertaken to evaluate the potential of using solar-thermal technologies, namely hot water, chilled water and heated air, at five agricultural sites in B.C.

Solar-thermal technologies can be used by the agricultural sector for a number of applications. Figure 5 shows some possible applications for solar-thermal technology including preheat of water or process water, preheat of radiant water space heat, chilled water for air-conditioning, preheated ventilation air for space heating and preheated ventilation air for dehydrating fruit. What all these systems have in common is a solar collector.

4.1 COLLECTOR TYPES

Solar collectors used for the solar-thermal technologies investigated in this study can be divided into evacuated tube, flat plate and perforated absorber.

Evacuated tube collectors consist of a copper heat pipe and absorber inserted into an evacuated glass tube. The ends of the heat pipe are connected to a header pipe that is inside an insulated box (see Figure 6). This type of collector is used in solar hot water and solar chilled water systems. Evacuated tube collectors are ideal for applications that require medium to high fluid temperatures (above 80°C). In cold weather these collectors will not melt snow cover and will not operate when covered. A single evacuated tube collector assembly costs about $3,500 and weighs about 57 kilograms. The average gross area of collector is about 3 square metres.

Flat plate collectors consist of a frame, glazing cover, copper absorber plate, copper tubes and insulation (see Figure 7). This type of collector is used in solar hot water and solar chilled water systems. Flat plate collectors are ideal for applications that require low to medium fluid temperatures (20 to 60°C). In cold weather these collectors have the ability to melt snow cover and continue to operate. A single flat plate collector (about 4 by 8 feet) costs about $900 and weighs about 45 kilograms. The average gross area of collector is about 2.5 square metres with an aperture area of about 2.32 square metres (glazing area).
Perforated absorber collectors consist of a perforated absorber plate, air space (plenum) and a fan (see Figure 8). This type of collector is used in solar heated air systems. Perforated absorber collectors can raise the temperature of incoming air by 16 to 38°C. The cost of a perforated absorber collector is about $300 per square metre. There are currently two options for these types of collectors: glazed and unglazed. An unglazed system mimics the appearance of perforated metal cladding, while a glazed system looks like a glass wall. In a glazed system, the absorber is placed behind a clear, perforated polycarbonate plate. Enerconcept Technologies, a Canadian company, has developed a glazed system called the Lubi Transparent Collector.
4.1.1 COLLECTOR EFFICIENCY

The efficiency of a collector (either flat plate or evacuated) changes throughout the day and is affected by the temperature difference between the collector and the outside ambient air temperature. As the temperature difference increases, the efficiency of the collector drops due to an increase in thermal losses. In other words, the greater the temperature difference the greater the heat loss to the air. This behaviour can be plotted and is called the efficiency curve. Figure 9 is an example of a plot for a given collector, which has a maximum efficiency of 80 per cent. In other words, when the collector is at the same temperature as the outside air the collector is operating at its maximum efficiency.

![Collector Efficiency Curve](image)

Figure 9. Collector Efficiency Curve

For example, when the temperature difference between the collector and outside ambient air temperature is 40 C the collector operating efficiency is about 65 per cent as shown in Figure 9. This means that 65 per cent of the incoming sun’s energy is available to heat the fluid circulating in the collector. The remaining 35 per cent of sun’s energy is lost due to optical and thermal losses (20 and 15 per cent respectively). For most hot water applications (up to 60 C temperature) the average annual efficiency of the collector ranges from 20 to 40 per cent depending on make and model of collector chosen.
Hence, every solar collector has its own efficiency curve. When comparing performance of a flat plate collector and an evacuated collector for a solar hot water or solar chilled water system you use the efficiency curves. The most suitable collector is chosen based on the required load temperature and the climatic conditions for the location. Figure 10 plots the efficiency curve of a flat plate and an evacuated tube collector. In this example, the flat plate collector has an efficiency of at least 50 per cent up to a temperature difference of about 65 C; and the evacuated tube collector has an efficiency of at least 50 per cent up to a temperature difference of about 120 C. In other words, the evacuated tube collector in this example will work better for higher temperature loads than the flat plate collector.

![Figure 10. Evacuated Tube Versus Flat Plate Collector Efficiency Curve](image)

For example, a farmer in Abbotsford is considering solar hot water and wants to know which collector in Figure 10 would be suitable for his application. The farmer's hot water temperature demand is 60 C. The average daytime temperature in Abbotsford in July is 22 C; and the average daytime temperature in Abbotsford in December is 4 C. From the graph the farmer determines the flat plate collector will operate at about 64 per cent efficiency in July (temperature difference = 60 – 22 = 38 C) and at about 55 per cent efficiency in December (temperature difference = 60 – 4 = 56 C). The evacuated tube collector will operate at about 70 per cent efficiency in July and at about 68 per cent in December. Farmer concludes that both collectors would be suitable for his application.
4.1.2 COLLECTOR ORIENTATION

What a solar collector needs is sun. In the Northern Hemisphere that means the preferred orientation is to face collectors directly south. Generally, solar collectors can be positioned anywhere between 30 degrees to the east, and 30 degrees to the west of south and still perform efficiently. This angle is known as the azimuth angle and is shown in Figure 11. For example, a south pointed collector has an azimuth angle of 0 degrees; and a southwest pointed collector has an azimuth angle of 45 degrees.

Because of the change in position of the sun in the sky from winter to summer, a steeper collector tilt will perform better during the winter months, whereas, a less steep collector tilt will perform better in the summer months. The tilt of a collector is referred to as the slope angle and is shown in Figure 11. The slope angle of the collector can be orientated to maximize its potential as follows:

1) For a solar-thermal system working year-round, tilt the collector at an angle equal to the location's latitude. For example, in Abbotsford, 50 degrees latitude, mount the collector at 50 degrees;
2) To collect the most sun in winter, tilt the collector at an angle equal to the location's latitude plus 15 degrees (like for a roof mounted solar heated air system). For example, in Abbotsford, 50 degrees latitude, mount the collector at 65 degrees (steeper to collect the low angle of the sun);
3) To collect the most sun in summer, tilt the collector at an angle equal to the location's latitude minus 15 degrees (like for a solar chilled water system). For example, in Abbotsford, 50 degrees latitude, mount the collector at 35 degrees (flatter to collect the high angle of the sun);
4) For collectors mounted on a wall, as for solar heated air systems, the angle is equal to 90 degrees.

In addition to the orientation of the collector, the location should have no shading from trees, buildings or mountains.
4.2 SOLAR HOT WATER HOW IT WORKS

A solar hot water system is used to preheat either potable or process water using the sun’s energy. This heat is transferred to a heat transfer fluid (either water or some non-freezing liquid) that is circulated through the collector. This heat can then be used directly or stored for later use. Figure 12 shows the process.

![Solar Hot Water Flow Diagram](image)

Figure 12. Solar Hot Water Flow Diagram

4.2.1 HEAT TRANSFER PASSIVE VERSUS ACTIVE SYSTEMS

Solar hot water systems are designed to store heat remotely from the solar collector. Mass flow of fluid is used to transfer heat from the collector to a storage tank. There are two ways of moving fluid through a solar hot water system: passive and active.

A passive system moves fluid between the collector and heat storage tank naturally via convection (upward movement of the heated fluid). Hence this system requires the storage tank to be located higher than the collector, which is outside of the building. This system is either "on" feeding water through the storage tank when the sun is shining or "off" bypassing the collector loop. The drawback to this system is there is no freeze protection for winter and hence the system must be drained in the fall and recharged in the spring after the danger of freezing weather has passed.

An active system uses a pump and controller to circulate fluid through the collector. This system offers more control than a passive system and is more suitable for agricultural and agri-food operations.

4.2.2 DIRECT AND INDIRECT SYSTEMS

Solar hot water systems are designed as either direct (open loop) or indirect (closed loop).

Direct-active systems circulate water (or process water) from the heat storage tank through the collector (see Figure 13). When the sun is out the collector heats up and the controller turns on the pump to circulate the water through the collector. The expansion tank minimizes changes in the system due to volume change of the water as the system heats up.

Indirect-active systems use a heat exchanger in the heat storage tank, which isolates the stored hot water (or process water) from the heat transfer fluid that is circulated through the collector (see Figure 14). When the sun is out the collector heats up and the controller turns on the pump to circulate the heat transfer fluid through the collector. The heat is transferred from the heat transfer fluid to the water in the storage tank via the heat exchanger. The expansion tank minimizes changes in the system due to volume change of the heat transfer fluid as the system heats up. Since the heat transfer fluid and the water (or process water) do not mix, typically an antifreeze liquid is added to the heat transfer fluid for freeze protection. Depending on whether the system is used for potable or process water, a single or double wall heat exchanger would be required (double wall for potable and single wall for process).

Both of these systems would be suitable for agricultural and agri-food operations depending on the application. In B.C. an indirect-active system is used if the solar hot water system is required to operate on a year-round basis; and a direct-active system is used if the solar hot water system is only required for seasonal use when there is no danger of freezing weather.
Direct-active solar hot water systems circulate water (or process water) from the heat storage tank through the collector.

When the sun is out the collector heats up and the controller turns on the pump to circulate the water through the collector. The expansion tank minimizes changes in the system due to volume change of the water as the system heats up.

Indirect-active solar hot water systems use a heat exchanger in the heat storage tank, which isolates the stored hot water (or process water) from the heat transfer fluid that is circulated through the collector.

When the sun is out the collector heats up and the controller turns on the pump to circulate the heat transfer fluid through the collector. The heat is transferred from the heat transfer fluid to the water in the storage tank via the heat exchanger. The expansion tank minimizes changes in the system due to volume change of the heat transfer fluid as the system heats up.

Since the heat transfer fluid and the water (or process water) do not mix, typically an antifreeze liquid is added to the heat transfer fluid for freeze protection. Depending on whether the system is used for potable or process water, a single or double wall heat exchanger would be required (double wall for potable and single wall for process).

Figure 13. Direct-Active Solar Hot Water System (top)

Figure 14. Indirect-Active Solar Hot Water System (bottom)
4.2.3 FREEZE PROTECTION STRATEGIES

During cold weather water in the solar collector would freeze and cause damage, hence the need for antifreeze protection in winter. All solar hot water systems in B.C. that operate year-round require antifreeze protection, which can be achieved by installing a closed-loop system with a water–propylene glycol solution as the heat transfer fluid.

4.2.4 SOLAR HOT WATER COMPONENTS

The main parts that make up a solar hot water system include (refer to figures 13 and 14):

- Collectors,
- Storage tank,
- Expansion tank,
- Controller,
- Pump, and
- Heat exchanger if indirect system.

4.2.5 SOLAR HOT WATER OPERATING PARAMETERS

In order to make a solar hot water system technically and financially viable the following operating parameters are required:

- Hot water temperature demand 50 to 100 C.
- Hot water demand at least 10 months of the year including summer months.

4.2.6 SOLAR HOT WATER SYSTEM SIZING

Generally, solar hot water systems are sized to supply 60 to 70 per cent of the annual hot water demand to minimize the risk of damage due to overheating during summer peak solar intensities. For example, a dairy farm with an annual hot water demand of 100,000 kWh (360 GJ) could offset 60,000 to 70,000 kWh (216 to 252 GJ) of annual hot water demand using solar.

4.2.7 SOLAR HOT WATER AGRICULTURAL APPLICATIONS

Solar hot water systems can be used in agricultural and agri-food operations where there is a daily demand for hot water such as found on dairy farms. These systems can also be used in agricultural and agri-food operations that use radiant water space heating 10 months of the year such as found in poultry barns.
4.3 SOLAR CHILLED WATER HOW IT WORKS

A solar chilled water system is used to cool either air (also known as solar assisted air-conditioning) or cool process water using the sun's energy. Solar chilled water systems use the sun's energy to drive the cooling process. Figure 15 shows the process.

![Figure 15. Solar Chilled Water Flow Diagram](image)

What is interesting about solar chilled water systems is that the cooling load of a building closely follows the solar resource. We already learned in the previous chapter that a solar-thermal collector will generate more heat at noon than at 6 p.m. Similarly, as illustrated in Figure 16, as the sun rises the building heats up and accordingly the building's cooling demand goes up. At the same time, as the sun rises it heats up the solar collectors which in turn drive the cooling process. In other words, a solar chilled water system uses the output from the solar collectors as it is being generated. There is no need to store the energy for later use like you do with solar hot water. What this means is less system losses for a more efficient use of the sun's energy.

![Figure 16. Solar Chilled Water Cooling Load Versus Solar Radiation](image)

In addition to providing air-conditioning in summer, a solar chilled water system can provide useful preheating of water when there is no demand for air-conditioning. That is because the collectors used for a solar chilled water system are the same collectors that are used for a solar hot water system (either flat plate or evacuated tube).
4.3.1 SOLAR CHILLED WATER COMPONENTS

The main parts that make up a solar chilled water system include (refer to Figure 17):

- Collectors,
- Storage tank,
- Pumps,
- Controller,
- Absorption chiller, and
- Cooling tower.

Figure 17. Solar Chilled Water Schematic of Air Conditioning

4.3.2 SOLAR CHILLED WATER OPERATING PARAMETERS

In order to make a solar chilled water system technically and financially viable the following operating parameters must be met:

- Minimum cooling load of 35 kW (10 ton), based on current equipment available on the market;
- Chilled water temperature demand at or above 7°C, due to current technology limitations; and
• Chilled water demand during July and August, with a preheat hot water demand for the other 10 months of the year.

Even if all of the above operating parameters are met, solar chilled water may still not be a viable solution for agricultural and agri-food operations in B.C. because there is not as much solar radiation available in Canada as there is in the southern United States where most of these systems have been installed. For example, Sante Fe, New Mexico, has about 42 per cent more annual solar radiation than Vancouver and about 78 per cent more annual solar radiation than Abbotsford. So while the system might seem promising it has its limitations here in Canada.

4.3.3 SOLAR CHILLED WATER AGRICULTURAL APPLICATIONS

Most of the solar chilled water installations have been in the southern United States for office buildings for air-conditioning. This study found no examples of solar chilled water systems being used in the agricultural sector in North America.
### 4.4 SOLAR HEATED AIR HOW IT WORKS

A solar heated air system (also known as transpired solar) is used to preheat ventilation air using the sun's energy. In the Northern Hemisphere the collector (perforated absorber) is located on the roof or south facing exterior wall of a building to maximize exposure to the sun. The perforated absorber allows air to pass through into the air space between absorber and building. The absorber, typically painted black, is heated by incoming solar energy. As the mechanical air handling equipment draws fresh outside air into the building the air is heated as it passes through the perforated absorber. Figure 18 shows the process.

![Solar Heated Air Flow Diagram](image)

**Figure 18. Solar Heated Air Flow Diagram**

### 4.4.1 SOLAR HEATED AIR COMPONENTS

The main parts that make up a solar heated air system include (refer to Figure 19):

- Perforated absorber,
- Air space (plenum),
- Intake fan, and
- Ducting.

### 4.4.2 SOLAR HEATED AIR OPERATING PARAMETERS

In order to make a solar heated air system technically and financially viable the following operating parameters are required:

- Heated ventilation air temperature demand of 25 to 35 C (system can heat air 16 to 38 C above ambient on a sunny day);
- Heated air demand at least 6 hours during the daytime;
- Heated air demand at least 10 months of the year (September to July); and
- Ventilation demand between 18 to 180 cubic metre per hour per square metre of floor area (equivalent to 1 to 10 cubic feet per minute per square foot).

### 4.4.3 SOLAR HEATED AIR AGRICULTURAL APPLICATIONS

Solar heated air systems have been used extensively in the agricultural sector for livestock ventilation of poultry and hog barns, in Quebec and Ontario. Other agricultural sectors that might benefit from solar heated air are crop-drying facilities. For example, solar heated air systems have been used in other countries for drying herbs, nuts, fruit, coffee, tea, cocoa and rice. The system heats the incoming ventilation air for the fuel-fired dryers. By installing a solar heated air system, burners not only get turned down, on sunny days burners are often turned off. Solar heated air systems are credited with decreasing the use of traditional fuels by up to 30 per cent.
For animal welfare, there are minimum ventilation and temperature requirements for poultry barns. Typical indoor temperature begins at around 32°C for the brooding period, and is lowered by 2 to 3°C each week, down to a temperature of between 21 and 23°C at the age of six weeks, and thereafter maintained between 20 and 25°C (BCSPCA: Standards for the Raising and Handling of Broiler Chickens). A solar heated air system can preheat incoming ventilation air by 25 to 35°C.
5 PARTICIPATING SITES

The following is a brief description of the five participating sites. The detailed feasibility studies of each property can be found in Appendix A.

5.1 FARM #1: DAIRY OPERATION

- Site description: Dairy has about 100 cows and produces 620,000 litres of milk annually.
- Location: Rosedale, B.C. (Fraser Valley)
- Heat needs: Dairy uses an estimated 3,300 litres of water at 82 C per day for cleaning and sterilization.
- Cooling needs: Dairy cools milk down to 4 C from 37 C, and stores milk at 2.2 C.
- Most appropriate technology: Solar hot water.

5.2 FARM #2: ROSE GREENHOUSE

- Site description: Floriculture operation has 1,000 square metre greenhouse and harvests about 300 rose stems a day, year-round.
- Location: Coldstream, B.C. (North Okanagan)
- Heat needs: Greenhouse uses radiant water space heating from November until the end of June with a supply temperature of 82 C.
- Cooling needs: None.
- Most appropriate technology: Solar hot water.

5.3 FARM #3: CHERRY ORCHARD AND PACKING

- Site description: Orchard and packing facility packs over 600 tons of cherries in an 8 week period starting around mid-July.
- Location: Kelowna, B.C. (Okanagan Valley)
- Heat needs: None.
- Cooling needs: Cherry packing facility uses cold water to cool cherries in three stages. Cold water temperature demand of 8 to 10 C; 4 to 7 C; and 0 to 2 C.
- Most appropriate technology: Solar chilled water for initial chilling (8 to 10 C).

5.4 FARM #4: CO-OPERATIVE PRODUCE/POULTRY/DAIRY FARM

- Site description: An 18-hectare farm that produces a variety of commodities including goat milk and milk products, eggs, fruits, vegetables, herbs and food products. In 2011, the farm's cash receipts added up to about $16,000. There is a 320 square metre propagation greenhouse, which is unheated and naturally vented.
- Location: Salt Spring Island, B.C. (Vancouver Island/Gulf Islands)
- Heat needs: Dairy uses an estimated 4 litres of water at 60 C per day for cleaning and bottle washing.
- Cooling needs: None.
• Most appropriate technology: Solar hot water, but only if residence is included.

5.5 FARM #5: BOUTIQUE WINERY

• Site description: Winery produces over 50,000 cases of wine annually and operates a wine shop and full-service restaurant that seats about 114 persons (open daily for lunch and dinner). Operation is open year round.

• Location: West Kelowna, B.C. (Okanagan Valley)

• Heat needs: Winery restaurant uses an estimated 9,080 litres of water at 60 C per day for cleaning. Also, some hot water used in winemaking process to wash barrels. In addition, restaurant requires 830 cubic feet per minute of preheated ventilation air.

• Cooling needs: Winery uses chilled glycol to control temperature of wine during fermentation. Glycol temperature demand of –3 to –10 C.

• Most appropriate technology: Solar hot water and solar heated air, but only if restaurant is included.
6 BENCHMARKS

One of the main goals of this study was to develop benchmarks to help individuals and groups in B.C.'s agricultural sector to make informed decisions regarding the financial viability of solar-thermal systems (namely hot water, chilled water and heated air) for agricultural and agri-food operations.

To determine conditions required to make the proposed solar-thermal systems financially viable three scenarios were investigated:

1) What does the minimum price of fuel have to be?
2) What one-time upfront capital payment does there need to be?
3) What renewable heat incentive does there need to be?

The return on investment for scenarios one and three above was set at 10 per cent and for the capital payment scenario a 5 per cent return on investment was deemed reasonable in relation to operator's reduced capital cost and the associated risks.

The method used to determine the financial requirements for viability was the Chabot profitability index (CPI). This index is defined as the net present value of the sum of the discounted energy bills over \( n \) years of operation divided by the initial investment cost. This method was developed by Bernard Chabot, French engineer and energy economist. Based on analysis of different business sectors it was found that the profitability index of successful renewable energy investment projects should be at least 0.3 and this is the standard value used for the CPI method.

The CPI method was used by Paul Gipe, a respected authority on feed-in tariff policy, when making his recommendation to the Ontario Sustainability Energy Association in regards to proposed pricing for the development of a feed-in tariff program for wind energy. Additional information on the CPI method can be found online at www.wind-works.org.

The following notes apply to the financial analysis carried out in this study.

- The dollar year for this study (year to which all cash flows are converted and reported) is the current 2012 year.
- Useful life of investment 25 years.
- Analysis period 25 years.
- Annual rate of inflation of 2 per cent.
- No salvage value assumed for investment.
- Analysis carried out on a pre-tax basis.
- CPI = 0.3

Financing charges for the cost of capital have not been included due to the numerous variables such as interest rate obtainable, amount financed, term of financing etc.

Capital costs used in this study are estimates only, based on Stantec's past experience in the development of solar hot water projects throughout B.C., as well as, from information provided by individual parties including equipment supplies and installers. All capital costs include labour, materials and permitting for a fully operational solar-thermal system.

Typical solar hot water systems include collectors, storage tank, pump, controller, piping, valves and miscellaneous parts. The budget cost of $1,800 per square metre of flat plate collector is an established industry standard from numerous installations.
The same cannot be said for solar chilled water systems. There are no established budget costs for this type of system because there have been so few installations in Canada. According to Yazaki Energy Systems, one of the largest suppliers of solar-thermal cooling systems in North America, only one of its systems has ever been installed in Canada, and that was in a building for the 2010 Vancouver Olympics. More of a demonstration project, the system was under-sized and has never worked properly. Most solar chilled water installations have been for office buildings in the United States. We found no examples of solar chilled water systems being used in the agricultural sector.

However, all solar chilled water systems share common components with a solar hot water system (collectors, storage tank, pump, controller, piping, valves and miscellaneous parts). Additional components required for a solar chilled water system include, but are not limited to, a cooling tower, a buffer tank, more pumps, more pipes and more valves. The costs of these additional components are a variable that depends on the required cooling capacity (in tons and the more tons required, the cheaper per ton cost). As such, for a 70 kW (20 ton) system, the budget cost is estimated to be $2,350 per square metre of flat plate collector.

On the other hand, solar heated air systems have been extensively used in the agricultural sector. Enerconcept Technologies, a Canadian manufacturer of solar heated air systems, reports hundreds of these systems have been installed in poultry and hog barns, in Quebec and Ontario, for livestock ventilation. Other agricultural sectors that could benefit from these systems are crop-drying facilities. Typical solar heated air systems include collector and intake fan. Another Canadian manufacturer of solar heated air systems, Conserval Engineering Inc., provided a budget cost of $300 per square metre of collector. Ductwork to connect the system is not included in the estimate because this cost is more variable and depends on where existing ventilation equipment is located in relation to the south-facing collector.

6.1 SOLAR HOT WATER

Of the five sites participating in this study, two had solar hot water loads that warranted investigation. Farm #1 had an estimated load of 3,300 litres of water at 82 C per day; and Farm #5 had an estimated load of 9,080 litres of water at 60 C per day (both use natural gas to heat water).

Due to the average low price of natural gas in B.C. of $9.23/GJ this study concludes that to make a solar hot water system financially viable requires one of the following conditions to be met:

1) The price of natural gas would need to increase to between $21.50/GJ to $25.00/GJ based on a 10 per cent return on investment (refer to Figure 20); or

2) A one-time capital cost rebate of between $800 to $825 per square metre of installed flat plate collector (about 45 per cent of total cost of installation) would be needed based on a 5 per cent return on investment (refer to Figure 21); or

3) A renewable heat incentive of $0.045/kWh to $0.054/kWh of heat energy produced over a 25-year period would be needed based on a 10 per cent return on investment (refer to Figure 22).

Furthermore, this study concludes that for agricultural or agri-food operations who currently meet their daily hot water demand using either electricity or propane, it is financially viable today to install a solar hot water system based on the average price of electricity and propane in B.C. of $0.087/kWh and $0.55/L respectively. In other words, no capital cost rebate or renewable heat incentive would be required for these situations.
Figure 20. Scenario #1 Minimum Price of Fuel Requirement

Figure 20 summarizes the minimum energy price, by fuel type, that is needed to make the proposed solar hot water systems financially viable today (shown in $/kWh for visual comparison).

For Farm #1, the cost of natural gas would need to increase from $9.94/GJ to $25.00/GJ; and for Farm #5, the cost of natural gas would need to increase from $8.87/GJ to $21.50/GJ. It is unreasonable to expect the price of natural gas to more than double in the foreseeable future. Hence, a solar hot water system would not be financially viable for producers who currently meet their hot water demand using natural gas.

However, if an operation is currently using electricity to heat water, the financial analysis tells us it would be viable today to install a solar hot water system based on the local price of electricity (Farm #1 pays $0.090/kWh; and Farm #5 pays $0.084/kWh).

Furthermore, if an operation is currently using propane to heat water, the financial analysis reveals that a closer look at solar hot water is warranted. Based on results from Farm #1 study, the cost of propane would need to increase from $0.55/L to $0.61/L; but for Farm #5, the financial analysis tells us it would be viable today to install a solar hot water system based on the local price of propane of $0.55/L.
Figure 21 summarizes the one-time capital payment, by fuel type, that is needed to make the proposed solar hot water systems financially viable given today’s energy prices.

Farm #1 would need a one-time capital incentive of $825 per square metre of installed flat plate collector based on the local price of natural gas of $9.94/GJ; and Farm #5 would need a one-time capital incentive of $800 per square metre of installed flat plate collector based on local price of natural gas of $8.87/GJ.

However, if an operation is currently using either electricity or propane to heat water, the financial analysis tells us no incentive is required, that it is financially viable today to install a solar hot water system based on the local price of electricity and propane (Farm #1 pays $0.090/kWh and $0.55/L respectively; and Farm #5 pays $0.084/kWh and $0.55/L respectively).
Figure 22 summarizes the renewable heat incentive, by fuel type, that would be required over a 25-year period to make the proposed solar hot water systems financially viable given today’s energy prices. In other words, an incentive based on the amount of energy saved through on-site heat production.

Farm #1 would need a renewable heat incentive of $0.054/kWh of heat energy produced over a 25-year period based on the local price of natural gas of $9.94/GJ; and Farm #5 would need a renewable heat incentive of $0.045/kWh based on the local price of natural gas of $8.87/GJ.

However, if an operation were currently using electricity to heat water, the financial analysis tells us it would be viable today to install a solar hot water system with no incentive based on the local price of electricity (Farm #1 pays $0.090/kWh; and Farm #5 pays $0.084/kWh).

Furthermore, if an operation is currently using propane to heat water, the financial analysis reveals that a closer look at solar hot water is warranted. Based on results from Farm #1 study, a renewable heat incentive of $0.009/kWh would be required based on the local price of propane of $0.55/L; but for Farm #5, the financial analysis tells us no renewable heat incentive is required, that it is viable today to install a solar hot water system based on the local price of propane of $0.55/L.

### 6.2 SOLAR CHILLED WATER

Of the five sites participating in this study, three had chilled water loads. Farm #1 had a temperature demand of 2.2 C; Farm #3 had three different temperature demands of 8 to 10 C, 4 to 7 C and 0 to 2 C; and Farm #5 had a temperature demand of –3 to –10 C. Solar chilled water systems are limited to delivering down to a temperature of 7 C; therefore this type of system is suitable for one of the above applications.
To supplement Farm #3’s chilled water demand of 8 to 10 C with solar would require at least 200 square metres of collectors. This system would cost a minimum of $470,000 and save the farm operator a maximum of $1,000 per year. Based on these findings, this study concludes solar chilled water is not a financially viable application for this operation.

As mentioned earlier in this chapter, we found no examples of solar chilled water installations in the agricultural sector. Suitability will largely depend on the agricultural site meeting all the system requirements: minimum cooling load of 35 kW (10 ton), chilled water temperature demand at or above 7 C, and chilled water demand during July and August with preheat hot water demand for the other 10 months of the year (refer to Chapter 4 on solar chilled water system).

6.3 SOLAR HEATED AIR

Of the five sites participating in this study, one had an application for solar heated air. Farm #5 had a preheated ventilation air demand of 830 cubic feet per minute (cfm). This system would cost about $5,700 and save the operation a maximum of $272 per year. Based on these findings, this study concludes solar heated air is not a financially viable application for this operation.

As mentioned earlier in this chapter, examples in the agricultural sector of where this technology has been successfully used include livestock ventilation for poultry and hog barns, in Quebec and Ontario. An example is Sheldon Martin poultry farm, in Quebec. This poultry farm has a 1,512 square metre barn to house 14,000 chickens and has a 19,000 cfm ventilation demand. The operation installed a 188 square metre solar heated air system on the wall of its barn (Source: SolarWall product literature).

Other agricultural sectors that might benefit from solar heated air are crop-drying facilities. While there are no examples in Canada, in other countries these systems have been used for drying herbs, nuts, fruit, coffee, tea, cocoa and rice. For example, the Sonoma County Herb Exchange, in California, dries herbs and saves 31 million Btu annually by displacing 1,230 litres of propane with solar. The agri-food facility installed a roof mounted 10 square metre solar heated air system plumbed to air intake of dryer. The system was designed to provide an average temperature rise of 12 C (Source: SolarWall product literature).

Another crop-drying example is Keyawa Orchards, in California, a walnut production and process facility. This agricultural facility dries over 12 million pounds of walnuts every year and saves 1,431 million Btu annually, corresponding to annual natural gas fuel cost savings of $13,800. The operation installed a roof mounted 864 square metre solar heated air system plumbed to air intake of the walnut dryer. The system was designed to provide 65,000 cfm of air with an average temperature rise of 17 C (Source: SolarWall product literature).

Solar heated air systems are credited with decreasing the use of traditional fuels by up to 30 per cent. For more agricultural examples of solar heated air installations visit online www.solarwall.com.
7 SELF-ASSESSMENT GUIDE

Given the many variables that influence the financial viability of solar-thermal systems, it can be a challenge to determine the suitability for a particular agricultural or agri-food operation without a detailed site assessment. However, based on known common characteristics of profitable scenarios, an agricultural or agri-food operator can use the following to judge the likelihood that a solar-thermal system will be suitable for their location.

7.1 PREDICTING SITE SUITABILITY FOR SOLAR-THERMAL SYSTEMS

Figure 23 and 24 offer a guide to predicting site suitability. The majority of agricultural and agri-food operations will likely have a combination of characteristics from both diagrams. If this applies to your operation, you should carefully weigh the benefits of potential energy cost savings (calculations in next section) against the relevant features at your site. Agricultural or agri-food operations with the potential for considerable energy cost savings and at least one of the features listed in the high likelihood circle calls for a discussion with a professional to determine if a detailed evaluation is warranted.

If your agricultural or agri-food operation has all the features of profitable systems that are listed in the High Likelihood of Suitability (Figure 23), you are likely to benefit from solar-thermal systems and you are encouraged to take further steps to evaluate the possibility of using solar-thermal technology at your site.
If your operation has all the features of unprofitable systems that are listed in the Low Likelihood of Suitability (Figure 24), it is unlikely your operation will benefit from solar-thermal systems without additional information to suggest otherwise.

**Figure 24. Low Likelihood of Solar-Thermal Suitability**
7.2 POTENTIAL ENERGY COST SAVING OF SOLAR-THERMAL SYSTEMS

The following will provide agricultural and agri-food operators with a rough estimate of the potential energy cost savings that can be expected from installing solar hot water or solar heated air at their site. While all calculations are based on a number of simplifying assumptions, the following results will provide operators with a good indication as to whether or not a proposed solar-thermal system warrants further evaluation.

### Potential solar hot water savings if currently using electricity for heating water

1) Current cost of electricity: $/kWh __________ (A)
2) Input your hot water flow rate: _________ US-gallon/minute (B)
3) Input your temperature rise: _________ Fahrenheit (C)
   (temperature of your hot water minus incoming supply water temperature)
4) Calculate thermal energy required: Multiply (B) x (C) x 500 = __________ Btu/h (D)
5) Convert Btu/h to kW: Divide (D) by 3,416 = __________ kW (E)
6) Input your estimated annual hours of hot water use: __________ hours (F)
7) Calculate annual hot water energy required: Multiply (E) x (F) = __________ kWh (G)
8) Assume a load saving of 65 per cent due to solar: Multiply (G) x 0.65 = __________ kWh (H)
9) Calculate potential electricity savings: Multiply (A) x (H) = $ __________

### Potential solar hot water savings if currently using natural gas for heating water

1) Current cost of natural gas: $/GJ __________ (A)
2) Input your hot water flow rate: _________ US-gallon/minute (B)
3) Input your temperature rise: _________ Fahrenheit (C)
   (temperature of your hot water minus incoming supply water temperature)
4) Calculate thermal energy required: Multiply (B) x (C) x 500 = __________ Btu/h (D)
5) Convert Btu/h to kW: Divide (D) by 3,416 = __________ kW (E)
6) Input your estimated annual hours of hot water use: __________ hours (F)
7) Calculate annual hot water energy required: Multiply (E) x (F) = __________ kWh (G)
8) Convert kWh to GJ: Divide (G) by 278 = __________ GJ (H)
9) Assume a load saving of 65 per cent due to solar: Multiply (H) x 0.65 = __________ GJ (J)
10) Calculate potential natural gas savings: Multiply (A) x (J) = $ __________
Potential solar heated air savings if currently using electricity for heating air

1) Current cost of electricity: $/kWh __________ (A)
2) Input your ventilation air requirement: __________ cubic feet/minute (B)
3) Calculate solar wall area: Divide (B) by 4 = __________ square feet (C)
4) Calculate annual energy savings: Multiply (C) by 41 = __________ kWh (D)
5) Calculate potential electricity savings: Multiply (A) x (D) = $ __________

Potential solar heated air savings if currently using natural gas for heating air

1) Current cost of natural gas: $/GJ __________ (A)
2) Input your ventilation air requirement: __________ cubic feet/minute (B)
3) Calculate solar wall area: Divide (B) by 4 = __________ square feet (C)
4) Calculate annual energy savings: Divide (C) by 6.75 = __________ GJ (D)
5) Calculate potential natural gas savings: Multiply (A) x (D) = $ __________

7.3 SIZING SOLAR-THERMAL SYSTEMS

Sizing a solar-thermal system is an involved process. However, Natural Resources Canada has developed a free software program called RETScreen, an Excel-based, clean energy project analysis software tool that helps decision makers to quickly determine the technical and financial viability of potential renewable energy and energy efficiency projects.

It was developed with the contribution of numerous experts from government, industry and academia. The software can be used worldwide to evaluate the energy production and savings, costs, emission reductions and financial viability for various types of renewable energy including solar hot water and solar heated air.

The software (available in multiple languages) also includes product, project, benchmark, hydrology and climate databases, a detailed user manual, and a case study based college/university-level training course, including an engineering e-textbook.

The RETScreen user manual is an integral part of the software. The user manual is a help file directly linked to each RETScreen model. The user automatically downloads the user manual help file while downloading the RETScreen software.

Appendix B contains useful information on user inputs for agricultural and agri-food operators who are interested in evaluating the potential of a solar hot water system for their operation. Of the three solar-thermal technologies explored in this study (namely hot water, chilled water and heated air), solar hot water is the best use of solar energy per square metre of installed collector and represents the greatest potential for cost effective solar energy use for agricultural operations.

For a free download of the software visit online www.retscreen.net/ang/home.php.
8 SOLAR-THERMAL SYSTEM TECHNOLOGY SUPPORT AND ACCREDITATION

While solar-thermal systems (namely hot water, chilled water and heated air) are not new technologies, they are relatively new to B.C. In B.C. there are numerous examples of solar hot water installations for residential applications; only one solar chilled water installation for a commercial building in Vancouver; and a handful of solar heated air installations in schools. There are few, if any, agricultural examples of installed solar-thermal systems in B.C. Therefore, it is important that any planned system be designed and installed by professionals who have experience in the technology and who are not simply learning on the job. It is also recommended to have a structural engineer review any aspects of the project that may have structural implications to it.

8.1 SOLAR HOT WATER

Engineers and installers should be familiar with CSA F379 Packaged Solar Domestic Hot Water Systems (liquid to liquid heat transfer) and CSA F383 Installation of Packaged Solar Domestic Hot Water Systems.

There are no specific regulatory requirements engineers have to meet to engage in the design of these systems.

Contractors should be certified installers listed under CanSIA (Canadian Solar Industry Association). For more information visit online www.cansia.ca.

There are several manufacturers of solar hot water systems including Viessmann, one of the world's leading manufacturers of renewable energy systems with manufacturing and distribution facilities around the world. For more information visit online www.viessmann.ca.

8.2 SOLAR CHILLED WATER

There are no specific regulatory requirements engineers have to meet to engage in the design of these systems.

Contractors should be certified installers listed under CanSIA (Canadian Solar Industry Association). For more information visit online www.cansia.ca.

There are few manufacturers of solar-thermal cooling systems; Yazaki Energy Systems is one of the largest suppliers of solar-thermal cooling systems in North America. For more information visit online www.yazakienergy.com.

8.3 SOLAR HEATED AIR

There are no specific regulatory requirements engineers have to meet to engage in the design of these systems.

There are no certifying bodies contractors need to belong to.

There are several manufacturers of solar heated air systems in Canada and one of them is Enerconcept Technologies of Quebec. For more information visit online www.enerconcept.com.
9 REGULATIONS, PERMITTING AND APPROVALS

There are no specific or additional regulatory and/or permitting requirements of solar hot water, solar chilled water or solar heated air systems to those required for conventional heating or cooling systems. The standard permits include a building permit, a plumbing permit, and certification by WorkSafe BC and the BC Safety Authority for any work related to electrical, gas and/or boilers.

It has been Stantec's experience on previous solar-thermal projects that solar is still a relatively new technology to many of the authorities having jurisdiction in B.C. To facilitate the permitting process, it is recommended all projects involve the authorities having jurisdiction at a very early stage to help address any concerns they may have.
10 BARRIERS TO DEVELOPMENT

This study found several barriers to the development of solar-thermal systems in B.C.'s agricultural sector.

One of the barriers is the lack of experienced consultants, contractors and authorities having jurisdiction who are familiar with solar-thermal technology. A barrier that will likely be addressed over time as the industry grows. In the meantime, as long as the market remains small, there will only be a few individuals willing to put the time and effort into the required learning.

Another barrier to the implementation of solar-thermal systems in B.C.'s agricultural sector is the seasonal nature of energy demand at these operations. For example, in one of the case studies, the agricultural operation only had an energy demand for 8 weeks of the year, during the summer. Outside of this window of opportunity, there was little, if any, heating or cooling demand, and therefore, limited opportunity to take advantage of solar-thermal technologies.

A common feature of profitable solar-thermal systems is a long duration temperature demand. This is because these systems can only generate a return on the capital investment when operating. Short duration temperature demand is the least profitable because the equipment will only operate for a limited number of hours per year, and therefore, cannot produce enough savings to overcome the installation cost. The estimated cost for installing a solar hot water system is $1,800 per square metre of flat plate collector; the estimated cost for installing a solar chilled water system is $2,350 per square metre of flat plate collector; and the estimated cost for installing a solar heated air system is $300 per square metre of collector.

Another barrier to the implementation of solar-thermal systems in B.C.'s agricultural sector is the load temperature requirements at agricultural operations. For example, in three of the case studies, the required chilled temperature demands were beyond the capabilities of the solar-thermal system. In another case study, the required high temperature demand was during winter when output of a solar-thermal system is at its lowest, necessitating a system so large it became impractical and financially unviable.

About 70 per cent of the annual energy output of a solar collector is generated over the period April to October. In other words, for a given load, a solar-thermal system that only operates in the winter will need twice as many collectors as compared to a solar-thermal system that operates year-round to meet the same load demand.

Solar collectors can only capture so much energy, and the amount depends on location, time of year and climatic conditions. For example, in Abbotsford the energy input to a square metre of south-facing collector is about 1,447 kWh annually; in Kelowna the energy input to a square metre of south-facing collector is about 1,526 kWh annually; and on Salt Spring Island the energy input to a square metre of south-facing collector is about 1,378 kWh annually.

This study concludes solar-thermal hot water systems have the highest performance potential for agricultural and agri-food operations where hot water loads exist on a consistent, daily basis all year-round. On the other hand, solar chilled water systems do not offer the same performance potential because the available solar radiation in B.C. during the fall, winter and spring season is not sufficient to drive the absorption chiller used in these types of systems. Solar heated air likely has potential for B.C. agricultural operations such as poultry and hog barns, and crop-drying facilities, however we were not able to evaluate the feasibility of this technology within a local context due to lack of study participants.
APPENDIX A – SOLAR-THERMAL FEASIBILITY STUDIES

- Farm #1 Dairy Operation
- Farm #2 Rose Greenhouse
- Farm #3 Cherry Orchard
- Farm #4 Co-operative Farm
- Farm #5 Boutique Winery
APPENDIX B – RETScreen Inputs for Solar Hot Water

RETScreen is a clean energy project analysis software tool that helps decision makers to quickly determine the technical and financial viability of potential renewable energy and energy efficiency projects. The following is a step-by-step guide to user inputs for agricultural and agri-food operators who are interested in evaluating the potential of a solar hot water system for their operation.

1) The user selects the technology under consideration, in this case solar water heater.

2) The user selects the application, in this case hot water.

3) The user enters the daily hot water use, averaged over the season of use of the solar water heater. If this value is known, it should be used here. If it is not known, the hot water use has to be estimated using energy bills and a manual calculation (see Farm #1 case study).

4) The user enters the temperature set point on existing boiler or hot water tank.

5) The user enters the number of days per week the solar water heater is used, during the season of use. Values range from 1 to 7. For example, in the case of a dairy operation that uses hot water everyday of the year, the user would enter 7. For a winery restaurant open weekends only throughout the year, the user would enter 2.

6) The user selects the type of method used to specify cold (mains) water temperature. The options from the drop-down list are: "Formula" and "User-defined." If "Formula" is selected, the model automatically calculates the temperature of the supply water from temperature data specified in the site reference conditions section at start of worksheet. The corresponding yearly minimum and maximum are shown in the next two lines. If "User-defined" is selected, the user enters the minimum and maximum supply water temperature values. If mains water comes from a deep well, of which the temperature is nearly constant throughout the year, the user should set the calculation method to "User-defined" and set the minimum and the maximum values equal to the well water temperature.

7) The user selects the type of sun tracking device upon which the solar collector is mounted. The options from the drop-down list are: "Fixed," "One-axis," "Two-axis" and "Azimuth." For agricultural and agri-food operations always choose "Fixed."

8) The user enters the slope angle of the solar collector, the angle between the solar collector and the horizontal (refer to Chapter 4, Figure 11), in degrees (°). To maximize the annual solar radiation for a system working year-round, slope equal to the latitude of the site. To maximize solar radiation in summer, slope equal to latitude of the site minus 15°. To maximize solar radiation in winter, slope equal to latitude of the site plus 15° (this slope is also suggested in cold climates to minimize snow accumulation). For fixed collectors mounted on roof and slope equal to roof slope, while this does not necessarily represent an optimum in terms of energy production, it can reduce installation costs by eliminating the need for a separate support structure, or may be more desirable from an aesthetics standpoint.

9) The user enters the azimuth angle of the solar collector (refer to Chapter 4, Figure 11), in degrees (°). In the Northern Hemisphere, the preferred orientation is facing south, in which case the azimuth angle is 0°. In the case of a solar collector mounted directly on the roof of a building, the azimuth is equal to that of the roof, which should be chosen to be as close to south facing as possible. For example, a solar collector in B.C. facing southwest would have an azimuth angle of 45°.

10) The user selects the collector type from the four options in the drop-down list: "Unglazed," "Glazed," "Evacuated" and "Other." For agricultural and agri-food operations choose glazed or evacuated (refer to Chapter 4). Then the user will be asked to choose collector manufacturer and model from the list.
11) The user enters the actual number of collectors for the solar water heating system. As a first pass, the user should use the suggested number of collectors calculated by the model in the cell to the right of the input cell, then vary the value of the number until a financial optimum is found.

12) The user enters the solar water heater miscellaneous losses as a percentage of heating delivered. This value includes, for example, losses due to the obstruction of the solar collector by snow and/or dirt. The value depends on local climatic conditions, on the tilt angle of the collector, and on the presence of personnel on-site to remove the snow or clean the collector. This value ranges between 2 to 5 per cent for evacuated tube collectors rack-mounted on flat surfaces or well-maintained collectors, and between 3 to 10 per cent for other collectors.

13) The user selects whether the configuration of the system includes storage or not. User selects from drop-down list: "Yes" or "No." Systems with storage should be considered for agricultural and agri-food operations requiring the solar water heater to provide a significant part of the water heating load. Systems without storage are typically industrial applications.

14) The user enters the desired number of litres of storage per square metre of solar collector (L/m²). The larger the storage, the better the system will be at going through long periods with little sunshine, although this will increase stand-by losses and initial equipment costs. The nominal value should be 75 L/m²; typical values range from 37.5 to 100 L/m².

15) The user selects whether or not a heat exchanger is used. The user selects "Yes" if the collector loop is separated from the rest of the system by a heat exchanger. If this is the case, the model assumes that an antifreeze fluid, such as glycol, circulates through the collector loop, thereby providing antifreeze protection to the system in the winter. The user selects "No" if there is no heat exchanger. In this case service hot water is assumed to circulate through the collector loop, and the system should be turned-off and drained whenever freezing conditions are encountered.

16) The user enters the balance of system miscellaneous losses as a percentage of heating delivered. This value accounts, for example, for heat losses from the pipes and/or the tank to the surrounding environment. This value depends on several factors. In systems without storage the only losses for this item are piping losses, which depend on the length of piping. The user should enter 1 or 2 per cent if there is a short distance between the collector and the rest of the system, and between 4 and 8 per cent otherwise. The lower values should be used for well-insulated piping and the higher values for poorly insulated piping. In systems with storage, additional heat losses from the tank have to be taken into account. The user should enter an additional 5 to 10 per cent for tank losses. The values above can be lowered if the system is used only during summer months or hot water tanks are installed in a warm mechanical room.

17) The user enters the pumping power per unit of collector area. This value is used to calculate the electricity required to operate the solar water heating system. Values ranging from 3 to 22 watts per square metre of collector (W/m²) are typical.