CHBE 492 – Undergraduate Thesis

Solar Thermal Water Heating

A Simplified Modelling Approach
&
Potential Application for CHBE

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Executive Summary

This project took a multi-faceted look at solar thermal water heating technologies, and their potential application for the Chemical and Biological Engineering building at UBC. Estimates of yearly system performance were obtained through development of a simplified modelling procedure, and indicate that such a system has the potential to supply 25% of the annual hot water heating load. System output is highly weighted towards the sunnier summer months of June through August. These results were compared with values generated from a RETScreen analysis, and found to be in good agreement. RETScreen is a renewable energy technology analysis program distributed by the government of Canada and used in over 100 countries worldwide. The development team has forged partnerships with major international organizations such as the World Bank and the United Nations Environmental Programme and is well respected as a pre-feasibility analysis technique.

Solar thermal water heating technologies have proven themselves as feasible and practical systems through several large scale installations in BC. Two notable examples are the Hyde Creek recreation center in Port Coquitlam, and the Vancouver international airport. They can qualify for up to 25% subsidy on total installed cost through the federal governments REDI program, are exempt from provincial sales tax, and qualfity towards LEED certification in new and retrofit projects. A solar thermal installation on the University campus would set a milestone for Universities in Canada, contribute towards the UBC sustainability pledge, and be an excellent demonstration project and learning opportunity for a wide range of disciplines. The most likely route to such a project would be consideration in the design phase of a new construction project. Current building are heated using steam, and already have a supply of hot water in the form of steam condensate which could be utilized in a heat recovery system very similar to what would be required as part of a solar thermal system. Hard figures on current building energy use could not be found during the timeline of this project, making a proper economic analysis of a retrofit project or a heat recovery project impossible.

Acknowledgements

There are many people who deserve thanks for assisting in this project. Brenda Sawada from the UBC Sustainability office has provided contacts to all the right people on campus, and made this project an official UBC SEEDS initiative. Jorge Marques of the Sustainability office has lent advice and guidance.   Aleksander Paderewski P.Eng and Richard Hugli of UBC Utilities have helped to provide what information they could on current building operation and mechanical systems. Mark Scott, building management system supervisor with plant operations, has gone out of his way to provide information whenever possible. Doug Yuen and Dave Roberts of the CHBE shop have granted access to the building plans and helped get a hold of the right people. Kevin Paquette, construction supervisor during CHBE construction, was helpful in providing details of how the buildings mechanical systems worked initially, even though he had moved on to other projects. Dr. Andy Black and Rick Ketler of UBC agroecology provided data sets from their climate monitoring station located at the UBC farm. Morgan Macdonald from Taylor Munro Energy Systems designs systems like this for a living and has been helpful. Thanks also to the British Columbia Sustainable Energy Association (BCSEA), CHBE Sustainability club, and Thermo-Dynamics Ltd®. Finally, I would like to thank my supervisor, Dr. Naoko Ellis for providing both an open learning opportunity and guidance when needed on all aspects of assembling this project, and my co-supervisors, graduate students Alan Illic and Alex Bauer.

Table of Contents

List of Figures

List of Tables

List of Equations

1.0 Introduction

The sun has been a powerful presence and force throughout the history of human existence on earth. It has been regarded by many cultures as a god of one form or another, and understood by most to be the ultimate source of life on this planet. It has also been intentionally exploited by many clever means over the centuries, in order to better utilize this life giving energy. As far as renewable energy sources go, the sun represents the best and most stable we have. It is infinite with respect to all practical timescales, immensely powerful, understood and predictable in its overall trends and patterns, and for the foreseeable future beyond anthropogenic effects. In short, the perfect energy source; but it is not without difficulties.

Harnessing the sun as a clean and renewable source of energy has proven to be a challenge over the centuries, and in modern times has fallen off in favour of other technologies which are easier to commercialize and capitalize on. The last few decades have shown exponential increases in the energy demands and consumption patterns of many countries, who have opted to meet this challenge with more conventional means such as fossil fuels. However this attitude is beginning to change and we are coming to realize our habits must evolve towards lower impact, both for the good of our planet and ultimately ourselves. Research into solar technologies has been quietly progressing for decades, and these technologies, generally summarized below, are ready to take on greater roles in a more energy aware society.

1.1 Current Solar Energy Systems

Solar technologies are commonly grouped into three major categories, generally differing in the ways they collect, store and use energy. They are passive solar, solar thermal, and photovoltaic systems; listed in approximately the order of sophistication and inherent complexity involved.

Passive solar systems involve direct utilization of the suns radiation as light or possibly heat. Examples include energy efficient windows, skylights, greenhouses, and hybrid lighting fixtures[1], which use fibre optic cable to transmit sunlight into interior rooms. Next are solar thermal, which collect and use the suns energy as heat. They are different from passive heating in their ability to store thermal energy for later use. Modern applications include domestic and industrial water heating, air and space heating, radiant slab heating, and even the operation of heat pumps and stirling engines. The focus of this report is solar thermal water heating, which will be expanded on in later sections. A third category is photovoltaic cells, which functionally convert sunlight into electricity. This is desirable for low draw applications, or where hard wired electricity is impractical or too expensive. Examples include electronic road signs and help phones, sail boats, and the space station.

1.2 Project Goals

The goal of this project is to conduct an investigation into solar thermal water heating systems, and to be able to relate findings to their potential application for the Chemical and Biological Engineering building on the UBC campus, and beyond. To get at this, a pre-feasibility analysis will be conducted using RETScreen software; as well a simplified modelling approach will be developed and the final results compared in terms of energy production. An investigation into current hot water heating methods at UBC, including benchmarking of current energy use and system operational parameters is also looked at.

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[1] http://www1.eere.energy.gov/solar/solar_lighting.html

2.0 Overview of Solar Thermal Water Heating

Modern systems designed for capturing the suns energy and transferring it to water, either for immediate use or as a storage medium, have been studied and put to use since the 1970's, when they were first used for pool heating in California. Continued research and innovation has resulted in products feasible in much colder and less sunny climates today.

A schematic diagram of a basic residential solar thermal water heating system is shown in Figure 1. In addition to an existing conventional hot water heater, the main components are a solar collector panel and an insulated storage tank and heat exchanger. These are integrated in Figure 1; however, a tank with external heat exchanger could also be used, and such systems are currently on the market. Also shown is a small electric recirculation pump powered by a photovoltaic (PV) panel, the advantage being a system that does not rely on external energy for operation. Strictly speaking, however, the pump can be powered by any means, and often, large scale installations require much larger units than a PV panel can power.

Basic system operation involves the pump circulating a heat transfer fluid, typically water or a food safe water/glycol mix, through the solar collector for heating. This hot liquid then passes through a heat exchanger where it warms up cold feed water before being re-circulated back to the roof. The cold feed water remains in this storage tank, constantly being heated while the system is operational, until required. As water is drawn from the existing hot water heater it is replenished with warm water. In this way the solar thermal system acts as a pre-heater and reduces load on existing hot water heaters but does not replace them. This coupled arrangement saves energy and also ensures a constant supply of hot water at the desired temperature.

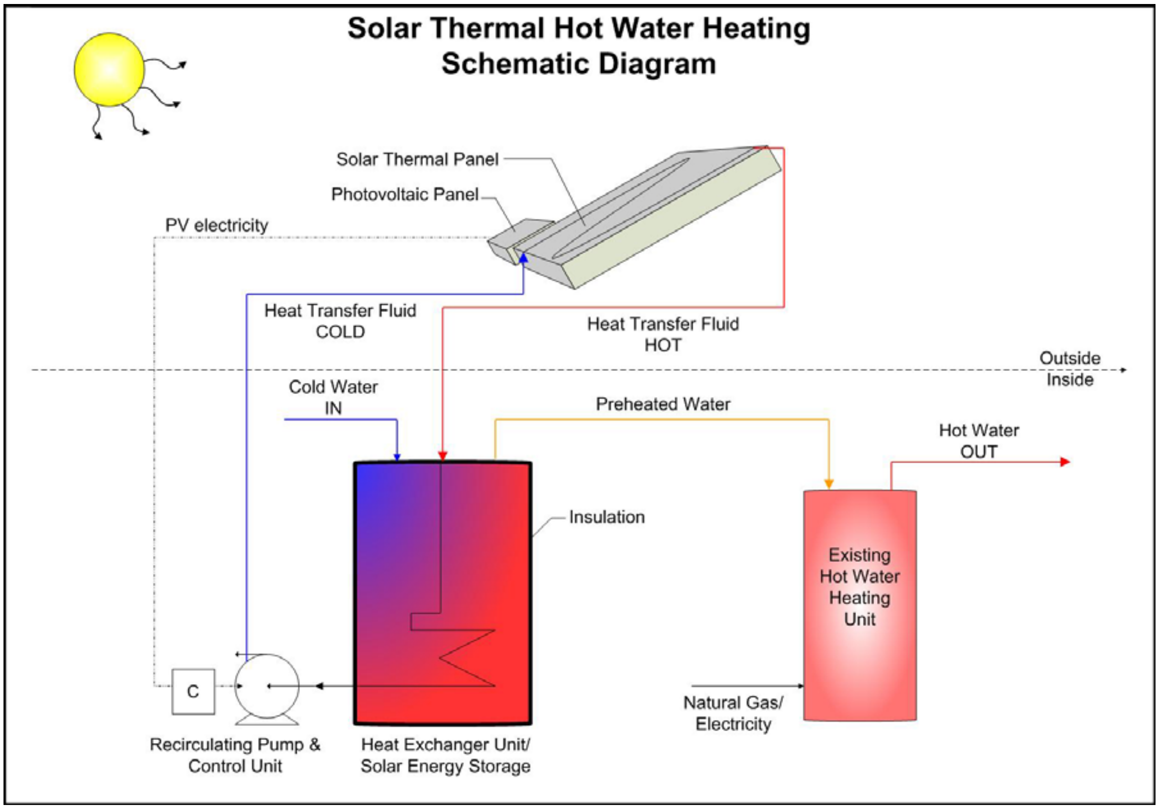

Figure 1 - Schematic diagram of a solar thermal hot water heating system

A very clever pumping design by Thermo-Dynamics Ltd® of Nova Scotia involves a photovoltaic cell and variable speed pump, such that the circulating flow rate is proportional to solar flux. This is a simple way of ensuring efficient performance.

A key feature of these systems is that they are modular and scalable. Large installations simply have more panels than smaller ones, with necessarily larger heat exchangers, pumps, and pipes. The principle of operation does not change.

In cold climates anti-freeze protection is a necessary component of system design, and is often accomplished using a drain back setup. A small tank located inside collects heat transfer fluid, which flows back out of the panel when the system is not operational such as a cold, cloudy day.

3.0 Hot Water Heating in CHBE Building

The University of British Columbia's new Chemical and Biological Engineering Building (CHBE) has been occupied by students and staff for over two years. Current water heating practices involve a combination of space heating, potable, and laboratory water. The ultimate source of thermal energy is steam from UBC Utilities at the other end of campus. The space heating loop uses steam to produce hot water for use in radiant space heaters throughout the building. While no hard figures are available, utilities *unofficially* estimates that approximately 85% of the winter water heating load is used for building heat, while the summer fraction is essentially 0. The potable and lab water loops also use steam, and are illustrated in Figure 2. Temperatures given are approximate and represent reasonable operating range, as exact measurements could not be taken during the duration of this project.

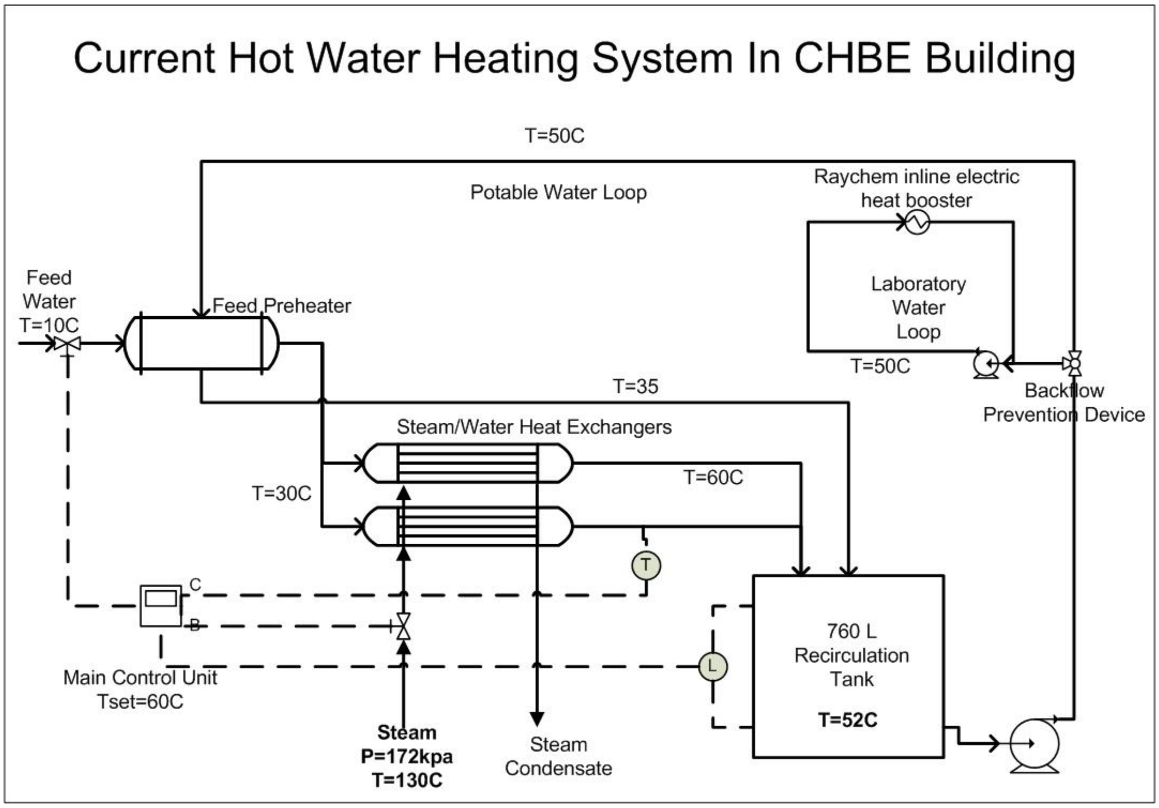

Figure 2 - Potable and lab hot water heating in CHBE (temperatures approximate).

Both potable and lab water share a common origin. Lab water branches off and is isolated from the rest of the system by a series of backflow prevention valves, which eliminates cross contamination of the supply. Water is kept in motion by a recirculation pump and temperature is maintained via a Raychem® inline electric heat booster which is controlled and monitored in the 3rd floor janitor's closet.

The potable water loop is kept in continual circulation such to avoid stagnation, minimize cooling in the pipes, and ensure instant flow of hot water at all faucets. This system is a multi-step process. Cold feed enters and is passed through a pre heat unit, where hot water returning from the upper floors is used to warm the feed. It then enters into a shell and tube style, steam to water heat exchanger and is brought up to 60°C. Both this water and the circulating load flow into a 760 L tank and from there the cycle begins again. This process is controlled based on tank level and heater outlet temperature to control the feed water and steam rates.

The potable and lab water systems are believed to be designed for heating 7600 L of water during one standard 8 hour work day, with a peak daily flow of 1900 L/hour. Operational values could not be confirmed, as utilities only monitors total water and steam flow rates and has no way of separating heat and potable loads. Also, temperatures are not required to be monitored with the exception of heater outlet, and so those listed in Figure 1 are reasonable guesses. We know for certain the pressure of steam entering the building since it passes through a standard pressure reducing valve when entering the building, and the hot water set point of 60°C. All other data is known in terms of sensor percentages and valve positions. In theory these could be used for indirect relations to process operation, but would produce rough estimates at best.

4.0 RETScreen Analysis

RETScreen stands for Renewable Energy Technology, and is a software tool made available internationally and free of charge by the government of Canada. It is currently used in over 100 countries throughout the world, and cracked the 100,000 user milestone this past March. A core team of engineers has been responsible for program development since its conception in the 1990's, working through Natural Resources Canada's CAMNET energy research and innovation facilities. The RETScreen team works directly with over 150 academic and industry contributors to ensure up to date information in a wide range of rapidly changing fields related to renewable energy. In addition, it has partnerships with many international organizations such as the World Bank and United Nations Environmental Programme.

The goal of RETScreen is to encourage and facilitate renewable energy and energy efficiency projects throughout the world. The program is a decision support and planning tool for use by politicians, technical staff, decision makers and others. A recent survey of users determined that its two primary functions were in project analysis (49%) and project development (27%). The same survey has also shown that between 1998 and 2004 RETScreen was used in some capacity during the development of renewable energy projects with a total installed capacity of 1000 MW worldwide and 320 MW in Canada alone. These projects have totalled $1.8 billion[2] and $750 million, respectively, saving some $600 and $240 million in energy costs, and with GHG emissions reductions of 630 kT CO_2/year and 130 kT CO_2/year.

An interesting case study is the Central American Bank for Economic Integration (CABEI) which used RETScreen in a due diligence analysis for a new 6.5 MW hydroelectric installation in Honduras before approval[3]

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[2] All dollars in CDN.

[3] RETScreen® International: Results and Impacts 1996- 2012, p 6.

The program itself takes the form of a series of Microsoft excel spreadsheets. Each spreadsheet contains a series of workbooks where project details are entered, as well as links to multiple databases with detailed information on relevant equipment specifications, costs, physical parameters, weather statistics and more. The range of topics currently covered by RETScreen sheets include wind power, small hydro, photovoltaics, biomass to heat, solar air heating, solar water heating, passive solar, and ground source heat pumps. Online help and engineering reference manuals, as well as a live help forum moderated by RETScreen staff and industry professionals are also available for use.

4.1 Solar Water Heating Analysis

The module used for the purpose of this project was for solar water heating. For our purposes there were two main worksheets, the energy model and solar resource and load information, requiring information on weather, load, and system configuration.

Climate data is automatically retrieved from an online data base for the weather office selected. Vancouver international airport was chosen for its proximity and similarity to the UBC campus. Monthly average daily solar radiation (w/m^2) and monthly average daytime temperature (°C) are the key numbers. Relative humidity and wind speed are also included but not used in energy calculations with the style of panel we are using.

Heating load data includes an estimate of daily hot water use, desired final temperature, days per week the system will operate, and inlet feed water temperature. These values are used to determine yearly energy demand for hot water heating. The design value of 7600 L/day was used, along with 7 days/week operation. This is based on my experience as an undergrad, with the building being occupied most weekends, especially near exams. Feed water can either be left as the default, or user defined. City of Vancouver water temperatures, which vary between 6°C and 16°C annually as given in Appendix I from a 2005 water quality report, are used.

Certain system specifications must also be entered, which involve basic engineering and preliminary system design. Based on the required heating load, RETScreen decided upon a 40 panel system. This is based on the smallest system that could potentially supply all of the required heating load if operating at 100% efficiency and capacity. In this manner RETScreen will not automatically oversize any system. A survey of the CHBE roof also concluded that 40 panels could potentially fit, so this number was used. Rough calculations are shown in Appendix II. Panels were selected to be TDL G32 series, manufactured by Thermo-Dynamics Ltd. ® out of Dartmouth, Nova Scotia. They were selected on the basis of a strong company reputation, and on operating a very informative website which could be used as an information resource during later stages of the project.

Based on general rules of thumb[4], the panels were oriented due south and at an angle of 45° to the horizon, approximately equal to the latitude of Vancouver in degrees. Panels in the northern hemisphere should always be oriented due south except when specific installations prohibit this, such as flush mounting on a roof that does not face due south. Setting the angle against the horizon approximately equal to the locations latitude has been found to provide excellent, year round performance. Storage tank size is also required, and the current 760 L tank was at first chosen to minimize extra equipment and cost. The analysis was also done using a much larger storage tank with a volume of ~11,000 L, the maximum recommended size in RETScreen. Finally a heat exchanger efficiency of 85% was chosen, which is on the high end of the recommended range in RETScreen but definitely within reasonable expectations. Inefficiencies are included in the model as losses due to dirt and snow on the panel, as well as thermal pipe and tank losses. Each was set at 5%, mid way in the recommended range of up to 10%.

Copies of these two excel spreadsheets can be found in Appendix III.

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[4] Designing a Commercial Solar Heating System.

4.2 Results

Based on the above inputs, energy calculations in RETScreen yield the numbers listed in table 1:

Tank Size (L)	760	11,000
System Capacity ($KW_{th)}$:	78	78
Specific Yield (kWh/m^2):	305	460
System Efficiency (%):	23	35
Solar Fraction (%):	23	34
Renewable Energy (MWh):	36	55
	130 GJ	196

Table 1 - Summary of RETScreen system analysis

System capacity is based on a 2004 recommendation of the International Energy Association (IEA), stating that for overall energy statistics the installed capacity of a system can be given by its installed area multiplied by 0.7, and stated in units of thermal kW[5]. Solar fraction refers to the total fraction of heating load that can be supplied by solar energy, in the first case 23% and equivalent to 36 MWh or 130 GJ. System efficiency is the fraction of total yearly solar radiation that is converted into usable thermal energy, equal to 23%.

As can be seen, the RETScreen model is relatively sensitive to storage tank size. The physical effect of this tank is storage of thermal energy so that differences between supply and demand are buffered, allowing the system to utilize a greater portion of total thermal energy. Figure 3 shows the effects of this tank on a monthly basis. Of particular note is that in winter months, this model predicts a larger tank is required to extract any useful energy. The basis for this condition is there is not sufficient residence time for water to heat up in the small tank, before it passes through and is used.

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[5] Referenced to RETScreen Online user guide. Originally referenced to IEA SHC 2004.

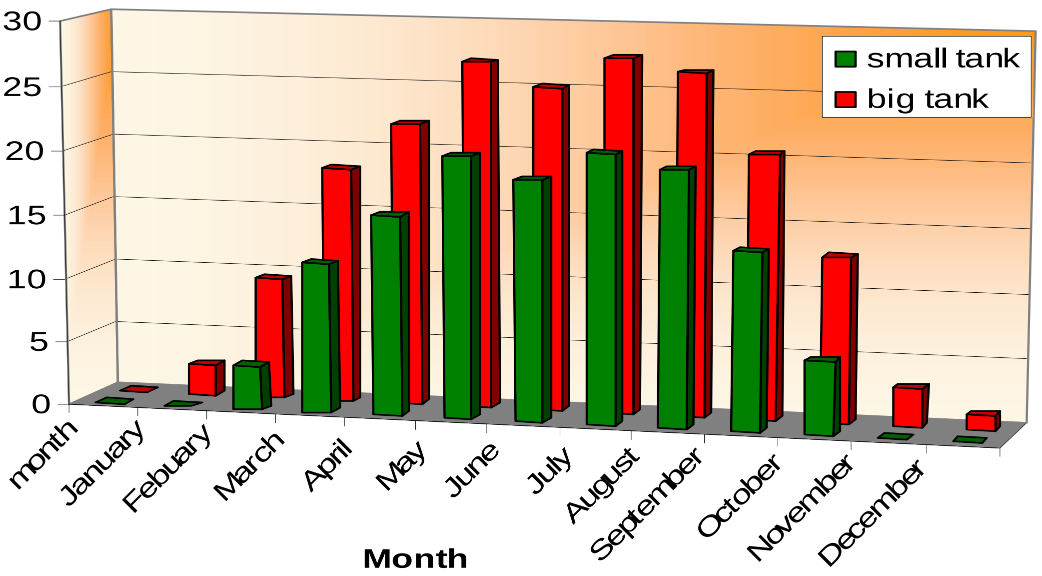

Figure 3 - Monthly energy production related to storage tank size

Also notice there is a dip during the month of June. This is simply due to the available weather statistics for Vancouver showing both May and July as sunnier months than June. People living in Vancouver have split opinions on whether this is true or not, but it is statistically shown.

One of the strengths of RETScreen we were not able to utilize was its capacity for economic analysis. While some system components were able to be priced out accurately, cost analysis is based on current base case energy consumption, which was impossible to determine, and therefore made meaningful economic analysis virtually impossible at the time.

5.0 Simplified Modelling Approach

Computational methods related to solar thermal processes generally fall into two categories; design procedures and simulation techniques. Design procedures include methods such as the utilizability-Φ, or f-chart methods, and are used for predicting long term performance on a monthly basis, such as in RETScreen. They are useful due to the low levels of input data required and their computational simplicity. Simulation techniques include programs such as WATSUN and TRNSYS, both developed for research purposes[6]. These work by rigorously solving the governing equations for each component in the system, and work is being done improve their flexibility by adding more modules for equipment like tanks and heat exchangers. They require detailed input parameters for weather and heating load and are computationally intensive, but provide dynamic system responses to various inputs allowing for sensitivity analysis and process control design amongst other things. Vast improvements to desktop computing power in the last decade have made these tools available and practical for the system design engineer, and spurred the patent holders to extract fees for program use.

In 1985, Elasfouri and Hawas[7] developed a simplified model for simulating dynamic performance of solar thermal systems, in an attempt to fill the computational gap between design method and the current simulation techniques which were impractical for many researchers to use due to available computing power. Their main simplifications involve component parameters, input metrological data, and solution methods. Their work was motivation for the simplified modelling approach described below.

A full list of nomenclature, including physical meanings and units can be found in appendix IV.

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[6] Detailed discussions of all the above methods and simulators can be found in the text by Duffie, in chaptaers 19 through 21.

[7] Elasfouri

5.1 Model Outline

Detailed metrological data is available through the Department of Agroecology at UBC, who maintain a climate monitoring station at the UBC farm. Ambient temperature and solar flux (w/m^2) in 30 minute intervals over a three year period from 2001-2004 were provided. This eliminated the need for climate assumptions. The focus of this modelling project is on panel performance and optimization, including a study of different panel array configurations, i.e., series versus parallel flow. The panels are coupled to a storage tank and heat exchanger through only a heat exchanger efficiency relationship, set to 85% for consistency with RETScreen, and ignoring any effects of tank dynamics. This also assumes the tank is well mixed and not stratified in any way. Finally a 5°C driving force temperature difference is maintained within the heat exchanger. The model loop and relevant equations are shown in Figure 4.

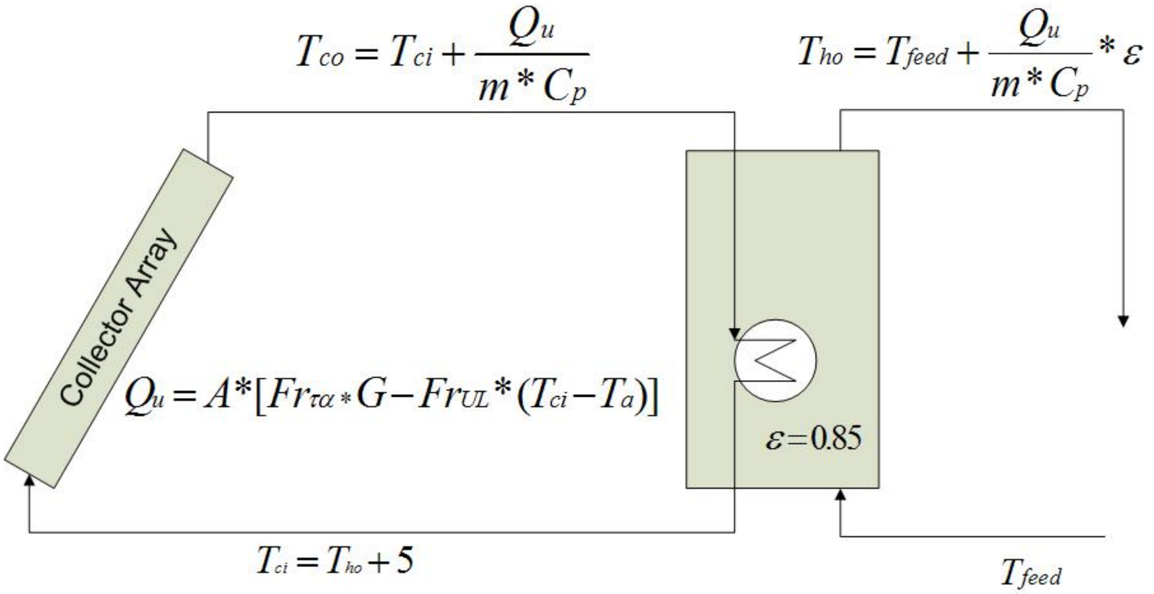

Figure 4 - Schematic diagram of simplified solar model

Temperatures in this model are derived using simple energy balances along with mass flow and heat capacity for each stream. T_{feed} is once again know. Q_u, is useful energy gain from the collector array in watts. Divided by collector area this yields specific energy gain per m^2 of panel, and again divided through by solar flux gives an expression representing panel efficiency.

The majority of solar thermal panels on the market today are tested by the Solar Ratings and Certification Corporation (SRCC), an independent and not-for-profit laboratory. It has been found that panel performance in terms of weather conditions and inlet temperatures can be accurately represented by the linear equation shown as Equation 1. In this equation Q_u is the useful thermal energy in watts. A is the area of the collector in m^2, and G represents solar flux in W/m^2. T_{ci} is the fluid inlet temperature and T_a is the ambient temperature, both in Celsius. $Fr_{\tau\alpha}$ is a number between 0 and 1 representing a solar absorptivity coefficient, essentially giving the upper limit of panel efficiency. Fr_{UL} is the thermal loss coefficient in units of W/m^2 °C. In some instances a higher order differential equation has been developed to describe performance based on the same parameters. This is almost always converted into the linear form found below which has been found over time to be within acceptable accuracy limits[8].

$$Q_u = A*[Fr_{\tau\alpha} * G - Fr_{UL} * (T_{ci} - T_a)]$$

Equation 1 – Empirically derived description of collector performance

Both empirical coefficients can theoretically be derived from first principles and a knowledge of panel construction, but this is rarely done in practice. Rather, the values are determined by the SRCC and made available through a variety of sources including SRCC documents, manufacturer websites and the RETScreen database. The main utility of these equations today is similar to the way cars are tested for miles per gallon, in that they give system designers and consumers a way to compare products from different manufacturers.

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[8] RETScreen online user manual, Technical note 1.

5.2 Flow rate Variation and Array Optimization

Consider variations in the way a set of panels can be installed; all in parallel, series, or some combination. One limiting case is 40 panels in parallel. Moving to a configuration of 20 parallel sets of 2 panels each in series will cause the flow rate in each panel to double. This increase in flow rate will decrease Fr_{UL}, hence decreasing thermal losses from the system. The governing equations are given in Appendix V. A competing effect is that the 2nd panel of each series has a higher inlet temperature, T_{ci}, than the first, causing a decrease in efficiency according to equation 1. The question is which configuration maximizes energy as a function of the interplay of these two effects.

The balance of these effects was calculated during one full day on July 2, 2003. Net energy gain is plotted in Figure 5, as a function of array configuration at two different flow rates. Sample calculations for the case of 20 groups of 2 panels at 40 l/min on July 2nd are given in Appendix VI.

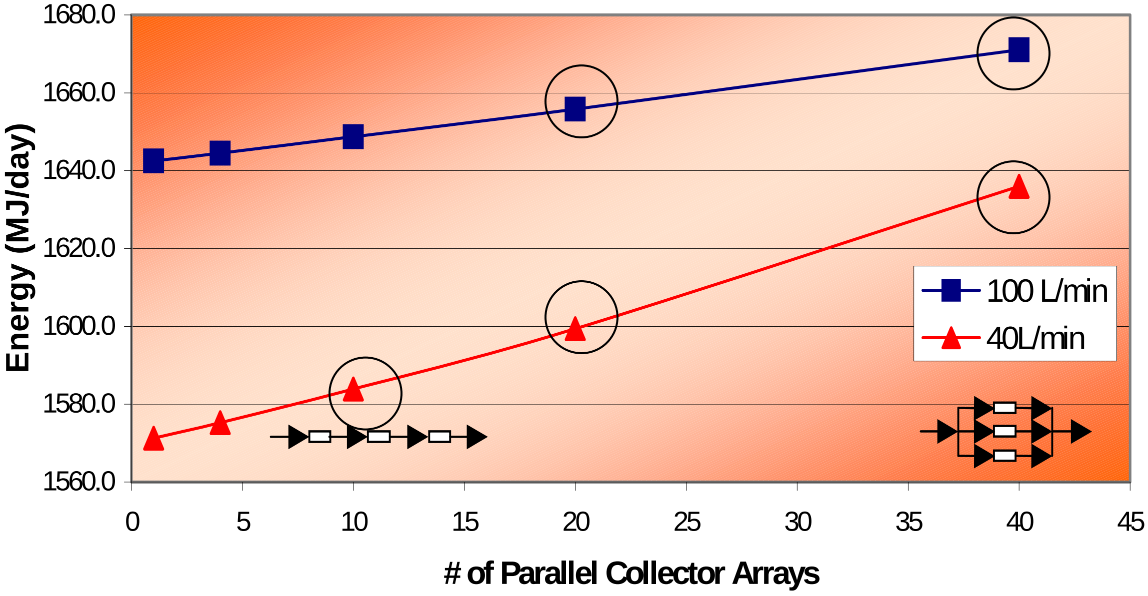

Figure 5 - Energy versus flow rate, array configuration, for a 40 panel system

The optimization curve shown is a straight line, indicating that you might want to operate at the limit of all panels in parallel. This suggests the decrease in efficiency from panels in series is dominant over the increase in efficiency from lower thermal losses. Furthermore, as the flow rate is increased from 40 L/min to 100 L/min the line becomes less steep, suggesting that at increased flow rates the effect of Fr_{UL} is more important but not yet dominant. A practical limit is that only the circled data points above correspond to realistic flow rates. With too many panels in series, the flow rate can exceed maximum operating limits.

Practically speaking, the difference between maximum and minimum in Figure 5 is only on the order of 6-7%. While the relative trends noticed are reasonable, the absolute changes noticed are insignificant. In all examples of large installations, the array has been set up with several parallel sets of 3-5 panels in series. The benefit of such an arrangement is higher exit temperatures for the heat transfer fluid, and hence better downstream heat exchanger performance. Simply put, it is better to have a smaller volume of hotter fluid.

5.3 Single year net energy production.

Vancouver’s solar resource is characterized by strong seasonal variation. Our model was used to calculate the highest solar flux day of each month, in order to gain an understanding of what seasonal performance variations could be expected. Here an iterative calculation was required in order to converge temperatures coming out of the heat exchanger. An estimate of T_{ci} was made and the net daily energy production was determined, and this energy total was used to calculate the possible temperature increase for 7600 L of feed water, again on a daily basis. T_{ci} was then adjusted in order to converge with the predicted preheat water outlet temperature. A sample of this calculation is given in Appendix VII. In this way our model ignores the effect of tank size and assumes all energy extracted by the solar panels is useful, and simply multiplied by a heat exchanger efficiency. Figure 6 plots feed temperature along with inlet temperature of the solar collectors and the pre-heated water temperature, kept at a 5°C difference. The 3 months of June through August show little variation in T_{ci} and T_{ho}. Water enters the system at ~15°C and is brought up to 50°C, representing approximately 80% of the water heating load. Between January and May, and again between September to December, performance decreases approximately linearly, and in the peak of winter the maximum attainable temperature rise is only on the order of 10°C.

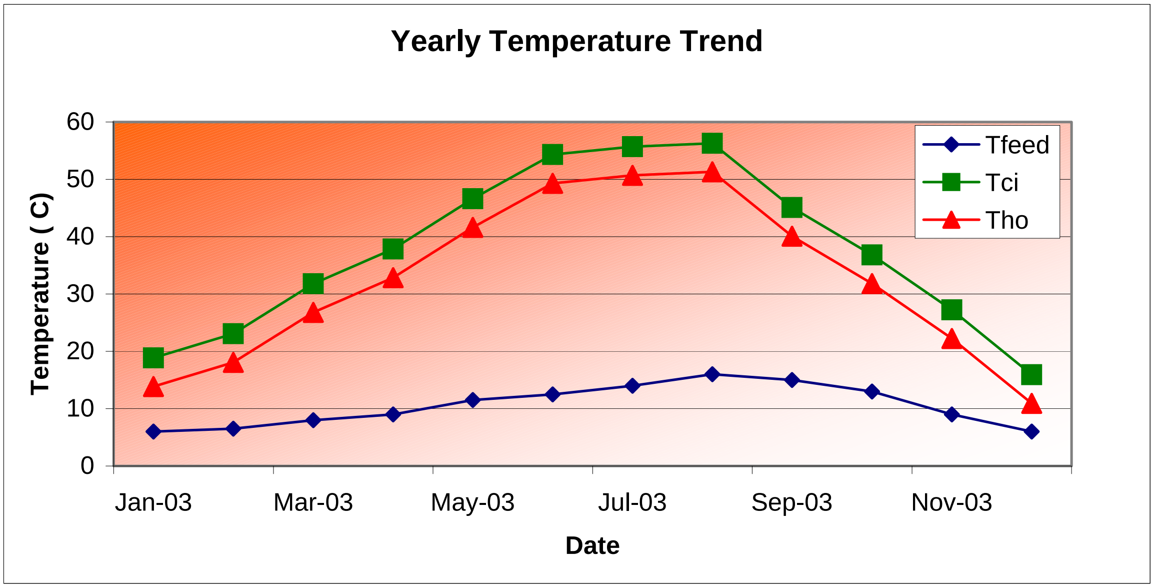

Figure 6 - Yearly temperature trend based on sunniest day of each month

Solar flux in summer months is relatively more constant than in winter months. So while the temperature rise indicated above is a good estimate of summer performance, winter performance will be somewhat less. Figure 7 shows the daily variation in solar flux for the month of January, indicating that over half of the days are well below values the above temperature was calculated at.

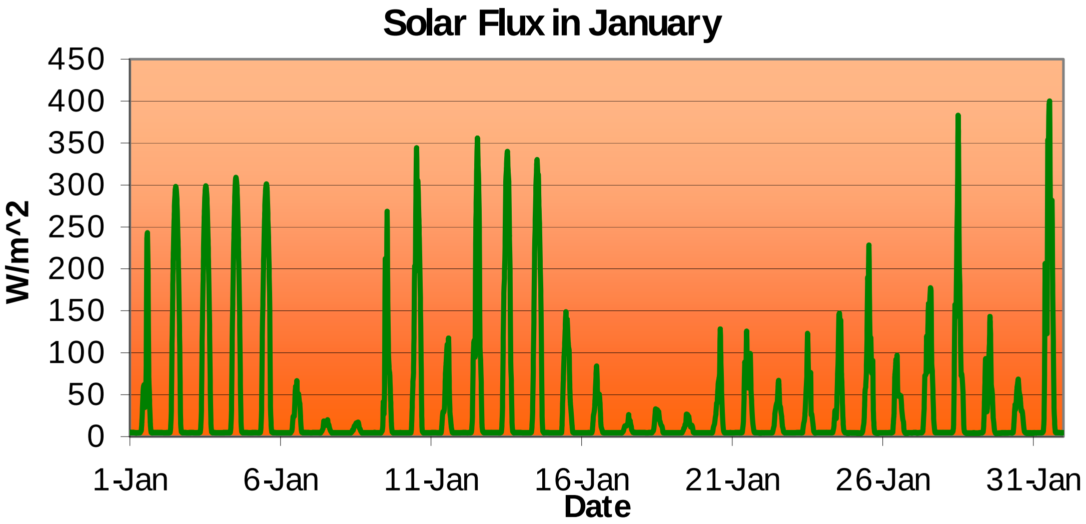

Figure 7 - Daily variation in solar flux for the month of January

The next computational step was to determine system performance over the course of an entire year. An array configuration of 10 groups of 4 panels in series was chosen as described above. A major assumption in this calculation is that the panel inlet temperature remains constant on a monthly basis, and is set at the monthly values of T_{ci} given in Figure 6. This has several ramifications. First of all, it eliminates the need to perform iterative calculations for each data point during the year. It also produces a very conservative estimate of system performance as described below, even though this statement is at first counter intuitive.

Consider Equation 1, where panel performance is inversely proportional to inlet temperature. At any time, this inlet temperature is proportional to solar intensity, such that on sunny days the system operates at higher temperatures. If that operating temperature remains constant but the panel receives less sun it will operate at less than its most efficient. The operating temperature will tend to move towards a lower equilibrium value with lower sun levels. So even through the plot of temperatures above is a best case scenario for each month, using the given T_{ci} values will produce a final result that is very conservative.

With the above assumptions in place, the model was used to calculate energy output for every data point during one full year, and the results summarized by month and year. After including the 85% heat exchanger efficiency and 10% inefficiency for optical fouling and thermal losses, our model predicts 156 GJ of renewable energy produced, approximately equal to 26% of the yearly heating load. Sample calculations are given in Appendix VIII. In an attempt to simplify this data set, all points that did not correspond to the minimum solar flux required to activate the system were filtered out. Monthly breakdown is shown below in Figure 8, and can be seen to follow closely the temperature curve of figure 6. It also approximately follows the RETScreen distribution shown in Figure 3. What this figure indicates is that the 6 winter months from October through March contribute approximately 26 GJ of renewable energy, or 17% of the yearly energy production of the system.

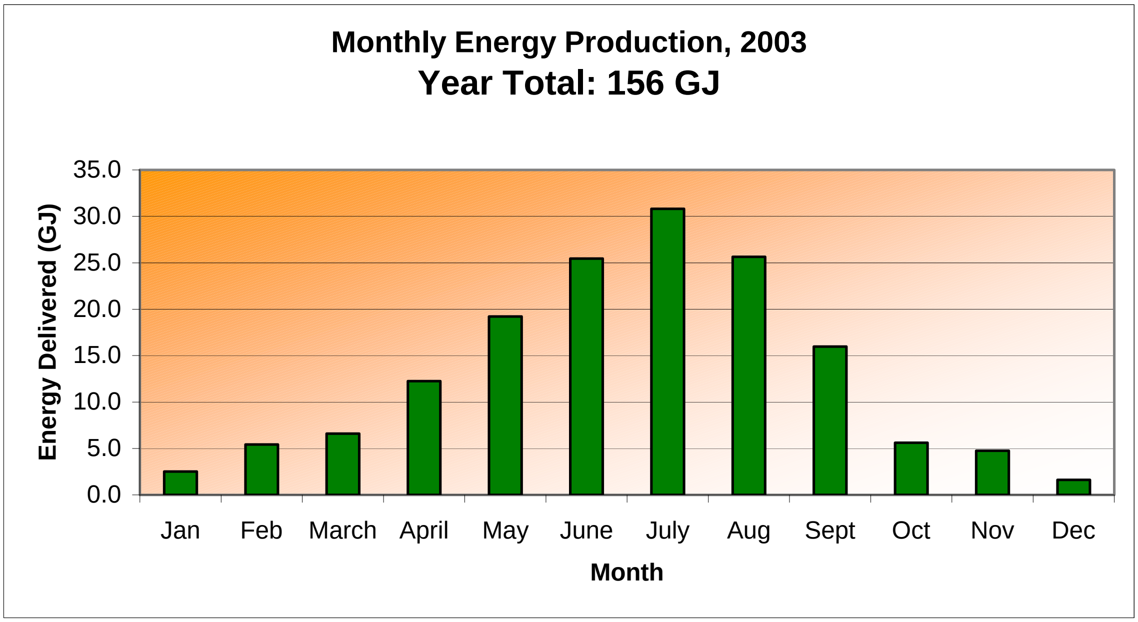

Figure 8 - Monthly distribution of renewable energy production

6.0 Comparing Results

RETScreen is a feasibility analysis tool which uses the f-chart design method to predict monthly performance for a solar thermal system. This involves seemingly simple calculations using a few key input parameters and monthly average weather data. However the f-chart method which is used actually calls upon the results of a large number of simulations conducted in the past, and the method is anything but simple even though final calculations are easy by comparison. The modelling approach taken in this report uses a detailed metrological data set, relatively simple equations to describe system performance, and energy calculations done on an hourly basis. Given all of the inherent assumptions and simplifications mentioned previously, these two approaches give remarkably similar results, as shown in Table 2.

Calculation Type	**Energy Delivered (GJ)**
Simulation	156 GJ
RETScreen – existing tank	130 GJ
RETScreen – very large tank	198 GJ

Table 2- Comparison of RETScreen and simulation results

One important factor our model did not consider was the effect of storage tank size on system performance. Solar flux and load profile generally do not match, and a storage tank is needed to buffer supply and demand. This buffer is often the storage and preheat tank. The larger this tank, the better the system is able to capture and utilize energy during non peak hours or during high loads. In not considering tank size or dynamics, our model implicitly assumed an infinite buffer size such that all energy could be collected irregardless of load or time. RETScreen analysis using the existing 760 L tank showed 130GJ of energy produced. However 760 L is below the recommended size of storage tank for a system this size. More appropriate would be a tank between 4,000 – 10,000 L. Using the upper end of this range, we find the RETScreen analysis to yield 198 GJ of energy. These two predictions bracket our models predicted value.

7.0 Potential Application of Solar Thermal in CHBE

The initial driving force for this work was to determine potential feasibility of a solar thermal water heating system in the CHBE building. It was realized early on in the project that all buildings on the UBC campus already have an ample supply of hot water in the form of steam condensate. This condensate is normally sent directly back to UBC utilities without further heat recovery attempts. While some of this thermal value is realized with a hotter feed temperature at the utility boilers, a large fraction of the heat is lost to ambient during transmission across campus. These transmission losses could be minimized by instead returning a cool liquid, after extracting thermal energy in each building. To the best of my knowledge no such projects are in the works at UBC.

In terms of solar hot water heating, the question now becomes why make hot water when you already have it? The greatest need for hot water comes during winter months when undergraduate classes are in session, which is when the supply of steam condensate is greatest. A case could potentially be made for solar thermal in the summer months when the system would function best, but at this time the demand is expected to be lower with only researchers, faculty, and staff occupying the building. Interestingly, summer demand has been increasing with more summer classes and researchers with offices in the building.

Building the economic case for such a system would require a very detailed analysis of both current energy use and the proposed system. Unfortunately it has proven to be extremely difficult to obtain the required metrics on current energy consumption, in many instances because they are simply not measured. The building is considered non-billable by utilities, and is brand new, so detailed energy records and breakdowns are not available. Also, these values will change when the Clean Energy Research Center (CERC), a wing of the CHBE building, starts operating at full capacity, as both share a common mechanical room.

Ultimately, engineering aims to teach common sense through rigorous analysis of scientific principles applied to realistic situations. It also teaches us to recognize opportunities that warrant further work and those that likely do not, the approach taken here. Unknown and uncertain heating loads, an ample supply of hot water already available and difficult mechanical integration into the current system are challenges. Ultimately I believe the money such a project would cost could be better utilized for other projects on campus, such as condensate heat recovery.

7.1 Potential for Solar Thermal Outside of CHBE

Solar thermal has a proven record of feasible operationg when it comes to both residential and industrial installations in the province of BC. This is evident through two major installations that have come online in recent years. First is the Vancouver International Airport, which installed 100-4'x8'panels in May 2003, as part of a large energy efficiency retrofit. A second project is the Hyde Creek Recreation Center in Port Coquitlam, a 42 panel installation designed by Taylor Munro Energy Systems in conjunction with Coral Engineering. The installation was part of a larger energy retrofit including two heat reclaim units to collect evaporating pool water and a "demand" based ventilation system. The GVRD has been monitoring energy use since the project went online in January 2004, and estimates savings of $40,000 - 50,000 per year, with $4000 from the panels alone. Based on the success of these projects the GVRD is actively pursuing similar installations at other recreation facilities. Appendix IX contains more information on these projects.

7.2 Further Incentives: REDI and LEED certification.

The government of Canada, through its Renewable Energy Deployment Initiative (REDI), now also called the ecoEnergy Renewable Initiative, will pay up to 25% of the design and installation cost of solar energy systems, including solar thermal[9], with the

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[9] http://www2.nrcan.gc.ca/es/erb/erb/english/View.asp?x=68

assistance increasing to 40% for projects in remote communities. As an added financial benefit, the sale of solar thermal equipment is exempt from 7.5% in provincial sales tax in the province of BC.

Solar thermal systems are also beneficial for buildings trying to obtain Leadership in Energy and Environmental Design (LEED) certification, a widely accepted way of rating the environmental impact of new and renovation construction projects . The number of LEED points for a solar thermal system will depend on many factors, and is best considered on a case by case basis by qualified designers. Taylor Munro of Delta, BC, has experience in this field.

8.0 Concluding Remarks

There are two main techniques for the analysis of solar thermal engineering projects, namely design methods and simulation techniques. These procedures differ in their approach, required input data, calculation methods, and type of results. In general, design methods give predictions of long term performance, while simulation techniques give immediate dynamic system responses. For this project a simplified modelling approach was developed based on the governing equations for a collector array, which was coupled to a heat exchanger described using only a heat transfer efficiency factor. In its current form the model functions well as a design method, but has the capacity to serve as a basis for a more detailed simulation if several assumptions are more rigorously dealt with. The principle assumption here is a very simple linear relation between collector panels and heat exchanger. A more accurate model would necessarily include factor such as tank volume, temperature distribution or stratification, and instantaneous heat transfer rates. A more rigorous calculation procedure would also be used.

Using a detailed meteorological data set, out model looked at variations in system performance on a monthly basis, showing the expected strong seasonal dependence which characterizes Vancouver sunshine. Different plumbing configurations of parallel and series panels for the array were investigated. Net effects are minimal, and a strong practical consideration is given to systems using 3-5 panels in series, in order to obtain higher temperature rise for the heat transfer fluid. Net energy production for one full operational year was determined to be 155 GJ, approximately one quarter of the yearly hot water heating load required in CHBE. The actual seasonal variation as indicated above would be heavily weighted towards summer months, where upwards of 80% of the heating load could potentially come from renewable solar energy.

This estimate for yearly energy production is in close agreement with the results of a RETScreen analysis also conducted. The RETScreen model was heavily dependant on storage tank size, which acts as a buffer between solar supply and heating load demand.

Using a current 760L tank in the CBHE basement, renewable energy production was predicted to be 130 GJ, however, using a much larger 11,000L tank would increase this value to 198GJ. Our model implicitly assumes a large tank but is also conservative in nature, and gives a value intermediate between these two. Monthly variations predicted by RETScreen were similar to our model.

Solar thermal water heating systems are a very simple and ingenious source of energy, having the potential to contribute clean, renewable energy in a wide range of systems. Several successful large scale projects exist in the province of BC and more are on the drawing board. It is common to see retrofit applications in the residential market, and two high profile, large scale installations have been part of larger energy efficiency retrofits, both at the Vancouver International airport in 2003 and Hyde Creek Recreation Center in 2004. With demonstrated economic feasibility, it is time to start considering solar thermal water heating systems from the design stages of new construction projects. Further incentives are that projects can qualify for funding by the federal government through their REDI program, are exempt from provincial sales tax, and qualify towards LEED certification.

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www.californiasolarcenter.org	-California Solar Center. An information distributor and advocacy group.
www.cansia.ca	-Canadian Solar Industries Association
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www.nrcan.gc.ca	- Natural Resources Canada
www.retscreen.net	-RETscreen resource center
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www.solar-rating.org	-Solar Rating Certification Center, Florida.
www.taylormunro.com	-Solar system design engineers, Delta BC
www.thermo-dynamics.com	-ThermoDynamics Ltd, Dartmouth, NS.
www.weatheroffice.ec.gc.ca	Canadian Weather Office
http://www.gvrd.bc.ca/sustainability/casestudies/HydeCreekRecreationCentre.htm	-GVRD Case study

Appendix I - GVRD Water Quality Report, Temperatures

The city of Vancouver collects 40 water samples per week from a series of 52 dedicated sampling stations throughout the city, encompassing source, high and low flow, and dead end distribution lines. All samples are instantaneously tested for physical properties including turbidity and temperature; results of the latter are displayed below as the average monthly temperatures.

The 15°C aesthetic objective is a Canadian guideline for drinking water temperature, aimed at limiting microbial growth which can affect water taste, odour, and colour. As piece of mind, microbial activity did not increase in the city of Vancouver water supply during August, indicating sufficient levels of residual chlorine treatment.

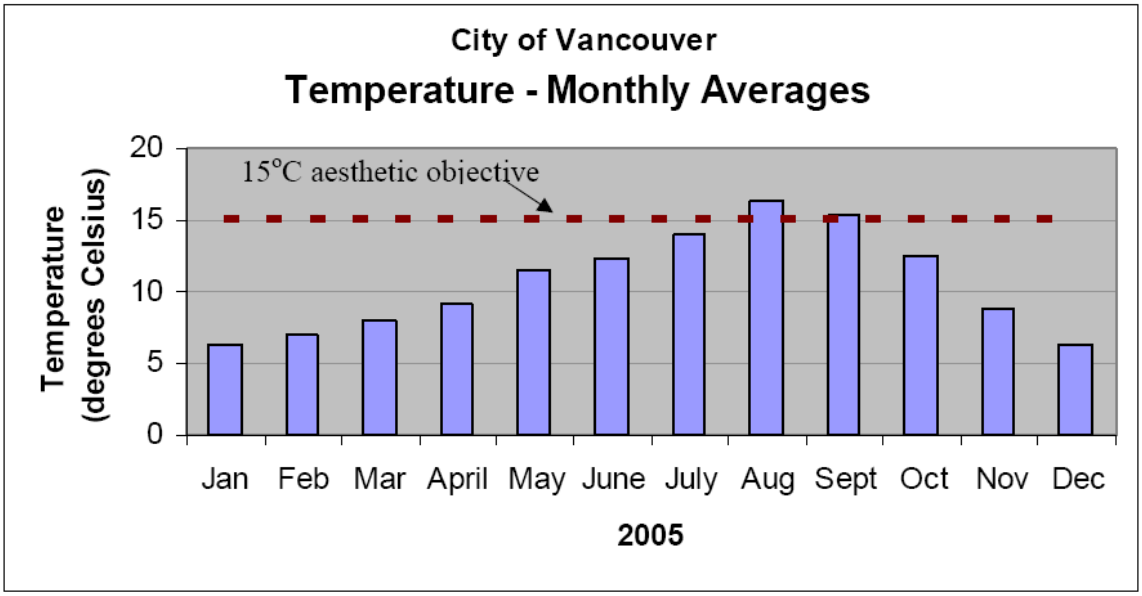


Figure 9 - City of Vancouver monthly average water temperature, 2005

Appendix II - CHBE Roof Survey

The CHBE roof is a combination of open space as well as heavy duty HVAC equipment and laboratory and fume hood ventilation. It is fully service accessible. The roof itself is constructed of thick concrete layer, capped with heavy duty drain cloth and a layer of +1" rock.

Three open zones were considered for panel placement. Their measurements were taken, and the number of panels that could fit was determined. Each 4'x8' panel was assumed to be installed on its side, and the spacing between adjacent rows was calculated to be 10.6' as shown below, such that they would not shade each other. This was assuming an angle of the sun with the horizon of 20°, which is typical for mid morning to mid afternoon in winter months. Also, the panels were assumed to pack very close to each other side to side, as all piping fixtures are on the bottom and top.

X = 4' * sin (45°)
= 2.82'
Y = 2.82' / tan (20°)
= 7.75'
X+Y = 10.6'

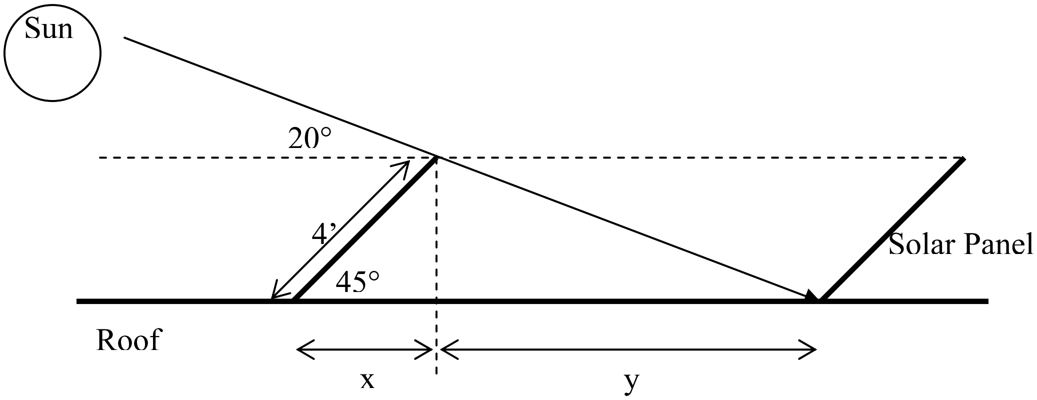


Figure 10 - Required spacing between rows of panels

The roof was then divided into 3 zones that were found to be suitable the installation of solar thermal collectors, the number of collectors that could fit in each was determined a shown in the table below.

Zone	Size	# Rows	Panels per row	# Panels
1	64’ x 13’	7	1	7
2	92’ x 10’	9	1	9
3	20’ x 56’	3	7	21
Total				**37 Panels**

Table 3 - Solar Collectors on Roof

Based on this very rough estimate, the roof should be able to hold 37 panels. It can likely accommodate more, but when measuring I was careful to leave a lot of room around the present equipment and the edge. Also, this was not considering the roof space located on top of CERC, which could potentially be used as it has a lot of open space but was not measured. Based on this result, it was decided that 40 panels would be used in our model, which is in agreement with the RETScreen suggestion.

Appendix III - RETScreen Input Sheets

RETScreen® Energy Model - Solar Water Heating Project

Internet Forums

Site Conditions		Estimate	Notes/Range
Project name		**CHBE Building**	*See Online Manual*
Project location		**Vancouver, BC**	
Nearest location for weather data		Vancouver Int'l. A, BC	➡ *Complete SR&HL sheet*
Annual solar radiation (tilted surface)	MWh/m^2	1.32	
Annual average temperature	°C	9.9	-20.0 to 30.0
Annual average wind speed	m/s	3.2	
Desired load temperature	°C	60	
Hot water use	L/d	7,600	
Number of months analysed	month	12.00	
Energy demand for months analysed	MWh	158.49	

System Characteristics		Estimate	Notes/Range
Application type		Service hot water (with storage)	
Base Case Water Heating System			
Heating fuel type	-	**Other**	
Water heating system seasonal efficiency	%	50%	50% to 190%
Solar Collector			
Collector type	-	Glazed	*See Technical Note 1*
Solar water heating collector manufacturer		Thermo Dynamics	*See Product Database*
Solar water heating collector model		G32	
Gross area of one collector	m^2	2.96	1.00 to 5.00
Aperture area of one collector	m^2	2.78	1.00 to 5.00
Fr (tau alpha) coefficient	-	0.74	0.50 to 0.90
Fr UL coefficient	(W/m^2)/°C	5.25	1.50 to 8.00
Temperature coefficient for Fr UL	(W/(m?°C)^2)	0.00	0.000 to 0.010
Suggested number of collectors		40	
Number of collectors		40	
Total gross collector area	m^2	118.4	
Storage			
Ratio of storage capacity to coll. area	L/m^2	100.0	37.5 to 100.0
Storage capacity	L	11,120	
Balance of System			
Heat exchanger/antifreeze protection	yes/no	Yes	
Heat exchanger effectiveness	%	85%	50% to 85%
Suggested pipe diameter	mm	N/A	8 to 25 or PVC 35 to 50
Pipe diameter	mm	25	8 to 25 or PVC 35 to 50
Pumping power per collector area	W/m^2	0	3 to 22, or 0
Piping and solar tank losses	%	5%	1% to 10%
Losses due to snow and/or dirt	%	5%	2% to 10%
Horz. dist. from mech. room to collector	m	10	5 to 20
# of floors from mech. room to collector	-	7	0 to 20

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
SWH system capacity	kW_{th}	78	
	MWth	0.078	
Pumping energy (electricity)	MWh	**0.00**	
Specific yield	kWh/m^2	460	
System efficiency	%	35%	
Solar fraction	%	34%	
Renewable energy delivered	MWh	**54.47**	
	GJ	196.09	
			Complete Cost Analysis sheet

RETScreen® Solar Resource and Heating Load Calculation - Solar Water Heating Project

Site Latitude and Collector Orientation		Estimate	Notes/Range
Nearest location for weather data		Vancouver Int'l. A, BC	*See Weather Database*
Latitude of project location	°N	49.2	-90.0 to 90.0
Slope of solar collector	°	45.0	0.0 to 90.0
Azimuth of solar collector	°	0.0	0.0 to 180.0

Monthly Inputs

(Note: 1. Cells in grey are not used for energy calculations; 2. Revisit this table to check that all required inputs are filled if you change system type or solar collector type or pool type, or method for calculating cold water temperature).

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m²/d)	Monthly average temperature (°C)	Monthly average relative humidity (%)	Monthly average wind speed (m/s)	Monthly average daily radiation in plane of solar collector (kWh/m²/d)
January	1.00	0.78	3.0	84.5	3.3	1.39
February	1.00	1.56	4.7	82.0	3.3	2.44
March	1.00	2.81	6.3	78.5	3.6	3.61
April	1.00	4.14	8.8	75.0	3.6	4.38
May	1.00	5.61	12.1	73.5	3.1	5.22
June	1.00	5.86	15.2	73.5	3.1	5.14
July	1.00	6.17	17.2	73.5	3.1	5.56
August	1.00	5.33	17.4	75.5	3.1	5.41
September	1.00	3.64	14.3	80.0	2.8	4.42
October	1.00	2.00	10.0	84.0	3.1	3.02
November	1.00	0.94	6.0	83.5	3.3	1.58
December	1.00	0.67	3.5	85.0	3.3	1.28

		Annual	Season of Use
Solar radiation (horizontal)	MWh/m²	1.21	1.21
Solar radiation (tilted surface)	MWh/m²	1.32	1.32
Average temperature	°C	9.9	9.9
Average wind speed	m/s	3.2	3.2

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	Other	
Number of units	-	-	
Rate of occupancy	%	-	50% to 100%
Estimated hot water use (at ~60 °C)	L/d	N/A	
Hot water use	L/d	7,600	
Desired water temperature	°C	60	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	User-defined	
Minimum	°C	6.0	1.0 to 10.0
Maximum	°C	16.0	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	158.49	
	GJ	570.54	

Return to Energy Model sheet

Version 3.1

NRCan/CETC - Varennes

Appendix IV - Nomenclature

Symbol	Description	Units
A	Collector array total area	m^2
A_c	Panel area	m^2
C_p	Thermal heat capacity	J/(g °C)
F'_{UL}	Collector overall heat loss coefficient efficiency factor	$kg/(s^3\ °C)$
$Fr_{UL\text{-}test}$	Thermal loss coefficient at testing conditions	$W/(m^2\ °C)$
$Fr_{UL\text{-}use}$	Thermal loss coefficient at operating conditions	$W/(m^2\ °C)$
$Fr_{\tau\alpha}$	Solar Absorptivity coefficient	n/a
G	Solar flux	W/m^2
m	Mass flow rate of heat transfer fluid in collector	kg/s
Q_u	Solar thermal energy produced	W
T_a	Ambient temperature	°C
T_{ci}	Collector inlet temperature	°C
T_{feed}	Feed water temperature	°C
T_{ho}	Preheat water temperature	°C
ε	Heat exchanger efficiency	%

Table 4 - Nomenclature list

Appendix V - Flow Rate Dependence of Fr_{UL}

The following equations describe flow dependence of the thermal loss coefficient. All can be found in the text by Duffie, p 317-318. This coefficient remains constant during test conditions, and by using a ratio r, as shown in equation 2, can be corrected for the application flow rate. This ratio term is found by using equations 3. This equation depends on F'$_{UL}$, the so called "overall heat loss coefficient efficiency factor", which is in turn calculated from equation 4. All equations essentially depend on mass flow rate through the collector panel, m, as all other terms remain constant. Derivations of these equations, for interested readers, can be found referenced in the above text.

$$Fr_{UL-use} = Fr_{UL-test} * r$$

Equation 2 - $Fr_{UL\text{-}use}$, calculation of coefficient at application flow rate

$$r = \frac{\frac{mC_p}{A_c}[1 - \exp(-A_c F'_{UL} / mC_p)]\Big|use}{Fr_{UL}\Big|test}$$

$$r = \frac{F'_{UL}\Big|use}{F'_{UL}\Big|test}$$

Equation 3 - Correction ratio for Fr_{UL}

$$F'_{UL} = \frac{-mC_p}{A_c}\ln\left(1 - \frac{Fr_{UL-use}A_c}{mC_p}\right)$$

Equation 4 - Collector overall heat loss coefficient efficiency factor

Appendix VI - Sample Calculation for July 2

Array - 20 Groups of 2 Panels in series each

Constants

Fr(ta)	0.738	
Fr(UL)	5.247	W/m2 C
Ac	2.87	m2
Cp(H2O)	4184	J/kg s

Flow Correction Factor

m	1	L/min/panel
	0.0333	kg/s
Fr'UL test	5.394	W/m2 C
Fr'UL use	5.552	W/m2 C
ratio	1.03	
FrUL	5.402	W/m2 C

Panel Inlet Temp Calculation

Hx efficiency	50%	
Tin(from city)	15	C
Tci	45.22	C

possible delta T 25.22

**plus 5C as the delta T in heat exchanger

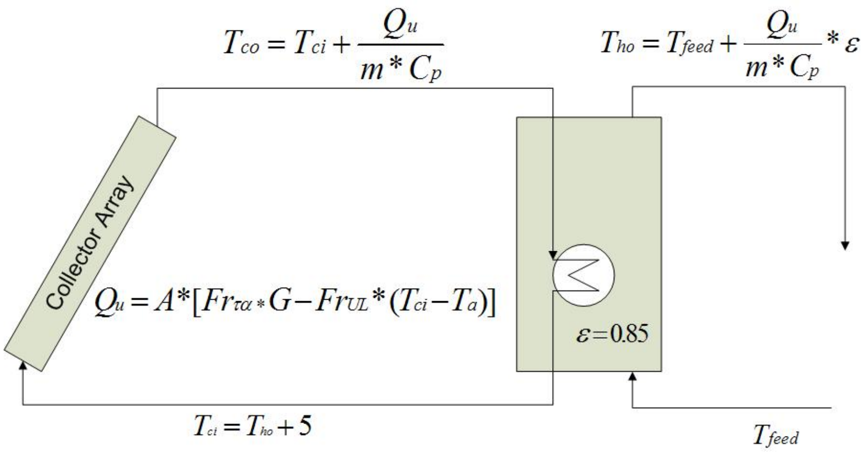
Net Energy 1599.41

45.22

0.00

Time	**Solar Flux** W/m2	**Temp** C	**Panel 1** W	**T1** C	**Panel 2** W	**T2** C
July 2, 2003 00:00	0.6	18	0	45.2	0	45.2
July 2, 2003 00:30	1.2	17	0	45.2	0	45.2
July 2, 2003 01:00	0.6	16	0	45.2	0	45.2
July 2, 2003 01:30	1.2	16	0	45.2	0	45.2
July 2, 2003 02:00	0.6	15	0	45.2	0	45.2
July 2, 2003 02:30	1.2	15	0	45.2	0	45.2
July 2, 2003 03:00	0.6	15	0	45.2	0	45.2
July 2, 2003 03:30	1.2	14	0	45.2	0	45.2
July 2, 2003 04:00	0.9	14	0	45.2	0	45.2
July 2, 2003 04:30	6.0	14	0	45.2	0	45.2
July 2, 2003 05:00	15.6	14	0	45.2	0	45.2
July 2, 2003 05:30	39.3	15	0	45.2	0	45.2
July 2, 2003 06:00	145.9	16	0	45.2	0	45.2
July 2, 2003 06:30	226.5	17	48	45.6	42	45.9
July 2, 2003 07:00	143.1	18	0	45.2	0	45.2
July 2, 2003 07:30	221.7	18	52	45.6	46	45.9
July 2, 2003 08:00	564.2	19	786	50.8	699	55.9
July 2, 2003 08:30	444.3	19	539	49.1	479	52.5
July 2, 2003 09:00	252.0	20	141	46.2	126	47.1
July 2, 2003 09:30	542.2	21	770	50.7	685	55.6
July 2, 2003 10:00	664.8	21	1034	52.6	919	59.2
July 2, 2003 10:30	854.7	21	1441	55.5	1280	64.7
July 2, 2003 11:00	922.0	21	1584	56.6	1408	66.7
July 2, 2003 11:30	964.3	22	1675	57.2	1489	67.9
July 2, 2003 12:00	954.1	22	1662	57.1	1477	67.7
July 2, 2003 12:30	965.6	22	1691	57.3	1503	68.1
July 2, 2003 13:00	913.0	23	1582	56.6	1406	66.6
July 2, 2003 13:30	936.1	23	1637	57.0	1455	67.4
July 2, 2003 14:00	901.5	23	1564	56.4	1390	66.4
July 2, 2003 14:30	857.1	23	1473	55.8	1309	65.2
July 2, 2003 15:00	805.3	23	1365	55.0	1214	63.7
July 2, 2003 15:30	707.6	23	1149	53.5	1021	60.8
July 2, 2003 16:00	471.0	23	651	49.9	578	54.0
July 2, 2003 16:30	511.1	23	735	50.5	653	55.2
July 2, 2003 17:00	494.2	22	694	50.2	617	54.6
July 2, 2003 17:30	466.8	22	628	49.7	558	53.7
July 2, 2003 18:00	376.9	21	430	48.3	383	51.0
July 2, 2003 18:30	266.5	21	190	46.6	169	47.8
July 2, 2003 19:00	168.6	21	0	45.2	0	45.2
July 2, 2003 19:30	81.9	20	0	45.2	0	45.2
July 2, 2003 20:00	23.4	19	0	45.2	0	45.2
July 2, 2003 20:30	5.8	19	0	45.2	0	45.2
July 2, 2003 21:00	1.2	19	0	45.2	0	45.2
July 2, 2003 21:30	1.3	19	0	45.2	0	45.2
July 2, 2003 22:00	0.6	18	0	45.2	0	45.2
July 2, 2003 22:30	1.3	18	0	45.2	0	45.2
July 2, 2003 23:00	0.6	18	0	45.2	0	45.2
July 2, 2003 23:30	1.3	18	0	45.2	0	45.2
Array Output		watts	23521		20907	
		MJ	846.764		752.643	

Appendix VII - Temperature Convergence of model



The following example is for July 1, 2003.

Known constants

Fr_{ta} = 0.738
Fr_{UL} = 5.160 W/m^2 °C
A_c = 2.87 m_2
C_p (H_2O) = 4184 J/kg K

HX efficiency ε = 85%
T_{feed} = 14 °C

Example of panel performance for a half hour interval at 10am

Panel 1:

Q_u = $A*[Fr_{ta}*G-Fr_{UL}(T_{ci}-T_a)]$
= $2.87m^2*[0.738*807.7\ W/m^2 - 5.160W/m^2{}^\circ C*(57.4^\circ C-16^\circ C)]$
=

Appendix VIII - Sample calculations for yearly energy production

Note, these results are truncated at the end of January, but were done for an entire year.

Constants

Fr(ta)	0.738	
Fr(UL)	5.247	W/m2 C
Ac	2.78	m2
Cp(H2O)	4184	J/kg K

Flow Correction Factor

m	1	L/min/panel
	0.0667	kg/s
Fr'UL test	5.394	W/m2 C
Fr'UL use	5.389	W/m2 C
ratio	1.00	
FrUL	5.243	W/m2 C

Panel Inlet Temp Calculation

Hx efficiency	50%	
Tin(from city)	10	C
Tci	41.38	C

Net Energy	203.3	GJ
	155.93	GJ

(includes 85% HX efficiency, 10% losses for thermal and dirt and wind)

Time	**Solar Flux** w/m2	**Temp** C	**Water T** C	**T0** C	**Panel 1** W	**T1** C	**Panel 2** W	**T2** C	**Panel 3** W	**T3** C	**Panel 4** W	**T4** C	**Net Energy** MJ
January 2, 2003 10:00	107.5	1	6	18.85	0	18.9	0	18.9	0	18.9	0	18.9	0.0
January 2, 2003 13:00	249.6	2	6	18.85	269	19.8	255	20.7	241	21.6	229	22.4	35.8
January 2, 2003 14:00	131.3	2	6	18.85	25	18.9	24	19.0	23	19.1	22	19.2	3.4
January 3, 2003 12:00	209.9	-4	6	18.85	99	19.2	94	19.5	89	19.9	84	20.2	13.2
January 3, 2003 15:00	132.3	-3	6	18.85	0	18.9	0	18.9	0	18.9	0	18.9	0.0
January 4, 2003 14:00	371.4	-4	6	18.85	434	20.4	411	21.9	390	23.3	369	24.6	57.7
January 5, 2003 10:00	159.7	-5	6	18.85	0	18.9	0	18.9	0	18.9	0	18.9	0.0
January 5, 2003 14:00	261.4	-5	6	18.85	195	19.5	185	20.2	175	20.8	166	21.4	25.9
January 5, 2003 15:00	181.0	-5	6	18.85	25	18.9	23	19.0	22	19.1	21	19.2	3.3
January 6, 2003 10:00	190.1	-6	6	18.85	26	18.9	25	19.0	23	19.1	22	19.2	3.5
January 6, 2003 11:00	284.0	-6	6	18.85	220	19.6	209	20.4	198	21.1	187	21.8	29.3
January 6, 2003 12:00	335.2	-5	6	18.85	337	20.1	319	21.2	302	22.3	287	23.3	44.8
January 6, 2003 13:00	337.9	-5	6	18.85	347	20.1	329	21.3	312	22.4	296	23.5	46.2
January 6, 2003 14:00	290.7	-5	6	18.85	254	19.8	241	20.6	228	21.4	216	22.2	33.8
January 6, 2003 15:00	200.4	-4	6	18.85	76	19.1	72	19.4	68	19.6	65	19.9	10.1
January 7, 2003 10:00	194.9	4	6	18.85	180	19.5	171	20.1	162	20.7	153	21.2	24.0
January 7, 2003 11:00	283.3	4	6	18.85	365	20.2	346	21.4	328	22.6	311	23.7	48.6
January 7, 2003 12:00	335.1	4	6	18.85	477	20.6	452	22.2	428	23.7	406	25.2	63.5
January 7, 2003 13:00	262.1	4	6	18.85	327	20.0	310	21.1	293	22.2	278	23.2	43.5
January 7, 2003 14:00	123.3	4	6	18.85	42	19.0	40	19.1	38	19.3	36	19.4	5.6
January 8, 2003 10:00	184.7	7	6	18.85	204	19.6	193	20.3	183	20.9	173	21.5	27.1
January 8, 2003 11:00	277.1	8	6	18.85	405	20.3	384	21.7	364	23.0	345	24.2	53.9
January 8, 2003 12:00	289.1	8	6	18.85	439	20.4	416	21.9	395	23.3	374	24.7	58.5
January 8, 2003 13:00	314.8	9	6	18.85	506	20.7	480	22.4	455	24.0	431	25.6	67.4
January 8, 2003 14:00	241.7	9	6	18.85	356	20.1	338	21.3	320	22.5	303	23.6	47.4
January 9, 2003 10:00	194.4	7	6	18.85	220	19.6	209	20.4	198	21.1	188	21.8	29.3
January 9, 2003 11:00	285.3	7	6	18.85	406	20.3	384	21.7	364	23.0	345	24.2	54.0
January 9, 2003 12:00	330.8	7	6	18.85	502	20.6	475	22.4	451	24.0	427	25.5	66.8
January 9, 2003 13:00	343.0	7	6	18.85	528	20.7	500	22.5	474	24.2	449	25.8	70.3
January 9, 2003 14:00	249.5	7	6	18.85	341	20.1	323	21.2	306	22.3	290	23.4	45.4
January 9, 2003 15:00	136.5	7	6	18.85	113	19.3	107	19.6	101	20.0	96	20.3	15.0
January 10, 2003 10:00	209.8	8	6	18.85	272	19.8	257	20.7	244	21.6	231	22.5	36.2
January 10, 2003 11:00	341.8	8	6	18.85	545	20.8	516	22.7	489	24.4	464	26.1	72.5
January 10, 2003 12:00	354.4	8	6	18.85	574	20.9	544	22.9	516	24.7	489	26.5	76.5
January 10, 2003 13:00	364.3	8	6	18.85	594	21.0	563	23.0	534	24.9	506	26.7	79.1
January 10, 2003 14:00	311.2	8	6	18.85	486	20.6	461	22.2	437	23.8	414	25.3	64.7
January 10, 2003 15:00	173.1	8	6	18.85	203	19.6	192	20.3	182	20.9	172	21.5	27.0
January 12, 2003 13:00	234.8	10	6	18.85	350	20.1	332	21.3	314	22.4	298	23.5	46.6
January 12, 2003 14:00	209.3	9	6	18.85	288	19.9	273	20.9	259	21.8	245	22.7	38.3
January 13, 2003 13:00	110.6	10	6	18.85	91	19.2	86	19.5	82	19.8	78	20.1	12.1
January 14, 2003 10:00	168.8	11	6	18.85	229	19.7	217	20.4	206	21.2	195	21.9	30.5
January 14, 2003 11:00	270.9	11	6	18.85	443	20.4	420	21.9	398	23.4	377	24.7	59.0
January 14, 2003 12:00	166.0	11	6	18.85	231	19.7	219	20.5	207	21.2	196	21.9	30.7
January 14, 2003 13:00	389.6	11	6	18.85	689	21.3	653	23.7	619	25.9	587	28.0	91.7
January 14, 2003 14:00	287.2	11	6	18.85	479	20.6	454	22.2	430	23.7	407	25.2	63.7
January 14, 2003 15:00	188.4	11	6	18.85	274	19.8	259	20.8	246	21.6	233	22.5	36.4
January 15, 2003 12:00	131.6	11	6	18.85	156	19.4	148	19.9	140	20.4	133	20.9	20.8
January 15, 2003 13:00	116.7	11	6	18.85	118	19.3	112	19.7	106	20.1	100	20.4	15.7
January 15, 2003 14:00	107.9	10	6	18.85	90	19.2	86	19.5	81	19.8	77	20.0	12.0
January 16, 2003 11:00	169.8	8	6	18.85	195	19.5	185	20.2	175	20.8	166	21.4	26.0
January 16, 2003 12:00	289.0	9	6	18.85	444	20.4	421	22.0	399	23.4	378	24.7	59.1
January 16, 2003 13:00	120.9	8	6	18.85	87	19.2	83	19.5	79	19.7	74	20.0	11.6
January 16, 2003 14:00	136.1	7	6	18.85	110	19.2	105	19.6	99	20.0	94	20.3	14.7
January 17, 2003 10:00	182.8	7	6	18.85	199	19.6	189	20.2	179	20.9	170	21.5	26.5
January 17, 2003 11:00	195.9	8	6	18.85	238	19.7	225	20.5	214	21.3	202	22.0	31.6
January 17, 2003 12:00	334.0	8	6	18.85	533	20.8	505	22.6	479	24.3	454	25.9	71.0
January 17, 2003 13:00	171.6	8	6	18.85	192	19.5	182	20.2	172	20.8	163	21.4	25.5
January 17, 2003 14:00	147.0	8	6	18.85	142	19.4	135	19.8	128	20.3	121	20.7	18.9
January 17, 2003 15:00	132.0	8	6	18.85	112	19.2	106	19.6	100	20.0	95	20.3	14.8
January 18, 2003 10:00	105.0	7	6	18.85	43	19.0	41	19.1	39	19.3	37	19.4	5.7
January 18, 2003 11:00	114.8	7	6	18.85	66	19.1	63	19.3	59	19.5	56	19.7	8.8
January 18, 2003 12:00	172.9	7	6	18.85	188	19.5	178	20.2	169	20.8	160	21.3	25.0
January 18, 2003 13:00	140.4	7	6	18.85	122	19.3	116	19.7	110	20.1	104	20.5	16.3
January 18, 2003 14:00	122.3	7	6	18.85	85	19.2	80	19.4	76	19.7	72	20.0	11.3
January 20, 2003 11:00	135.6	6	6	18.85	92	19.2	87	19.5	83	19.8	78	20.1	12.2
January 20, 2003 12:00	316.1	6	6	18.85	465	20.5	441	22.1	418	23.6	396	25.0	61.9
January 20, 2003 13:00	291.5	6	6	18.85	413	20.3	391	21.7	371	23.1	352	24.3	55.0
January 20, 2003 14:00	158.1	6	6	18.85	133	19.3	126	19.8	120	20.2	114	20.6	17.8
January 20, 2003 15:00	125.5	6	6	18.85	67	19.1	63	19.3	60	19.5	57	19.7	8.9
January 21, 2003 14:00	126.9	6	6	18.85	77	19.1	73	19.4	69	19.6	65	19.9	10.2
January 23, 2003 11:00	310.3	6	6	18.85	450	20.5	427	22.0	404	23.4	383	24.8	59.9
January 23, 2003 12:00	274.0	6	6	18.85	381	20.2	361	21.5	342	22.7	324	23.9	50.7

January 23, 2003 13:00	170.0	6	6	18.85	162	19.4	154	20.0	146	20.5	138	21.0	21.6
January 23, 2003 14:00	323.0	6	6	18.85	478	20.6	453	22.2	429	23.7	407	25.2	63.6
January 23, 2003 15:00	121.8	6	6	18.85	56	19.1	53	19.2	51	19.4	48	19.6	7.5
January 26, 2003 10:00	109.9	3	6	18.85	0	18.9	0	18.9	0	18.9	0	18.9	0.0
January 26, 2003 11:00	277.3	3	6	18.85	336	20.1	318	21.2	302	22.3	286	23.3	44.7
January 26, 2003 12:00	339.3	4	6	18.85	474	20.5	449	22.2	426	23.7	403	25.1	63.1
January 26, 2003 13:00	265.6	4	6	18.85	334	20.0	317	21.2	300	22.3	285	23.3	44.5
January 26, 2003 14:00	121.0	5	6	18.85	46	19.0	44	19.2	42	19.3	39	19.5	6.2
January 26, 2003 15:00	113.1	5	6	18.85	30	19.0	28	19.1	27	19.2	25	19.2	4.0
January 26, 2003 16:00	164.3	5	6	18.85	130	19.3	123	19.8	117	20.2	111	20.6	17.3
January 27, 2003 11:00	320.4	4	6	18.85	436	20.4	413	21.9	392	23.3	371	24.6	58.0
January 27, 2003 12:00	405.7	3	6	18.85	606	21.0	574	23.1	544	25.0	516	26.9	80.7
January 27, 2003 14:00	226.3	4	6	18.85	244	19.7	231	20.6	219	21.3	208	22.1	32.5
January 27, 2003 15:00	330.7	3	6	18.85	451	20.5	428	22.0	405	23.5	384	24.8	60.0
January 27, 2003 16:00	147.5	3	6	18.85	69	19.1	66	19.3	62	19.6	59	19.8	9.2
January 28, 2003 10:00	123.1	7	6	18.85	73	19.1	69	19.4	66	19.6	62	19.8	9.7
January 28, 2003 11:00	132.6	7	6	18.85	105	19.2	99	19.6	94	19.9	89	20.2	13.9
January 28, 2003 12:00	103.8	8	6	18.85	49	19.0	46	19.2	44	19.3	42	19.5	6.5
January 28, 2003 13:00	175.1	8	6	18.85	197	19.6	187	20.2	177	20.9	168	21.5	26.3
January 28, 2003 14:00	258.0	8	6	18.85	368	20.2	348	21.4	330	22.6	313	23.7	48.9
January 28, 2003 15:00	255.8	8	6	18.85	363	20.1	344	21.4	326	22.5	309	23.7	48.3
January 31, 2003 10:00	105.2	4	6	18.85	0	18.9	0	18.9	0	18.9	0	18.9	0.0
January 31, 2003 11:00	165.7	5	6	18.85	142	19.4	134	19.8	127	20.3	121	20.7	18.9
January 31, 2003 12:00	180.3	3	6	18.85	144	19.4	137	19.9	129	20.3	123	20.8	19.2
January 31, 2003 13:00	284.4	3	6	18.85	354	20.1	336	21.3	318	22.5	302	23.5	47.1
January 31, 2003 14:00	204.9	4	6	18.85	203	19.6	193	20.3	183	20.9	173	21.5	27.1
January 31, 2003 15:00	172.2	4	6	18.85	141	19.4	133	19.8	126	20.3	120	20.7	18.7
February 1, 2003 11:00	101.0	4	6.5	28.98	0	29.0	0	29.0	0	29.0	0	29.0	0.0
February 1, 2003 13:00	133.7	5	6.5	28.98	76	29.3	0	29.3	0	29.3	0	29.3	2.7
February 1, 2003 14:00	118.6	6	6.5	28.98	54	29.2	0	29.2	0	29.2	0	29.2	2.0
February 2, 2003 11:00	155.9	6	6.5	28.98	126	29.4	0	29.4	0	29.4	0	29.4	4.5
February 2, 2003 12:00	228.1	5	6.5	28.98	263	29.9	101	30.3	96	30.6	91	31.0	19.8
February 2, 2003 13:00	110.9	4	6.5	28.98	17	29.0	0	29.0	0	29.0	0	29.0	0.6
February 2, 2003 14:00	137.4	4	6.5	28.98	69	29.2	0	29.2	0	29.2	0	29.2	2.5
February 3, 2003 09:00	122.8	4	6.5	28.98	34	29.1	0	29.1	0	29.1	0	29.1	1.2
February 3, 2003 10:00	255.0	5	6.5	28.98	314	30.1	150	30.6	142	31.2	135	31.6	26.7
February 3, 2003 11:00	399.5	4	6.5	28.98	608	31.2	429	32.7	407	34.2	385	35.5	65.9
February 3, 2003 12:00	454.2	5	6.5	28.98	728	31.6	542	33.5	514	35.4	487	37.1	81.7
February 3, 2003 13:00	301.5	5	6.5	28.98	422	30.5	253	31.4	240	32.3	227	33.1	41.1
February 3, 2003 14:00	376.5	6	6.5	28.98	582	31.1	404	32.5	383	33.9	363	35.2	62.4
February 3, 2003 15:00	431.4	6	6.5	28.98	699	31.5	515	33.3	488	35.1	462	36.7	77.9
February 3, 2003 16:00	166.6	6	6.5	28.98	152	29.5	0	29.5	0	29.5	0	29.5	5.5
February 4, 2003 09:00	131.5	5	6.5	28.98	67	29.2	0	29.2	0	29.2	0	29.2	2.4
February 4, 2003 10:00	253.6	5	6.5	28.98	316	30.1	152	30.7	144	31.2	136	31.7	26.9
February 4, 2003 11:00	366.7	5	6.5	28.98	557	31.0	380	32.3	361	33.6	342	34.9	59.0
February 4, 2003 12:00	422.9	6	6.5	28.98	687	31.4	503	33.2	477	35.0	452	36.6	76.3
February 4, 2003 13:00	443.7	7	6.5	28.98	731	31.6	545	33.6	517	35.4	490	37.2	82.2
February 4, 2003 14:00	396.7	6	6.5	28.98	629	31.2	449	32.8	425	34.4	403	35.8	68.7
February 4, 2003 15:00	282.4	7	6.5	28.98	413	30.5	244	31.3	231	32.2	219	33.0	39.9
February 4, 2003 16:00	187.0	7	6.5	28.98	207	29.7	49	29.9	46	30.1	44	30.2	12.4
February 5, 2003 09:00	135.8	3	6.5	28.98	41	29.1	0	29.1	0	29.1	0	29.1	1.5
February 5, 2003 10:00	271.2	3	6.5	28.98	327	30.2	162	30.7	154	31.3	146	31.8	28.4
February 5, 2003 11:00	377.1	4	6.5	28.98	554	31.0	377	32.3	357	33.6	339	34.8	58.6
February 5, 2003 12:00	411.7	4	6.5	28.98	627	31.2	447	32.8	424	34.4	402	35.8	68.4
February 5, 2003 13:00	437.1	4	6.5	28.98	683	31.4	500	33.2	474	34.9	449	36.5	75.8
February 5, 2003 14:00	409.9	4	6.5	28.98	627	31.2	447	32.8	423	34.3	401	35.8	68.3
February 5, 2003 15:00	312.7	4	6.5	28.98	424	30.5	254	31.4	241	32.3	228	33.1	41.3
February 5, 2003 16:00	182.7	4	6.5	28.98	160	29.6	4	29.6	4	29.6	4	29.6	6.2
February 6, 2003 09:00	147.1	7	6.5	28.98	127	29.4	0	29.4	0	29.4	0	29.4	4.6
February 6, 2003 10:00	274.8	7	6.5	28.98	386	30.4	218	31.1	207	31.9	196	32.6	36.2
February 6, 2003 11:00	234.8	7	6.5	28.98	306	30.1	142	30.6	135	31.1	128	31.5	25.6
February 6, 2003 12:00	157.6	8	6.5	28.98	158	29.5	2	29.6	2	29.6	2	29.6	5.9
February 6, 2003 13:00	200.9	10	6.5	28.98	281	30.0	118	30.4	112	30.8	106	31.2	22.2
February 6, 2003 14:00	178.9	10	6.5	28.98	237	29.8	77	30.1	73	30.4	69	30.6	16.5
February 6, 2003 15:00	156.3	9	6.5	28.98	178	29.6	21	29.7	20	29.8	19	29.8	8.6
February 6, 2003 16:00	156.4	8	6.5	28.98	168	29.6	12	29.6	11	29.7	10	29.7	7.2
February 7, 2003 11:00	137.7	7	6.5	28.98	109	29.4	0	29.4	0	29.4	0	29.4	3.9
February 7, 2003 12:00	121.9	8	6.5	28.98	89	29.3	0	29.3	0	29.3	0	29.3	3.2
February 7, 2003 13:00	158.0	8	6.5	28.98	163	29.6	7	29.6	7	29.6	6	29.6	6.6
February 7, 2003 14:00	132.1	8	6.5	28.98	112	29.4	0	29.4	0	29.4	0	29.4	4.0
February 8, 2003 11:00	161.2	6	6.5	28.98	143	29.5	0	29.5	0	29.5	0	29.5	5.1
February 8, 2003 12:00	207.0	6	6.5	28.98	242	29.8	81	30.1	77	30.4	73	30.7	17.0
February 8, 2003 13:00	168.3	7	6.5	28.98	166	29.6	10	29.6	9	29.6	9	29.7	7.0
February 8, 2003 14:00	199.4	6	6.5	28.98	225	29.8	65	30.0	62	30.2	59	30.5	14.8

Appendix IX – Large Scale Installations in BC

Solar DHW for an International Airport

YVR International Airport, Vancouver B.C.

Solar DHW for domestic terminal building, installed May 2003
100 – 4'x8' glazed collectors, closed-loop glycol

Solar was one component of an integrated energy efficiency retrofit.

Project partner: Keen Engineering Ltd.

Taylor Munro Energy Systems Inc.
11-7157 Honeyman St., Delta, BC V4G 1E2
Tel: 604-946-4433 Fax: 604-946-3804
www.taylormunro.com

Solar DHW for a Community Centre

Hyde Creek Community Centre, Port Coquitlam B.C.

Solar DHW for year-round operation, installed January 2004
42 glazed collectors with storage, drainback

Collector racks made from reclaimed cedar.
System also provides some heat for swimming pool.

Project partner: Coral Engineering Ltd.

Taylor Munro Energy Systems Inc.
11-7157 Honeyman St., Delta, BC V4G 1E2
Tel: 604-946-4433 Fax: 604-946-3804
www.taylormunro.com

Hyde Creek Recreation Centre

(solar water heating technology)

Project in Brief

The City of Port Coquitlam has completed an energy retrofit of its Hyde Creek Recreation Centre, resulting in substantial annual cost savings. The installation of a high efficiency boiler, heat recovery system and a solar thermal system has contributed to reducing the energy consumption and costs.

> *"Aquatic facilities are one of the most expensive and energy intensive facilities a municipality operates. Energy and resource management programs and the use of renewable and sustainable energy resources are an essential part of the short- and long-term business plan for their economical sustainability and environmental impact."*

Project Description and Objectives

Energy consumption is one of the major costs at swimming pools in municipal recreation centres. In 2003, the GVRD released a report that documented the advantages of municipalities replacing natural gas systems with solar systems to heat swimming pools.

The City of Port Coquitlam, already advocating solar heat, completed a retrofit of its Hyde Creek Recreation Centre in 2004. Forty-two solar thermal panels were installed, primarily for use in heating domestic water, but with the capability of heating the pool in the future.

To recover the significant amount of energy lost through pool evaporation, two heat reclaim units were installed. One unit redirects previously lost heat back to the pools, while the other directs its recovered energy to heat domestic hot water. A ‘demand' ventilation system was installed in the gym, where outdoor air is added as the C02 increases in the gym.

Results

- With the panels installed, the solar thermal energy is almost free, because only one small pump is required.
- The panels have resulted in annual savings to the city of $4,000.
- The entire retrofit resulted in a 30% energy reduction at the centre, and total annual savings of between $40,000 and $50,000. The entire retrofit resulted in a 44% reduction in natural gas consumption and a 13.5% reduction in total energy use in 2005. (These numbers take into account an increase in the electrical load and a decrease in the natural gas load.)
- Total annual savings on energy costs were $14,400 for 2004 and $21,250 for 2005.

Next Steps

The Hyde Creek Infrastructure Project was the first of several projects that incorporate energy efficient technology into major renovations and new buildings.

- The Terry Fox Library in Port Coquitlam is receiving funding from the Canada – British Columbia Infrastructure Program to implement energy efficiency upgrades that are in progress.

- The Leigh Square Arts Village is a recently started project that includes a new building designed to meet the requirements for Silver LEEDS accreditation.

Lessons Learned

- Solar thermal water heating can be an important part of a greater energy reduction initiative.
- Researching and developing energy efficient proposals can help provide alternative funding for projects.

Partners

- Canada – British Columbia Infrastructure Project (BCIP)
- Renewable Energy Deployment Initiative (REDI)
- Coral Engineering
- Quantum Lighting

Contact

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