file copy pdf on S: drive 7

Lowe Street Solar Panels Monitoring Project
Final Report V.2

Whitehorse, Yukon

Submitted to:
Doug MacLean
Energy Solutions Centre
206A Lowe Street
Whitehorse, YT Y1A 1W6

March 15th, 2006

LESSOWAY MOIR PARTNERS
107A Copper Road
Whitehorse, YT Y1A 2Z7
Tel: 867-393-2905
Fax: 867-393-2910

LMP file: 0403034001
ESC Contract#: 2004-10

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Project Scope

The purpose of the Lowe Street Solar Panel Monitoring Project is to evaluate the feasibility of using solar energy as an alternative source of energy in the Yukon Territory. Three different types of solar collector panels were installed on the roof of Energy Solutions Centre located at 206A Lowe Street, Whitehorse. These solar panels are integrated into a solar water heating system to complement the building's domestic hot water heating system throughout the year. In addition, a solar wall was installed on the south-end wall of the building to preheat intake air going into the primary space-heating system during the heating season. By monitoring the performance level of the solar panels and the solar wall and comparing them to available data from other studies made by solar panel manufacturers and independent institutions such as Solar Rating and Certification Corporation (SRCC), the feasibility of using solar energy as an alternative source of energy in the Yukon Territory can be determined.

1.2 Report Objectives

There are three major objectives for this progress report:

1) To determine the relative and absolute performance level of the three different types of solar collectors used for domestic hot water heating throughout the year.
2) To determine amount of energy savings provided by the solar wall system during the heating season.
3) To ensure that the data collected for this project is correct and relevant.

2.0 BACKGROUND INFORMATION

Energy Solutions Centre installed three types of solar panels and one solar wall at their office building located at 206A Lowe Street in Whitehorse, Yukon. Their abilities to collect solar energy were monitored since fall of 2003 when this solar energy equipment was installed.

2.1 Solar Collectors

Three types of solar panels are being compared in terms of efficiency in providing heat to a domestic hot water system. They are installed side by side in an open area on the roof of the Yukon Energy Solutions Centre; therefore, they are exposed to the same conditions at all times (e.g. direct and indirect solar radiation level, wind, and ambient temperature).

The three solar collectors are described below; please refer to Appendix A for manufacturer's information on each of these collectors.

2.1.1 SP-1: Glazed Flat-Plate Solar Collector

Solar Panel No. 1 is a Solcan 2101L 46"x 96" glazed flat-plate solar collector with a net absorber area of 2.68 m^2. The glazing of the solar collector is made of tempered glass and its purpose is to transmit incoming shortwave solar radiation to the solar panel while preventing longwave radiation emitted from the panel from travelling back to the atmosphere; consequently, the net radiation energy per unit area absorbed by the solar panel should theoretically be higher than that of an unglazed flat-plate solar collector, thus making it more efficient. Solcan claims that one glazed solar collector should provide approximately 2400 kW*h of energy per year[1]. Since the typical Yukon environment is more extreme than most Canadian environments, the data collected from this solar panel is used to compare against Solcan's estimation.

---

[1] Solacan Ltd Website: http://www.solcan.com

The retail price of this solar panel was $995.00 CND at the time of purchase (Year 2003).

2.1.2 SP-2: Evacuated Tube Solar Collector

Solar Panel No. 2 is a Thermomax Solamax® 20 tube direct flow evacuated solar energy collector with a net absorber area of 2.0 m^2. This type of solar panel consists of heat pipes surrounded by glass tubes with vacuum in the spaces in between. The purpose of the vacuum is to prevent heat loss back to the atmosphere via convection and conduction. The combined effects of vacuum tube and heat pipe technologies allow this type of solar collector to achieve a higher operating temperature than those of the glazed or unglazed flat plate solar panel. Evacuated solar collectors can be up to 50% efficient even when the collector-ambient temperature reaches 110°C, whereas a flat plate solar collector would have 0% efficiency at this temperature[2]. Thermomax does not provide an estimated thermal performance value for its solar collector, but an independent study performed by Power Smart Technical Services & Research found that the Solamax® solar collector collected 2800 MJ/m^2 (778 $kW*h/m^2$) of solar energy per year when used in domestic water heating[3], which translates to 1556 kW*h of annual energy collection for a 2 m^2 solar collector.

The retail price of the Solamax® panel was $2300.00 CND at the time of purchase.

2.1.3 SP-3: Unglazed Flat-Plate Solar Collector

Solar Panel No. 3 is a Techno-Solis TS32 unglazed flat-plate solar collector with a net absorber area of 2.95 m^2. Its design is very simple in that it uses extruded plastic strips as the absorber and there is no glazing to prevent radiation loss from the absorber. Due to its simple design, this type of solar collector is very economical when compared with the glazed flat-plate and evacuated tube solar collectors; however, it is theoretically the least efficient of the three types of solar

---

[2] Thermomax® Evacuated Solar Energy Collector: Technical Reference & Installation Manual

[3] Technical Potential for Electrical Energy Savings from Residential Solar Domestic Water Heating in BC Hydro's Non-Integrated Areas

collectors being studied when used in domestic hot water heating. The manufacturer claims that this model of solar collector has a peak thermal performance of 8.9 kW*h/day; however the testing location was in Florida, U.S. and considerably lower level of performance would be expected in Yukon.

The retail price of this solar panel was $250.00 CND at the time of purchase.

2.2 Solar Wall System

The most common use of a solar wall system is to preheat ventilation from outside before it enters the building's primary space-heating system. With preheating, the difference between room temperature and outside temperature is reduced, and therefore, the building primary heating system would use less energy to heat the outside air to room temperature, which translates to energy savings.

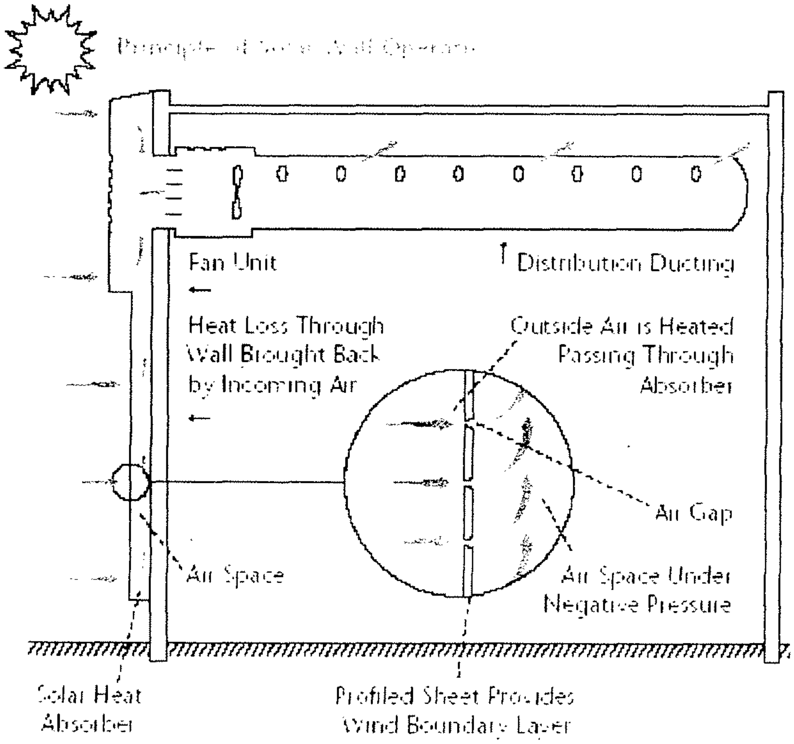


Figure 1: Principle of Solar Wall Operation[4]

---

[4] Conserval Engineering Inc. Website.

The basic working principle of a solar wall system is illustrated in Figure 1: a dark perforated cladding is mounted on the side of a building (preferably facing south). During daytime, solar radiation is collected by the dark perforated cladding and is transformed into thermal energy on the cladding. When the solar wall system is operational, the isolation damper is open and the solar wall system supply fan is activated; consequently, negative pressure would force outside air through the perforation of the cladding and, during this process, heat is transferred from the cladding to the outside air. The supply fan would then deliver this preheated air to the building's primary heating system if additional heating is needed. The Solar Wall installed at Energy Solutions Centre is 24'x6.8' (7.3mx2.1 m) in dimension and has a net collection area of 15.2 m^2.

The installed cost of the solar wall is estimated to be in the order of $5000.00 CND at the time of purchase.

3.0 METHODOLOGY

3.1 Data Logger

A web-based data logger was utilized to monitor the data required for this project. The JACE-403 platform has the ability to request and record signal outputs from multiple sensors and transmitters monitoring the conditions of the solar equipments. After its processor organizes all the signal outputs by the sensors, the JACE-403 platform can record this data into organized logs on a website on the World Wide Web where users can access this data remotely. To see this web-based data logger's interface and operation, please visit Energy Solutions Centre's website for this project[5].

3.2 Solar Collector Monitoring

The three solar collectors were installed side by side on the roof of Energy Solutions Centre situated on 206A Lowe Street, Whitehorse as shown in Figure 2. All three solar collectors were installed to face building south (true southeast) to maximize their exposure to sunlight during the summer months and were tilted approximately 55 degrees upward from the horizontal to collect the maximum solar radiation throughout the year for Whitehorse's latitude of 60.7° N. The intent of this set up was to ensure the same level of solar radiation would be exposed to each collector at all times; therefore, making the comparison between each collector's level of performance valid.

---

[5] [illegible] **(User Name:** user **Password:** user)

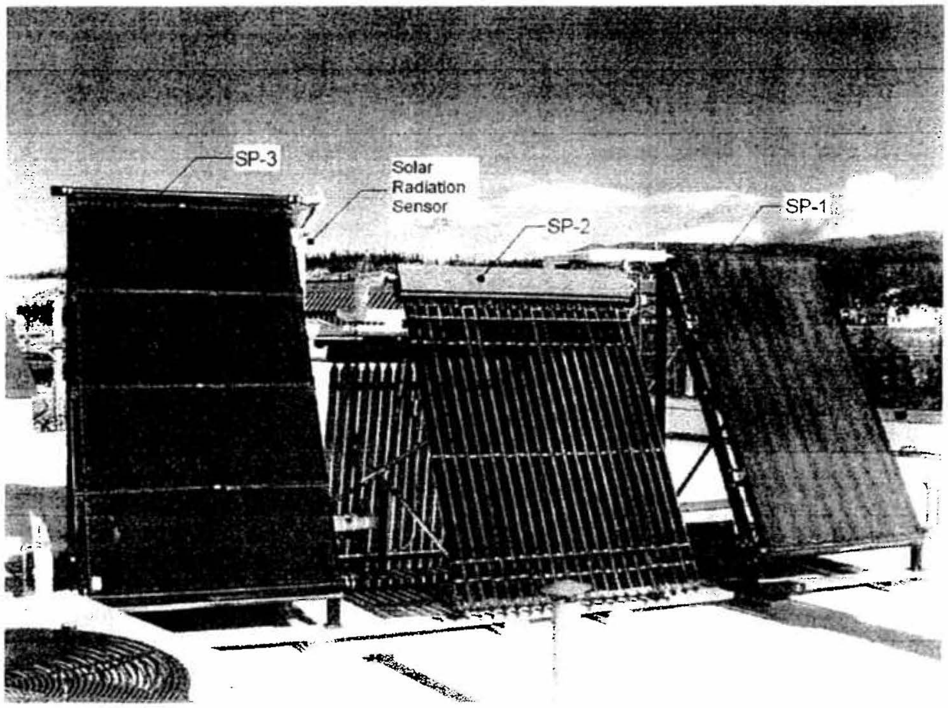


Figure 2: Setup of the Solar Collectors Being Evaluated

(From Left to Right: SP-3: Unglazed Flat-Plate Collector, SP-2: Evacuated Tube Collector, SP-1: Glazed Flat-Plate Collector)

3.2.1 Solar Radiation Sensor

A solar radiation sensor mounted on SP-3 monitors the solar irradiation level at site at all times. The sensing surface of the radiation meter is parallel to the absorber plate surfaces of the solar collectors to ensure that it has the identical solar radiation incident angle as all the collectors. The solar radiation data is used in the analysis to determine how much solar energy is available to the solar collectors for each month.

3.2.2 BTU(1) Transmitter

Each solar collector initiates an energy collection sequence once the absorber plate temperature of the collector reaches 40°C or above. For the sequence of operations of the solar water heating system, please refer to Appendix C. When the energy collection process is initiated, propylene glycol heat transfer fluid is pumped through the solar collector's manifold and collects the thermal energy released by

---

(1) BTU: British Thermal Unit ; a unit of measurement of energy

the solar collector's absorber plate during its circulation. As the glycol is pumped through the solar collector's manifold, temperature sensors monitor the inlet and outlet temperature of the solar collector while a metallic tee flow sensor, as shown Figure 3, measures the flow rate of the glycol through the solar collector's manifold.

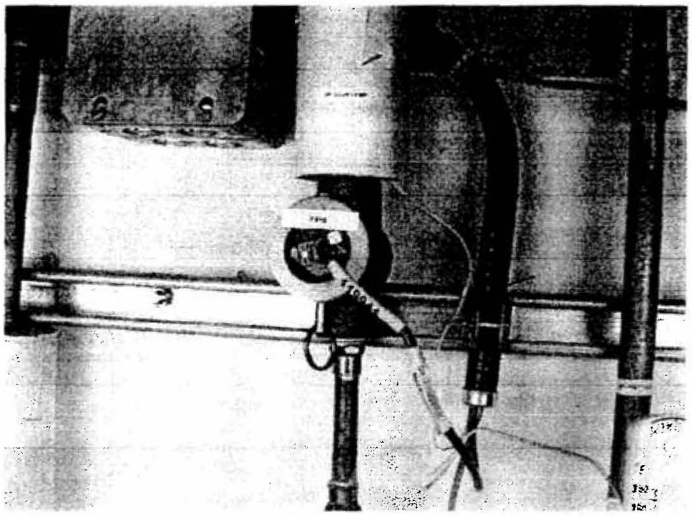


Figure 3: Metallic Tee Flow Sensor Measuring Glycol Flow Rate through SP-2

With the temperature difference or flow rate data available, a Data Industrial Series 340LW BTU transmitter uses the following equation to calculate the actual thermal energy being transferred from the solar collector to the heat transfer fluid:

$$Q_{delivered} = m_{gly} \cdot c_{gly} \cdot \Delta T \qquad \text{Equation i}$$

where

$Q_{delivered}$=Thermal Energy Transferred to Glycol by the Solar Collector (BTU)

m_{gly}=Mass of glycol Flowing Through the Solar Collector in a Specified Amount of Time (lb)

c_{air}=Specific Heat Capacity of Propylene Glycol (BTU/(lb*°F))

ΔT=Temperature Difference between Solar Collector Inlet and Outlet (°F)

The calculated thermal energy values for each solar collector are transmitted to the JACE-403 data logger where their energy unit is converted from BTU to kilowatt hour (kW*h), the common energy unit used by energy providers in Canada.

3.2.3 Determining Solar Collector's Efficiency

A solar collector's empirical efficiency can be defined by Equation ii:

$$\eta_{collector} = \frac{Q_{delivered}}{I_{collector}} * 100\% \qquad \text{Equation ii}$$

where

$\eta_{collector}$ =Solar Collector's Efficiency (%)

$Q_{delivered}$=Heat Energy Transferred to the Glycol by the Collector; Measured by BTU Transmitter using Equation i (kW*h)

$I_{collector}$ =Solar Radiation Energy Exposed to the Solar Collector; Measured by Solar Radiation Sensor (kW*h)

Using Equation ii, the empirical efficiencies of all three types of solar collectors were determined. In order to effectively illustrate the performance of each solar collector throughout a year, both $I_{collector}$ and $Q_{delivered}$ were tallied after each month and a monthly efficiency was determined for each solar collector.

3.3 Solar Wall System Monitoring

The solar wall system operates on a programmable occupancy schedule (refer to Appendix D for the solar wall system's sequence of operations). Once the system is in occupancy mode, an isolation damper opens and the solar wall system supply fan is energized. When the solar wall system supply fan is energized, it delivers approximately 200 cfm (cubic feet per minute) to the building's ceiling return plenum.

Two temperature sensors are used in the solar wall system performance evaluation: one to measure the outside ambient temperature and the other to measure the solar wall discharge air temperature. The temperature difference between the outputs of these two temperature sensors is the air temperature gained through the solar wall. Since the mass flow rate of the air is known, Equation iii is used to determine the amount of energy the solar wall captured for a specified duration of time by pre-heating the outside air:

$$Q = m_{air} \cdot c_{air} \cdot \Delta T \qquad \text{Equation iii}$$

where

Q=Heat Energy Captured by the Solar Wall for a Specified Amount of Time (kJ)
m_{air}=mass of air delivered by the Supply fan for a Specified Amount of Time (kg)
c_{air}=Specific Heat Capacity of Air (kJ/(kg*°C))
ΔT=Air Temperature Gained through the Solar Wall (°C)

4.0 EXPECTATIONS

4.1 Solar Collectors' Efficiency Expectations

The efficiencies of all solar collectors exhibit an inversely linear relationship with the heat loss parameter, an empirical variable that defines the relative heat loss of a solar collector to the environment while it is in operation[6]; it is defined by the following equation:

$$H.L.P. = \frac{(t_i - t_a)}{I_t} \qquad \text{Equation iv}$$

where

H.L.P. =Heat Loss Parameter (°C*m²/W)

t_i =Collector Inlet Temperature (°C)

t_a =Ambient Air temperature (°C)

I_t =Incident Solar Radiation Exposed to the Collector (W/m²)

A small heat loss parameter (i.e. <0.02) means that the heat that the solar collector is losing to the environment is very minor, while a large heat loss parameter (i.e. >0.09) means that the solar collector is losing a large amount of heat to the environment. In addition, a heat parameter of zero means that the solar collector is not experiencing any heat loss to the environment, while a negative heat loss parameter (i.e. <0) indicates that the collector is actually gaining heat from the environment (excluding solar radiation energy collected).

For the purpose of domestic hot water heating, ASHRAE(2) estimates that the heat loss parameter would be in the range of 0.02 to 0.065, with 0.02 being in a very warm climate and 0.065 being in a cool climate[7]. By examining the typical collector efficiency of the unglazed flat-plate, the glazed flat-plate and the

---

[6] 2000 ASHRAE Handbook: HVAC Systems and Equipment, Section 33.7

(2) ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

[7] 2000 ASHRAE Handbook: HVAC Systems and Equipment, Section 33.7 and 33.8

evacuated tube types of solar collectors in this heat loss parameter range, the following figure was constructed:

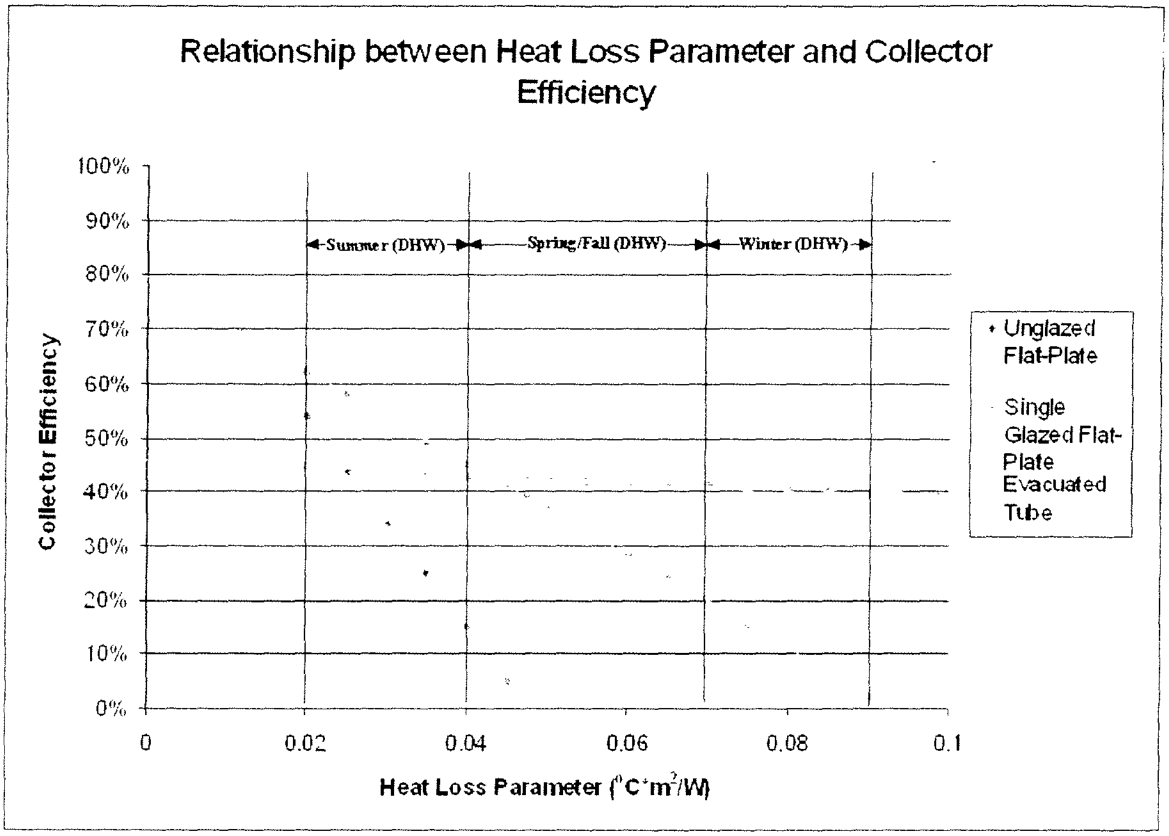


Figure 4: Relationship between Heat Loss Parameter and Collector Efficiency [8]

For the typical Yukon climate, the heat loss parameter is estimated at 0.020-0.04 during the summer, 0.04-0.07 during the spring and the fall, and 0.07-0.09 during the winter.

Using the information from Figure 4, it is expected that the glazed flat-plate solar collector would be the most efficient in heating domestic hot water during the summer months while the evacuated tube solar collector would be the most efficient during spring and fall.

---

[8] 2000 ASHRAE Handbook: HVAC Systems and Equipment. Section 33.7

During winter when the heat loss parameter for domestic hot water heating application could increase to 0.09 or higher, both the unglazed and glazed flat-plate solar collector would have practically zero efficiency while the evacuated tube solar collector would be expected to have efficiency as high as 40%. Although the evacuated tube solar collector is theoretically very efficient during winter, the duration of daylight in Whitehorse is so brief during this period (minimum of less than 5 hours) that there is not enough solar energy available for the collector to produce a significant level of useful energy for the domestic hot water system. Furthermore, the absorber plates of the solar collectors must heat up to 40°C before the solar collectors' energy collection sequence initiates. Consequently, unless solar radiation is intense enough to heat up the absorber plates from sub-zero temperatures to 40°C during the brief daylight hours, the solar collectors will not operate at all. For this reason, it is expected that none of the solar collectors will have significant impact on the domestic water heat system during winter (October 2004 to March 2004). The operation of the solar panels is also limited by frost in April and September. The existing water heater and boiler must take up the entire heating load.

4.2 Solar Wall System Energy Savings Expectations

A study performed by Enbridge Consumers Gas Inc.(3) indicates that the solar wall installed in their vehicle repair facility in Toronto was able to heat up the outside temperature for an average of 9°C during the heating season[9]. If this value is applied to the Lowe Street Site in Whitehorse, it is estimated that the solar wall would provide 1790 kW*h of energy savings from October to March when constant heating of the building is required.

---

(3) Enbridge Consumers Gas Inc.: A subsidiary of Enbridge Inc. based in Calgary, Enbridge Consumers Gas Inc. operates the largest natural gas distribution system in Canada.

[9] Natural Resources Canada Website: http://www.canren.gc.ca/prod_serv?index.asp?CaId=137&PgId=742

5.0 RESULTS

5.1 Solar Radiation

In order to measure the efficiency of the three solar collectors, the solar radiation available to these panels was tallied monthly for a period of one year. Figure 5 shows the amount of solar radiation available at the Lowe Street site.

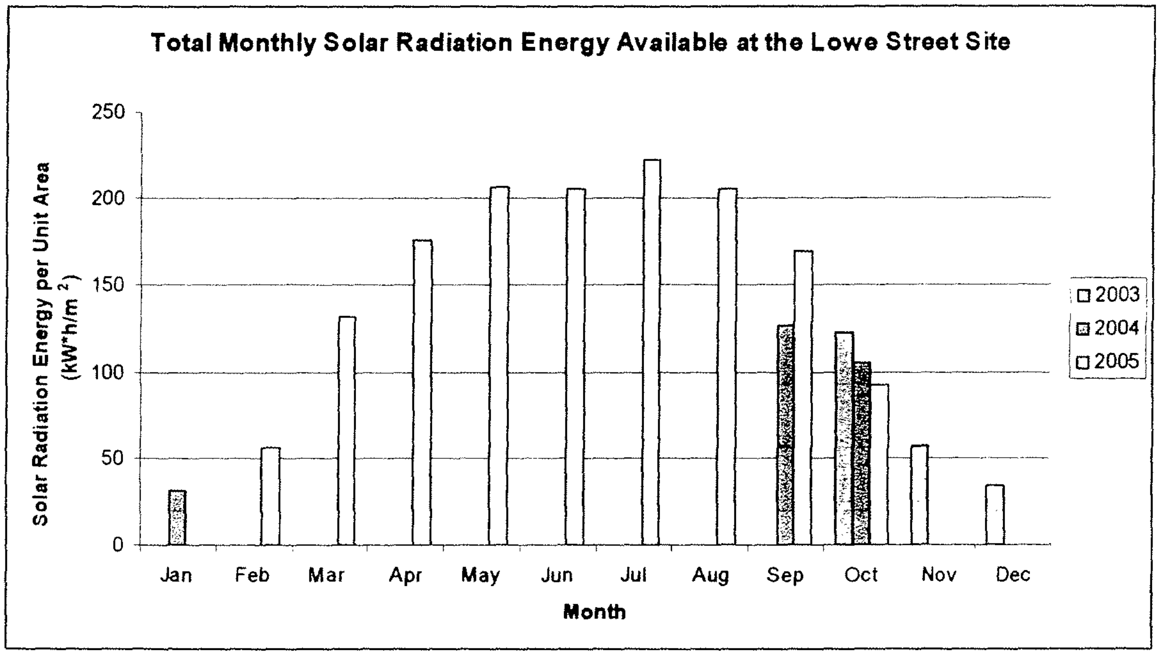


Figure 5: Total Available Solar Radiation at the Lowe Street Site

In Yukon, daytime is comparatively longer than the rest of the country during summer; however, it is also significantly shorter than the rest of the country during winter. Consequently, there is a considerable difference in the total available solar radiation energy between the summer months and the winter months. The 2005 total monthly solar radiation energy available peaked in July at 222 kW*h/m^2. In contrast, only 31 kW*h/m^2 was available during January 2004, approximately one seventh of the peak value.

5.2 SP-1: Glazed Flat-Plate Solar Collector

Using BTU transmitters in conjunction with temperature and flow sensors, the total energy each solar collector delivered to the heat transfer fluid was measured. Figure 6 shows the thermal energy collected from Solar Panel No.1 for each month.

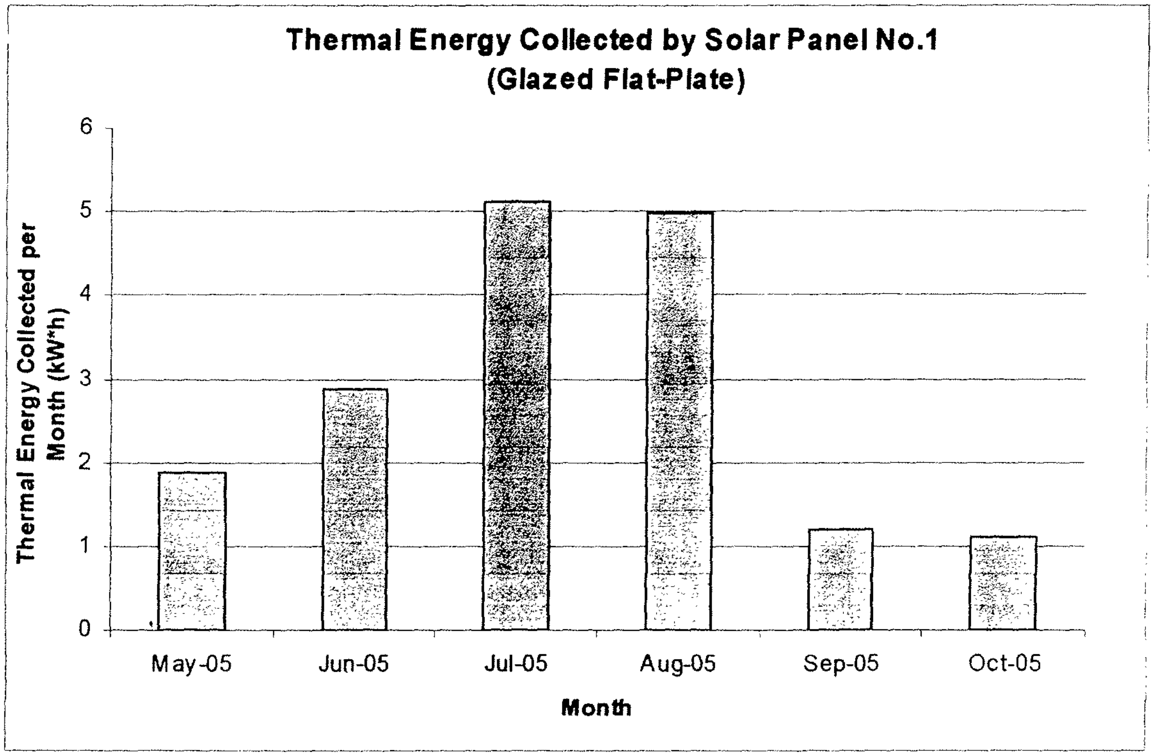


Figure 6: Total Thermal Energy Collected by Solar Panel No.1
*Note: Data from November, 2004 to April, 2005 are unavailable

The thermal energy collected by Solar Panel No.1 was significantly less than expected, with only approximately 27 kW*h of energy collected during the summer and fall months of 2005. While the manufacturer's claim that this solar collector could produce up to 2400 kW*h of energy annually, this estimate may be too high for the Yukon environment, as the measured result was less than 2% of the manufacturer's claim.

To determine the efficiency of Solar Panel No.1, the results of Figure 6 were plotted as a percentage of the total solar radiation available to this panel. The results are shown in Figure 7.

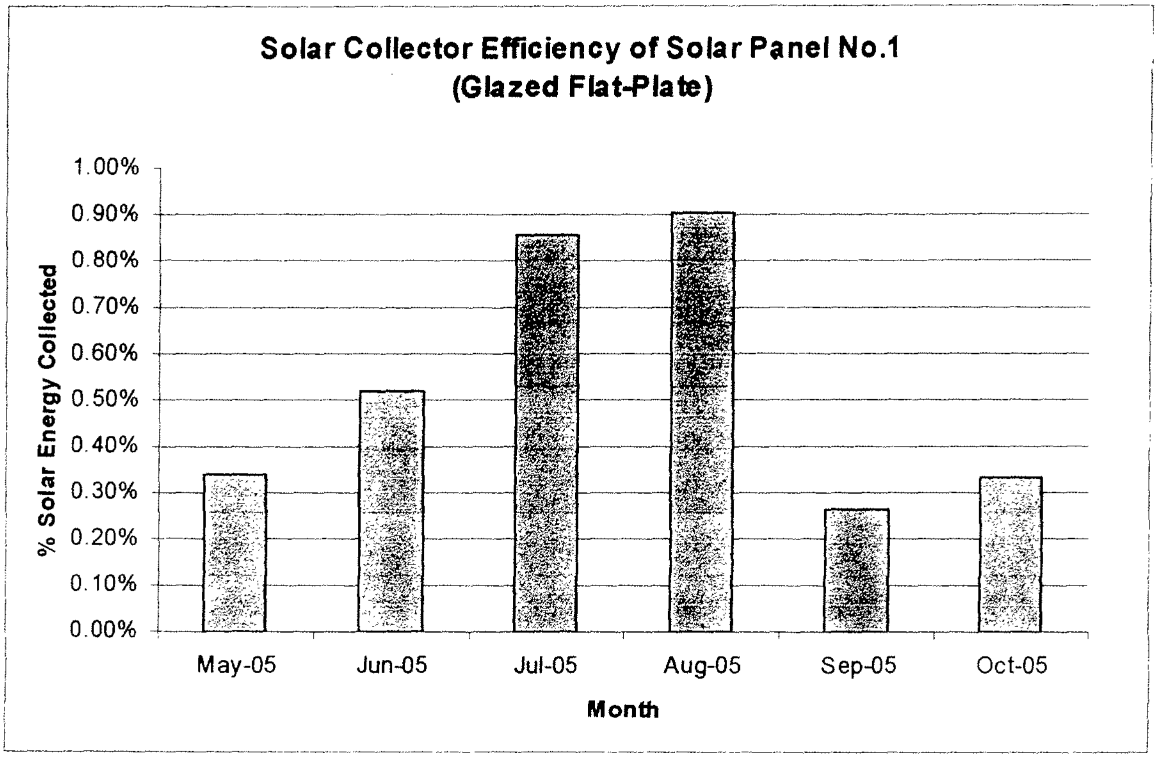


Figure 7: Solar Collector Efficiency of Solar Panel No.1
*Note: Data from November, 2004 to April, 2005 are unavailable

Since solar collector efficiency is directly proportional to the amount of thermal energy collected by the solar collector, as shown in Equation ii, the low values from Figure 6 carried over to yield unexpectedly low values of efficiency for Solar Panel No.1. From Figure 4, it was expected that a glazed flat-plate solar collector used for heating domestic hot water would have 24%-62% efficiency depending on the climate; however, the recorded data yielded efficiencies of only 0.26%-0.9%.

By comparing the monthly data, it is observed that Solar Panel No.1 is most efficient during July and August when the heat loss parameter is at its lowest level.

This result is consistent with Figure 4 which shows an inversely linear relationship between heat loss parameter and solar collector efficiency. This means that the solar collector was able to collect more solar radiation energy in the summer and deliver it to the glycol, not only because more solar radiation energy was available in the summer, but also because there was less heat loss from the system to the environment (higher ambient temperatures).

5.3 SP-2: Evacuated Tube Solar Collector

Similar to Solar Panel No.1, a BTU transmitter was also used to measure the total thermal energy collected by Solar Panel No.2. The total energy collected was tallied each month as shown in Figure 8.

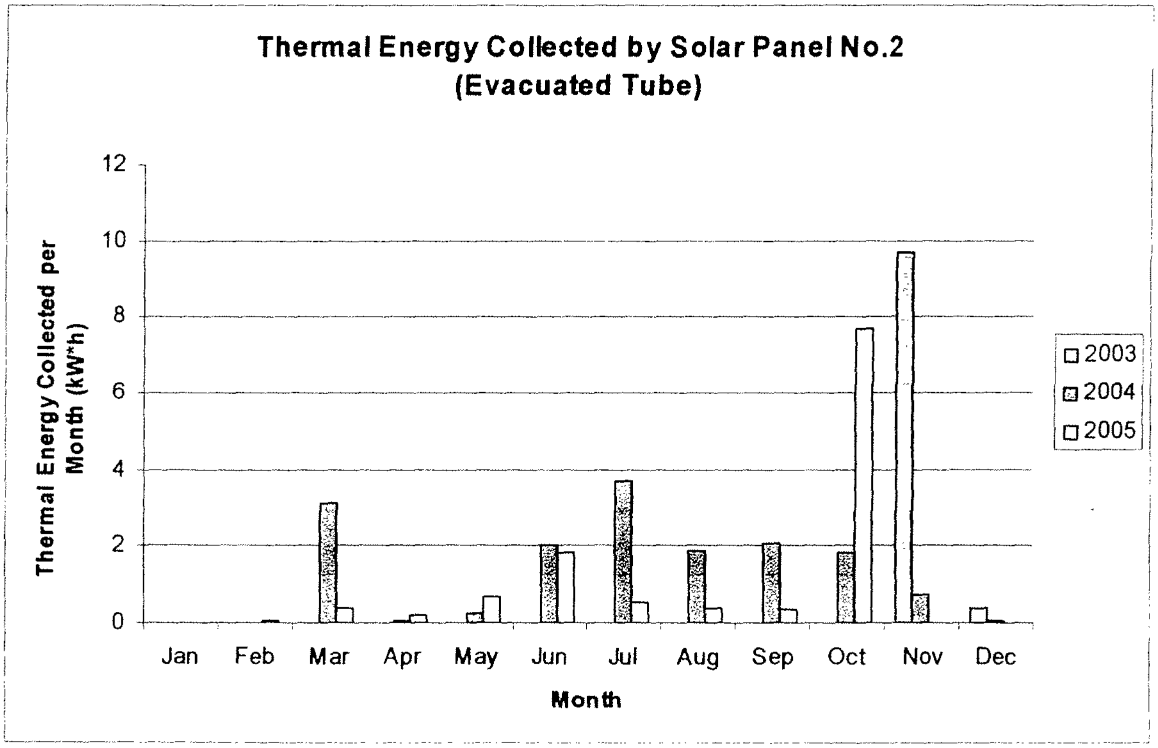


Figure 8: Total Thermal Energy Collected by Solar Panel No.2

The measured results looked particularly poor during July and August of 2005 with the solar collector delivering less than 2 kW*h of energy to the heat transfer fluid when over 400 kW*h of solar radiation energy was exposed to Solar Panel No.2 during each of these two months.

In addition, when a month-to-month comparison is performed between 2004 and 2005, there is a significant difference between the results of the two years (except June). Therefore, the data lacks consistency.

The results of November 2003 and October 2005 were significantly higher than the norm. For November 2003, the relatively high reading could be due to initial testing of the BTU transmitter as it was newly installed then. For October 2005, it was noted that glycol was flowing through the solar panel at two to three times higher than its designed flow rate; consequently, a flow balancing procedure was carried out to rectify the problem.

By summing the highest values of each month for the three years and averaging them, Solar Panel No.2 collected less than 40 kW*h of energy annually. When compared with the results of the independent study performed by Power Smart Technical Services & Research where an equivalent of 1556 kW*h of energy was collected by the same model of collector, Solar Panel No.2 collected only 2.5% of the energy claimed in the study.

Using the values from Figure 5 and Figure 8 in conjunction with Equation ii, the efficiencies of Solar Panel No.2 were determined as shown in Figure 9.

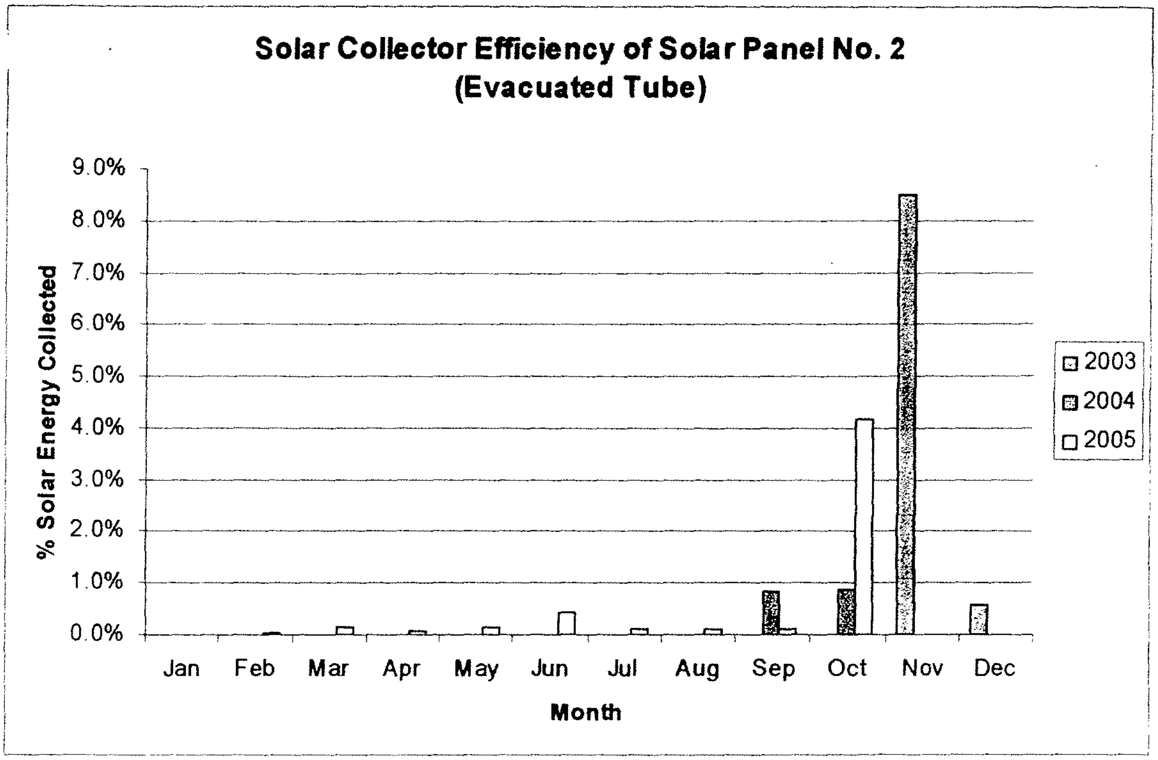


Figure 9: Solar Collector Efficiency of Solar Panel No.2

From Figure 4, it was expected than Solar Panel No.2 would have an efficiency of 40%-45% when used in heating domestic hot water; however, the measured efficiency of Solar Panel No.2 never reached 10% and stayed mostly below 0.5%.

Out of the three solar collectors, the evacuated tube solar collector should be able to better maintain its level of efficiency during the seasonal transition of summer to fall than the other two collectors. However, Figure 9 showed that the solar collector was much more efficient during the fall than in the summer. This result contradicted the relationship between solar collector efficiency and heat loss parameter shown in Figure 4 and did not appear to be valid. As mentioned above, the erroneous result of October 2005 could be attributed to the abnormally high flow rate through the solar collector, while the comparatively high values of November 2003 could be caused by initial testing of the BTU transmitter.

5.4 SP-3: Unglazed Flat-Plate Solar Collector

The Techno-Solis TS32 unglazed flat-plate solar collector was primarily designed for swimming pool heating during the summer. Since domestic hot water heating has a higher heat loss parameter range than pool heating, Solar Panel No.3 was expected to be less efficient than the other two solar collectors when used in a domestic hot water heating application.

Figure 10 shows the measured amount of thermal energy Solar Panel No. 3 collected each month.

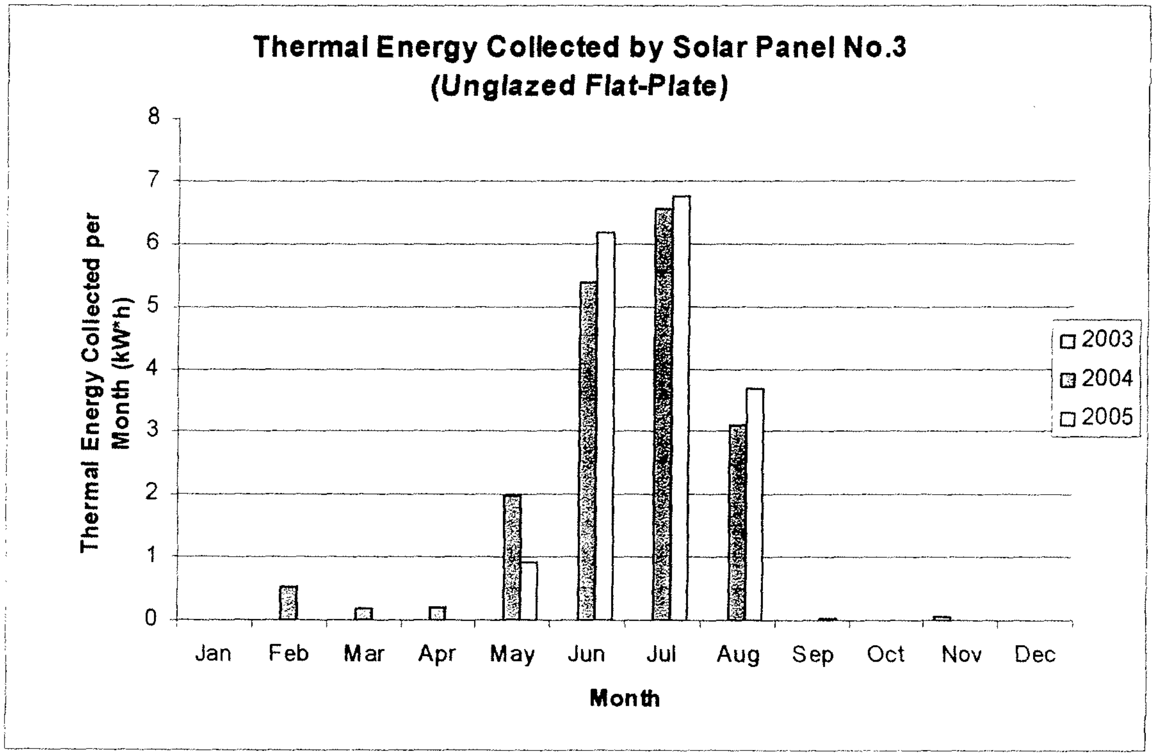


Figure 10: Total Thermal Energy Collected by Solar Panel No.3

Although Solar Panel No.3 was expected to be the least efficient of the three solar collectors, the amount of thermal energy collected each month was even less than expected. The manufacturer of this panel claimed that the panel could produce up to 8.9 kW*h per day of energy during the summer; however, Figure 9 showed than the solar collector collected less than 7 kW*h of energy per month during the summer, which is only 3% of the manufacturer's claim.

From Figure 4, it was expected that Solar Panel No.3 would have the largest performance drop-off of the three solar collectors when the heat loss parameter increases (i.e. transition from summer to fall); Figure 11 shows that this is indeed the case.

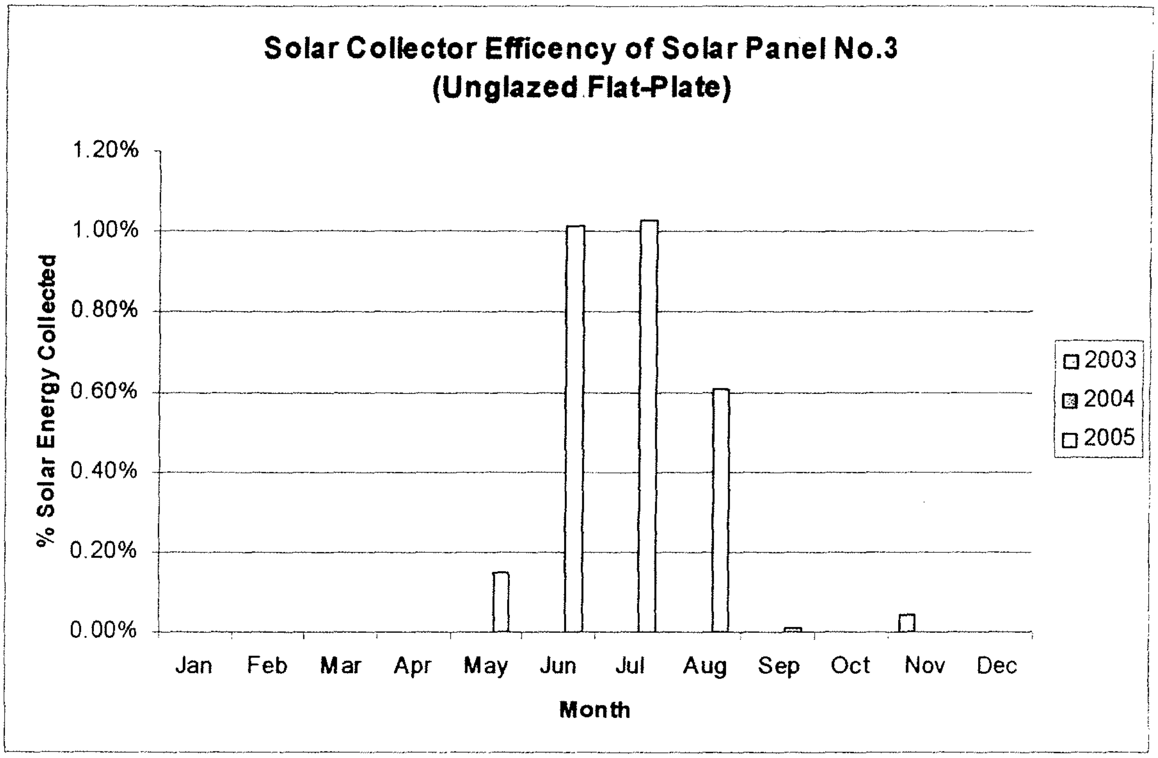


Figure 11: Solar Collector Efficiency of Solar Panel No.3

By comparing the efficiency of the collector between the months, it was observed that Solar Panel No.3 was more than 1% efficient during June and July, 2005 and 0.6% efficient during August, 2005. However, as soon as the fall season began in September, the efficiency of the collector dropped drastically to almost zero. The same level of significant increase can be seen at the transition from spring to summer.

While Solar Panel No.3 appeared to have the highest efficiency during the summer out of the three collectors, it only operated for approximately four months per year and became non-operational as soon as the fall arrived.

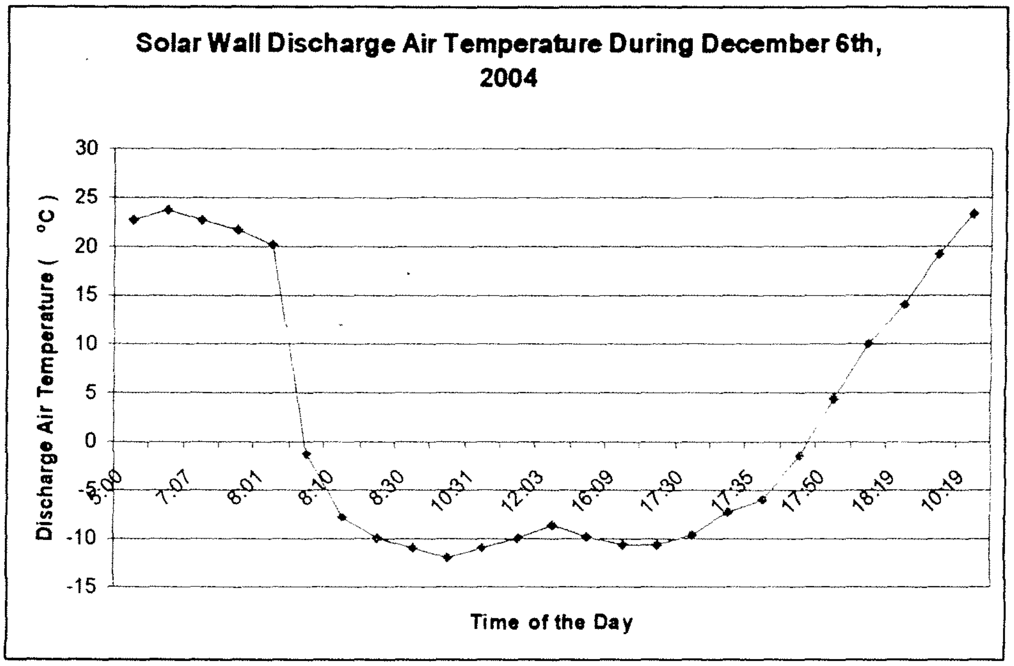
One reason behind such drastic drop-off in performance is that the bypass valve of the solar collector inlet only opens when the absorber plate temperature reaches 40°C or above (Refer to Appendix C). However, since Solar Panel No.3 is unglazed and poorly insulated, the onset of fall brought the onset of lower temperatures resulting in a sharp increase in heat loss to the environment. While the collector was still collecting solar energy from the sun, the absorber plate could no longer reach 40°C or above due to this heat loss and the energy Solar Panel No.3 collected could not be delivered to the glycol as the bypass valve was shut off.

5.5 Solar Wall System

To determine the amount of energy savings that the solar wall system was able to deliver to the space heating system in the Energy Solutions Centre, Equation iii was applied. With this equation, three parameters must be known: the mass flow rate of air into the building from the solar wall system supply fan, the outside air temperature, and the discharge air temperature from the solar wall.

The outside air temperature was monitored by placing a temperature sensor outside of the building where it was not exposed to direct solar radiation or exhaust air from the building. The supply fan maintained a volume flow rate of 200 cfm (339.8 m^3/hour); this value can be converted into a mass flow rate value by multiplying it by air density at the correct temperature value.

When the data for the solar wall discharge air temperature was examined, an irregularity was observed: the night time discharge air temperatures were at approximately room temperature values and decreased significantly once the system activated at 8:01am (refer to Appendix D for the sequence of operations of the solar wall system) as shown in Figure 12.



Solar Wall Discharge Air Temperature During December 6th, 2004

Figure 12: Solar Wall Discharge Air Temperature on a Typical Winter Day

The most likely cause for this irregularity was that the discharge air temperature sensor was placed too close to the inside of the building where warm air from the building would gradually heat up the sensor to room temperature once the isolation damper of the solar wall closed off at 5:30pm.

To resolve this problem, only data between 8:30am and 5:30pm during business days were analyzed. This would give the temperature sensor adequate time to stabilize and yield more accurate measurements. However, it should be noted that warm air from the building would still affect the discharge air temperature sensor when the solar wall system is in operation. Consequently, temperature readings higher than the actual discharge air temperature values may have been measured and recorded.

Due to the problem with the location of the discharge air temperature sensor, only data from the 2004-2005 heating season (October 2004 to March 2005), when the solar wall system was operational throughout the entire workday, was analyzed. During the time prior and subsequent to the heating season, when intermittent operation of the solar wall system was required during the day, warm air from the building would heat up the temperature sensor every time the isolation damper closed off; therefore, the data during these periods was too unstable to analyze and did not yield any meaningful results.

The difference between the solar wall discharge air temperature and the outside air temperature at any instant of time is defined as the solar wall temperature gain and represents ΔT in Equation iii. Figure 13 shows the monthly average solar wall temperature gain for the 2004-2005 heating season.

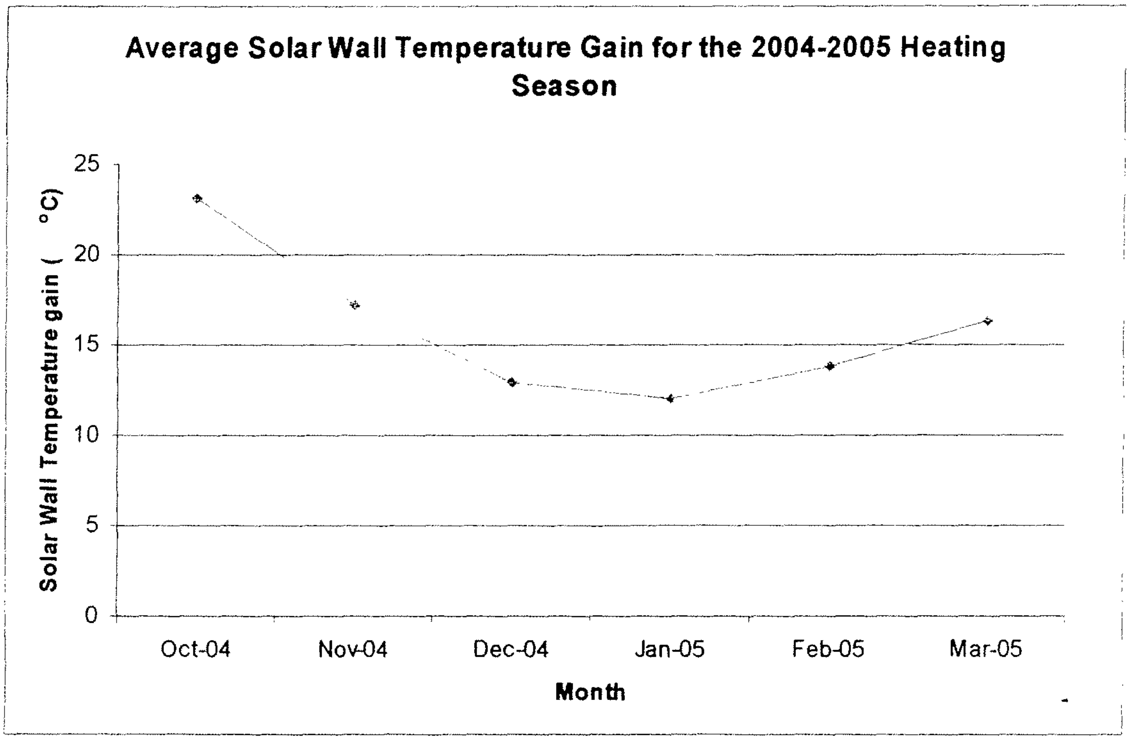


Figure 13: Average Monthly Solar Wall Temperature Gain for the 2004-2005 Heating Season

Average monthly solar wall temperature gain ranged from 23.1°C in October, 2004 to 12°C in January, 2005. The result is consistent because daylight hours gradually decreased until winter solstice (December 21st) became shorter and solar radiation intensity decreased as well. Therefore, during this darker period, less solar energy was collected by the solar wall to heat up the air when it went through the wall's perforations.

Using Equation iii, the total energy savings per month by the solar wall system were determined and are shown in Figure 14:

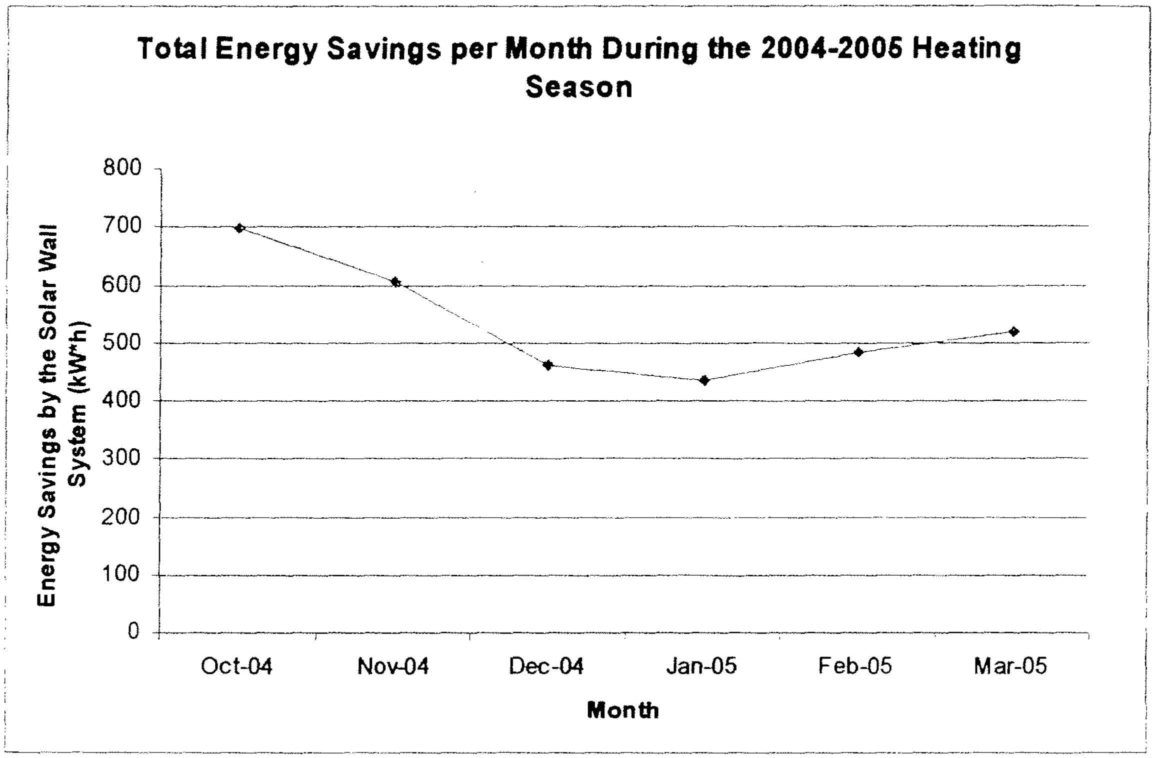


Figure 14: Total Monthly Energy Savings during the 2004-2005 Heating Season

*Note: Data was based on 22 business days per month

The solar wall was able to deliver substantial energy savings throughout the entire heating season. The average energy savings ranged from 698 kW*h in October to 436 kW*h in January.

Due to the inherent characteristics of solar energy equipment, the solar wall provided less energy to the building when the heating loads were at their highest; however, considering that daylight times in Yukon are so brief during the winter, the solar wall was still able to deliver approximately 436 kW*h of thermal energy to the building every month for a total of 3200 kW*h during the 2004-2005 heating season, which exceeded the earlier expectation of 1970 kW*h by 79%.

It is important to note that while measures were taken to account for the improper location of the solar wall discharge air temperature sensor, its effect on the measured energy savings is not be clear.

6.0 ANALYSIS

6.1 Solar Collectors

According to ratings published by the Solar Rating and Certification Corporation in Florida, U.S.A., solar collectors used for the purpose of domestic hot water heating generally have efficiencies ranging from 30% to 60% during the summer[10]. Since the heat loss parameters are generally higher in the Yukon Territory when compared to Florida, this range should be offset slightly lower. However, the maximum efficiency of the three solar collectors studied was only 1% and none of the three panels were able to collect more than 30 kW*h of energy throughout an entire year. These results indicate that all three solar collector installations are either flawed or not viable for the Yukon.

The potential for flaws were investigated subsequent to the data collection phase of this study as follows:

1. Arcrite Northern Ltd. was engaged to do a thorough review of the BTU transmitters and the associated wiring.
   a. A point for point review concluded that the wiring was done properly, and a complete relabeling was done for future reference.
   b. The flow sensors were manually inspected and the impellers spun by hand. The turbines did not spin freely and were suspected to be dirty.
   c. The spin of the impellers during the inspection did result in a reading by the logger so the transmitter was working properly.

   The BTU transmitters are sized for the design flow rates of the glycol heat transfer medium; however SP-3 has a design flow rate at the very bottom of the sensor's range. The BTU meters have Data Industrial Series 250 (0.25") metallic tee flow sensors which are designed for 0.3 – 15 ft/s. Current installation sees flow rates at as low as 0.3 ft/s.
2. Duncan's Ltd. was engaged to:

---

[10] Solar Rating and Certification Corporation Website: http://www.solar-rating.org/SUMMARY/Dirsum_20050613.pdf

   a. install isolation valves up and down stream of the flow meters so that they could be cleaned or replaced
   b. install Pete's plugs at the glycol supply and return of each solar collector for independent temperature gauges
   c. ensure that the system was not air locked by increasing the glycol level and monitoring the system pressure, and by installing an air bleeder on SP-2.

3. Arctech was engaged to complete a hydronic balancing of the system to ensure that the pump and balancing valves were set at the designed flow rates. These were confirmed as designed at:
   a. SP-1 = 5.8 gpm (design = 6.0gpm)
   b. SP-2 = 0.8 gpm (design = 0.7gpm)
   c. SP-3 = 0.3 gpm (design = 0.3gpm)
4. Lessoway Moir Partners did a visual inspection of the solar equipment and found that solar panel no.2 (evacuated tubes) showed the following signs of vacuum failure:
   a. During the summer months the tubes felt hot when they should feel cool to the touch
   b. There is chalky buildup on the inside of every tube similar to what is seen on an incandescent light bulb that has burned out
   c. There is condensed liquid on the inside of the tubes.
   d. There is a purple discoloration on the inside of the tubes.

6.2 Solar Wall System

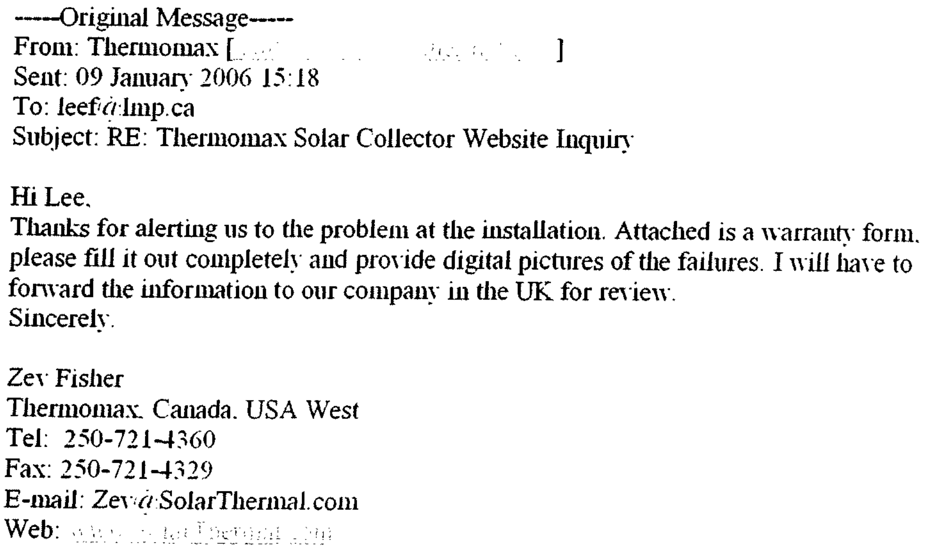
With the solar wall system the results are significantly higher than predicted (see section 4.2) at over 3200 kW*h of energy savings during the 2004-05 heating season. Due to the install cost of the system, however, the payback is high at over 10 years. It was also observed that the solar wall discharge air temperature sensor is located in an area where warm air from inside the building heats up the sensor whenever the isolation damper of the solar wall system is closed. Even though a corrective measure was taken to counter this problem, the full effect of this problem on the energy saving values cannot be known until the temperature sensor is relocated. Therefore, while energy savings were measured, they could be high due to erroneous discharge air temperature readings which caused the energy saving values to appear higher than they actually were.

7.0 RECOMMENDATIONS

7.1 Solar Collectors

The following are recommendations made to ensure data collection of the solar collectors is valid:

1. The BTU sensors do not appear to be measuring the flows properly. This is seen both in the data results of all three solar collectors, as well as during the manual inspection. It is recommended to maintain these sensors more stringently by periodically removing them and cleaning the impellers so that they spin freely. If the results do not improve subsequent to this, the sensors should be repaired or replacement sensors installed. Data Industrial sells impeller repair kits for $70 US (part# 230IPRK-1211) and they also have a Series 4000 sensor which is specially designed for low flows. Another alternative is the solar collector manufacturers' sensors which they use for testing their equipment. For example Thermomax has the SMT400 controller, however this is not internet compatible.
2. Solar equipment: Thermomax warranties their evacuated tubes at 100% for 5 years, and at 50% for another 5 years. Replacement of each tube is recommended using the warranty form found in Appendix H. Below is an e-mail communication from the Canadian representative of Thermomax Zev Fisher with his contact information.



-----Original Message-----
From: Thermomax [[illegible]]
Sent: 09 January 2006 15:18
To: leef@lmp.ca
Subject: RE: Thermomax Solar Collector Website Inquiry

Hi Lee,
Thanks for alerting us to the problem at the installation. Attached is a warranty form, please fill it out completely and provide digital pictures of the failures. I will have to forward the information to our company in the UK for review.
Sincerely,

Zev Fisher
Thermomax, Canada, USA West
Tel: 250-721-4360
Fax: 250-721-4329
E-mail: Zev@SolarThermal.com
Web: www.SolarThermal.com

Mr. Fisher has experience with tube failure and it would be beneficial for future installations to study the reason for the failure of these tubes. Once the causes of failure have been established, and the tubes have been replaced, collection of the performance data of SP-2 may resume and better conclusions as to their applicability in the Yukon may be drawn.

3. Evaluate advantages of adjusting the solar panel startup temperature to 34°C from 40°C to improve the operation time in colder weather. The associated costs of running the pump would have to be taken into consideration as well.
4. Evaluate the viability of adding a battery backup to the system to prevent overheating if there is a power failure.
5. Repeat hydronic balancing once the system has been reviewed as per the above recommendations.

7.2 Solar Wall System

To confirm the performance level of the solar wall system, the discharge air temperature sensor must be relocated. Subsequently, temperature readings should be logged and monitored throughout a one year period and especially during the heating season to ensure that there is not a significant difference between them and the present data.

The following are recommendations made to rectify the solar wall discharge air temperature sensor problem:

1. Relocate the solar wall discharge air temperature sensor to just outside of the isolation damper. With this new location, any influence indoor air has on the temperature sensor will be minimized since the isolation damper will be closed and will separate the sensor and indoor air when the solar wall system is inactivate.

2. After the sensor relocation, monitor the discharge air temperatures during the 2005-2006 heating season and compare them against those of the 2004-2005 heating season. If there are large discrepancies between the results of the two heating seasons, and barring any other technical problems that arise, then the data of the 2004-2005 heating season may be deemed erroneous and should not be used unless a correction factor can be determined.

LIST OF REFERENCES

2000 ASHRAE Systems and Equipment Handbook, Section 33.7 and 33.8

Conserval Engineering Inc. Website
http://www.solarwall.com/sw/swHow.html

Energy Solutions Centre's Lowe Street Solar Panel Monitoring Website
http://199.247.156.104/db/Energy_Solutions/Images/Home

Natural Resources Canada Website
http://www.canren.gc.ca/prod_serv/index.asp?CaId=137&PgId=742

Solar Rating and Certification Corporation Website
http://www.solar-rating.org/SUMMARY/Dirsum_20050613.pdf

Solcan Ltd. Website
http://www.solcan.com

Technical Potential for Electrical Energy Savings from Residential Solar Domestic Water Heating in BC Hydro's Non-Intergrated Areas, prepared by Power Smart Technical Services & Research, June 1, 1994

Techno-Solis Website
http://www.techno-solis.com/dimensionsmetric.htm

Thermomax® Evacuated Solar Energy Collector: Technical Reference & Installation Manual

APPENDIX A

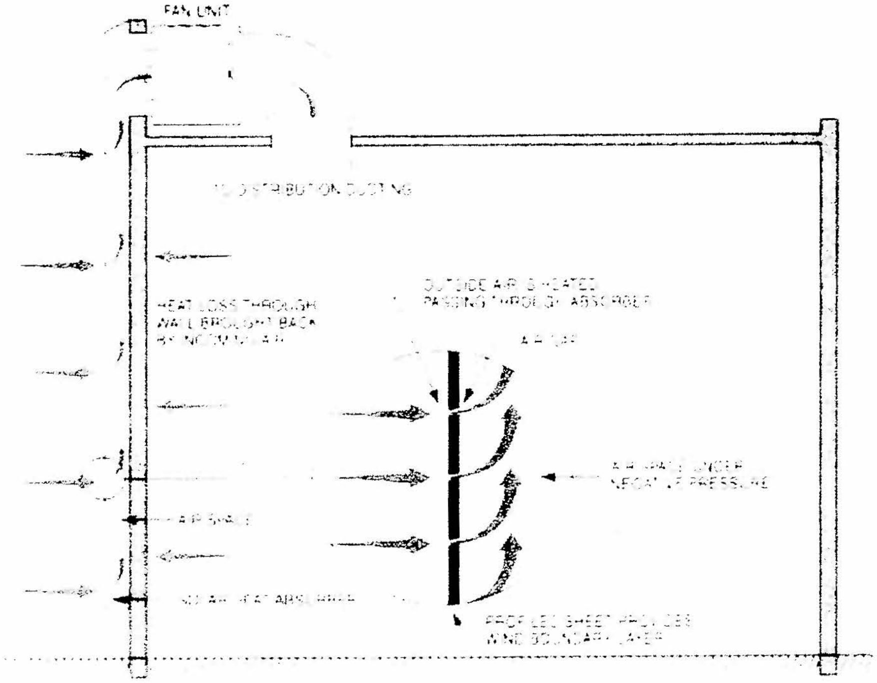
Solar Equipment Specifications

Solcan Ltd

information solar heating other products applications
contact us

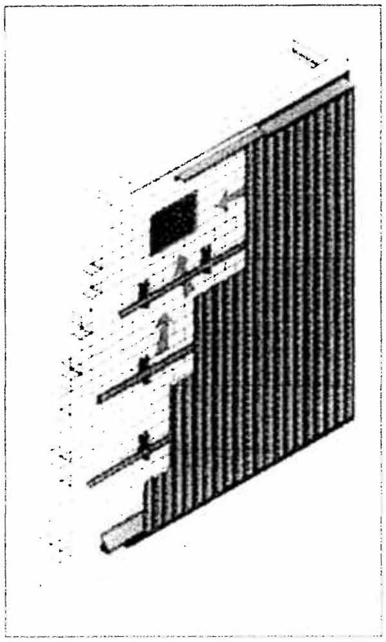
SOLARWALL® replaces conventional wall cladding. SOLARWALL® is available in many attractive colors (all dark, to increase solar heat gain).

Roof Mounted Fan

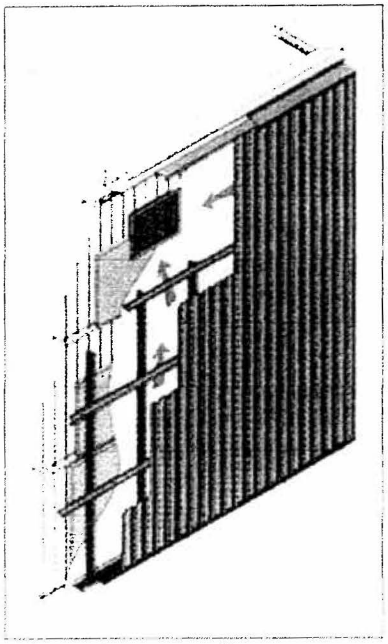


SOLARWALL® winter daytime operation

Typical SOLARWALL® Construction



SOLARWALL® panels on typical block wall construction



SOLARWALL® panels on typical metal wall construction

Summer Cooling

SOLARWALL® provides summer cooling by preventing solar radiation from striking the south wall of a building. Warm air between the SOLARWALL® and the building rises and is ventilated through holes at the top of the cladding. This reduces cooling loads in the building. Fresh ventilation air is drawn directly into the building by way of by-pass dampers.

Indoor Air Quality

Good indoor air quality is the result of an adequate, continuous, supply of fresh outdoor air. ASHRAE (the American Society of Heating, Refrigeration and Air Conditioning Engineers) states that the best way to avoid illness due to poor indoor air quality is to increase the volume of fresh air entering a building. The negative impact of uncontrolled entry of outdoor air is increased heating costs. SOLARWALL® solar energy systems can solve this problem by using solar energy to preheat ventilation air.

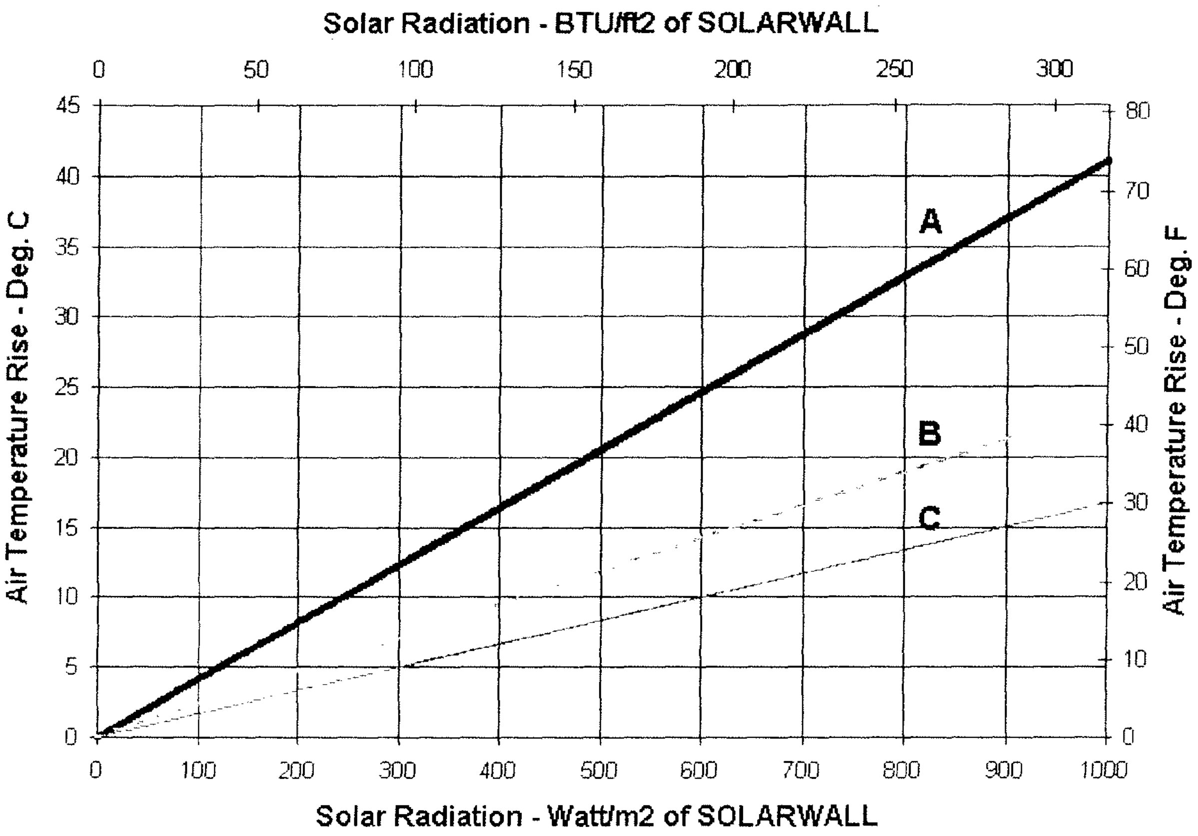
Maintenance

The movement of moisture through masonry walls causes bricks to crumble. Installing a SOLARWALL® protects walls from rain and moisture. The cost of a SOLARWALL® installation over a masonry wall can be recovered from the energy savings by the use of free solar energy to lower fuel costs.

Performance and Economics

- operating efficiency of up to 75% (rated by both the Canadian and US governments)
- on a sunny day, the temperature in the SOLARWALL® can raise the air temperature by 30° to 76°F (16° to 40°C) depending on flow rate
- the cost of a SOLARWALL® solar heating system in new construction is usually less than the cost of a brick wall or even a metal-clad wall; thus, energy savings are realized, with no payback period
- even on cloudy days, the SOLARWALL® provides significant energy savings as a preheating system for ventilation air
- a typical SOLARWALL® installation produces 50 to 70 kwh/ft^2 (500 to 700kWh/m^2)
- energy savings of $\$1$ to $\$6/\text{ft}^2$ ($\$10$ to $\$60/\text{m}^2$) of wall during the heating season; if a SOLARWALL® is utilized for process air heating, the savings are even greater
- the economic benefits of the SOLARWALL® system on the Federal Express distribution center in Colorado indicate that savings will be $12,000 US annually, and that 254,000 pounds (115,000 kilograms) of carbon dioxide emissions will not be released into the atmosphere
- paybacks of 1 to 6 years for most installations

AIR TEMPERATURE RISE vs. SOLAR RADIATION for Various Air Flow Rate.



Air-temperature rise vs. Solar radiation for various flow rates:
A=1cfm/ft^2, B=4cfm/ft^2, C=7cfm/ft^2

SOLARWALL® Performance and Economics

Operating Efficiency: up to 75%
Estimated RSI value: 9 (R-value: 50)
Annual Energy Savings: $\$1 - \$6/ft^2$ ($\$10 - \$60/m^2$)
Estimated Payback Period:
New: 0 - 3 Years
Retrofit: 3 - 8 Years

APPENDIX B

Design Schematic of Solar Water Heating System

APPENDIX C

Solar Water Heating System's Sequence of Operation

Energy Solutions Centre
Solar Water Heaters Installation

Indirect Closed System - Sequence Of Operations

The intent of this installation is to compare the efficiency and operation of three different style solar water heaters. The Jace will monitor the BTU contribution of each solar panel, the available solar radiation, and ambient outside air temperature and store this data in a log buffer. The data shall be manually archived periodically to a permanent database.

A glycol system will be used to preheat city water for use as domestic hot water. When there is insufficient energy transfer to properly heat the service water, an existing auxiliary heater will be used. A heat dump will be used to prevent excessive heating of the DHW. The Jace will also monitor the system for high glycol temperature conditions.

Normal Operation

1. The Jace will monitor the temperature differential of the solar collectors and the hot water in the preheat tank. When the absorber plate temperature in any given solar collector rises above the "Start Setpoint" of 35°C (adj.), the glycol circulation pump will be energized, and that solar panel's bypass valve will be opened to allow flow through the collector. The remaining solar collectors will be enabled (bypass valves opened to collector) when their absorber plate temperature's rise above setpoint.
2. While the solar water system is operating, the Jace will monitor the heat transferred to the glycol using BTU meters installed on each solar collector.
3. When the glycol supply temperature rises above the tank T-1 water temperature by at least 5°C, the heat exchanger bypass valve will be positioned to allow flow through the wand heat exchanger. If the glycol supply temperature drops to within 1°C of the tank T-1 temperature, the bypass valve will be closed to the heat exchanger.
4. Each solar collector's bypass valve will be energized when the collector's leaving glycol temperature is less than it's entering glycol temperature. When the temperature of all three solar panel absorber plates drop below the "Stop Set Point" (30°C, adj.), the circulating pump will be shut down.

Freeze Protection

1. No freeze protection is needed. If, in extreme cases, the temperature of any one solar collector plate drops below the limits of the glycol, the circulation pump will be energized, and the bypass valves will be opened to the collector.
2. This operation will continue until the temperature of the collector plate rises to a safe limit. The pump will run for a minimum of five minutes in this condition.

Overheating Protection

1. A dry fluid cooler with a modulating bypass valve will maintain the temperature of the return glycol to the solar collectors. As the return glycol temperature increases above setpoint (initially set at 70°C), the modulating valve will open to allow the glycol to flow through the dry cooler. On a continued call for cooling of the fluid, the dry cooler fan will be energized.
2. A DHW tempering valve will be installed on the tank supply side. The Jace will monitor the DHW supply temperature, and modulate the tempering valve to maintain the supply temperature at setpoint (50°C, adj.).

Domestic How Water Recirculation

1. An existing recirculation pump will be controlled by existing controls.
2. The Jace will monitor the DHW supply temperature. The new tempering valve will be modulated to maintain supply temperature setpoint (50°C, adj.).
3. The isolation valve on the tankless coil in the boiler will operate based upon the temperature in the DHW storage tank. If the tank water is above 50°C, the isolation valve will be closed. If the temperature drops below this setpoint (and deadband), the isolation valve will open, allowing water to become heated in the boiler.
4. At night, when the recirc pump is not running, the tempering valve will be positioned to a predetermined setting of 30%. The PID control of the valve will not be enabled until the scheduled time to run the recirc pump.

Alarms

1. The Jace will monitor the system conditions and generate the following alarms:
    a. Glycol High Temperature (each collector)
    b. Glycol Low Temperature (each collector)

APPENDIX D

Solar Wall System's Sequence of Operation

Duncan Mechanical
Lowe Street Upgrades

Solar Wall

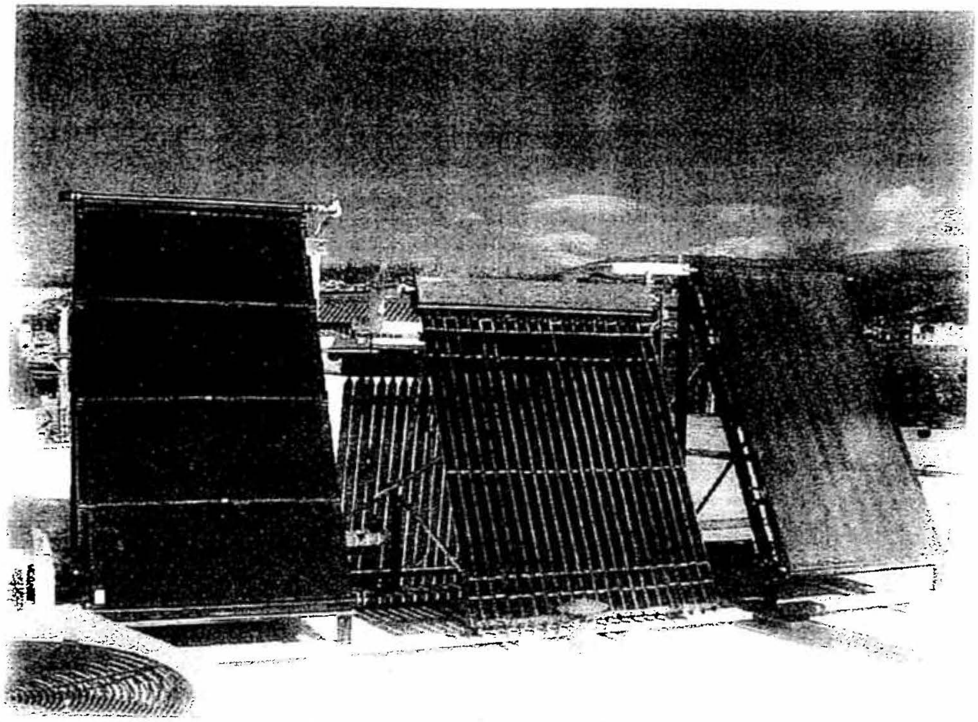
1. The solar wall system supply fan will operate based upon a programmable occupancy schedule. When the system is in occupied mode, the DDC system will de-energize the isolation damper, causing it to open. An end switch on the isolation damper will energize the supply fan through a hard-wired interlock.
2. If the solar wall discharge air temperature rises above it's high-limit setpoint (18°C, adj.) and the OA temp is above it's high-limit setpoint (20°C, adj.), the solar wall system will be shut down. The system will stay shut down for a minimum time delay (initially set at two hours).
3. The Jace will monitor the performance of the solar wall by logging the temperature rise through the solar wall (discharge air temp – outside air temp) and multiplying it by the air flow. Air flow shall be determined by an air balancer, and it is assumed that the flow will remain constant.
4. If the discharge air from the solar wall drops below the low-limit set point for a set amount of time (adj.), the solar wall system will shut down.

Ventilation Upgrade

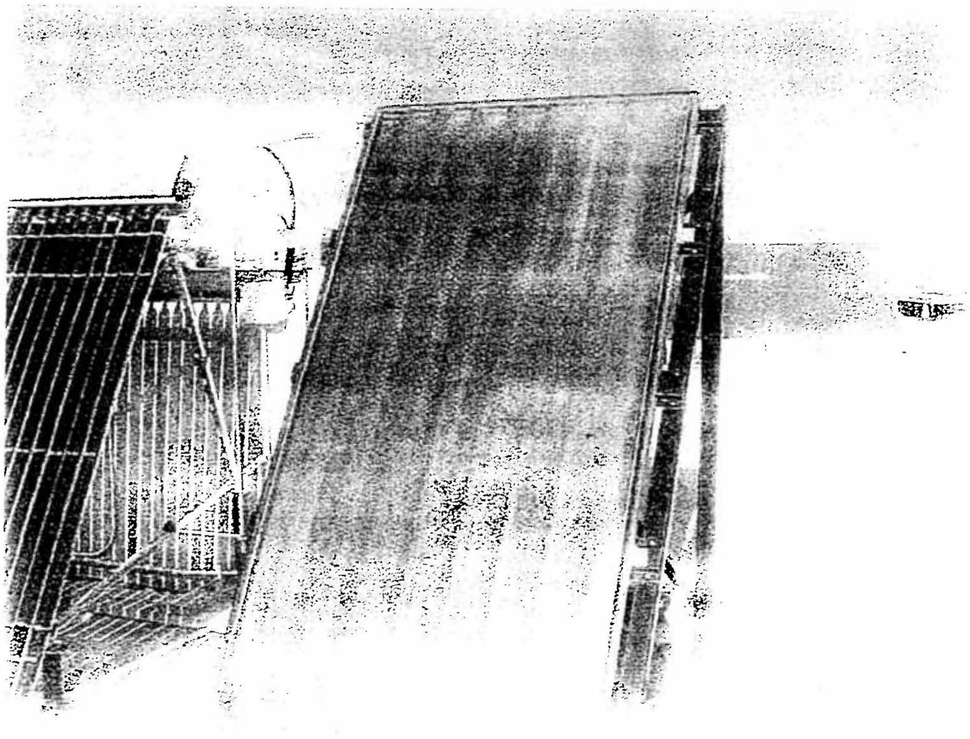
1. New electronic damper actuators shall be installed on the OA, RA, and EA dampers, on the upper and lower levels. The Jace will monitor the mixed air temperature in the mixing boxes of both the upper level and lower level.
2. When the system is in Summer mode (OA temp greater than 15°C, adj.), the dampers will be commanded to the minimum OA position.
3. In Winter mode, the dampers will modulate to maintain the mixed air setpoint (15°C, adj.).
4. The minimum OA setting of the upper level dampers will be reset to a lower value (adj.) any time the solar wall system is active.
5. If the mixed air drops below minimum setpoint of 5°C for a set period of time, the outside and exhaust air dampers will go fully closed, and the return damper will go fully open. The dampers will stay in this fail-safe position for a predetermined time delay of 30 minutes.

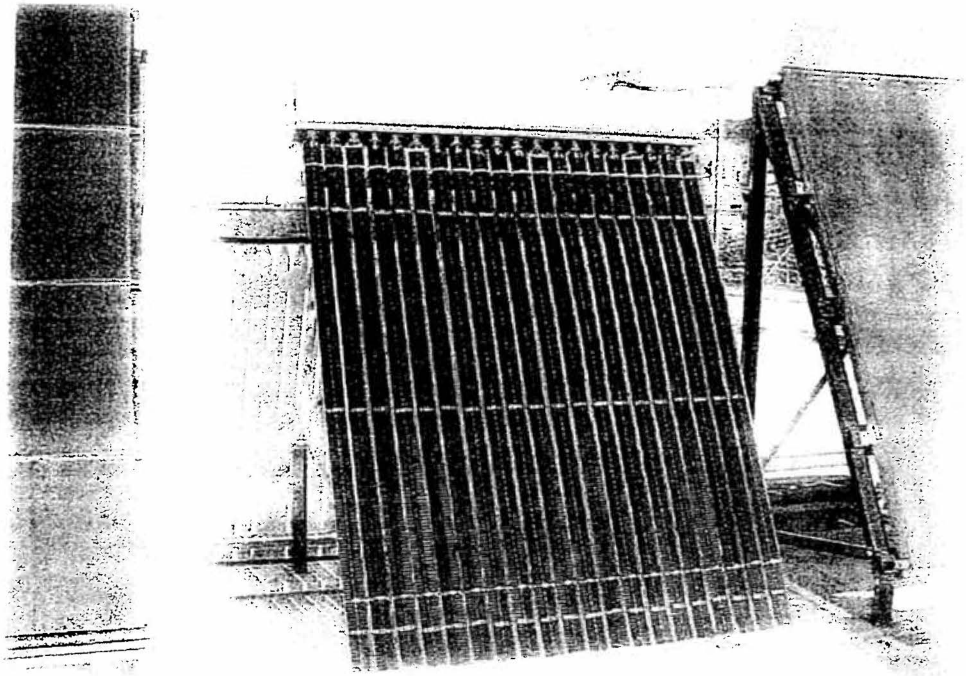
APPENDIX E

Lowe Street Solar Panel Photographs

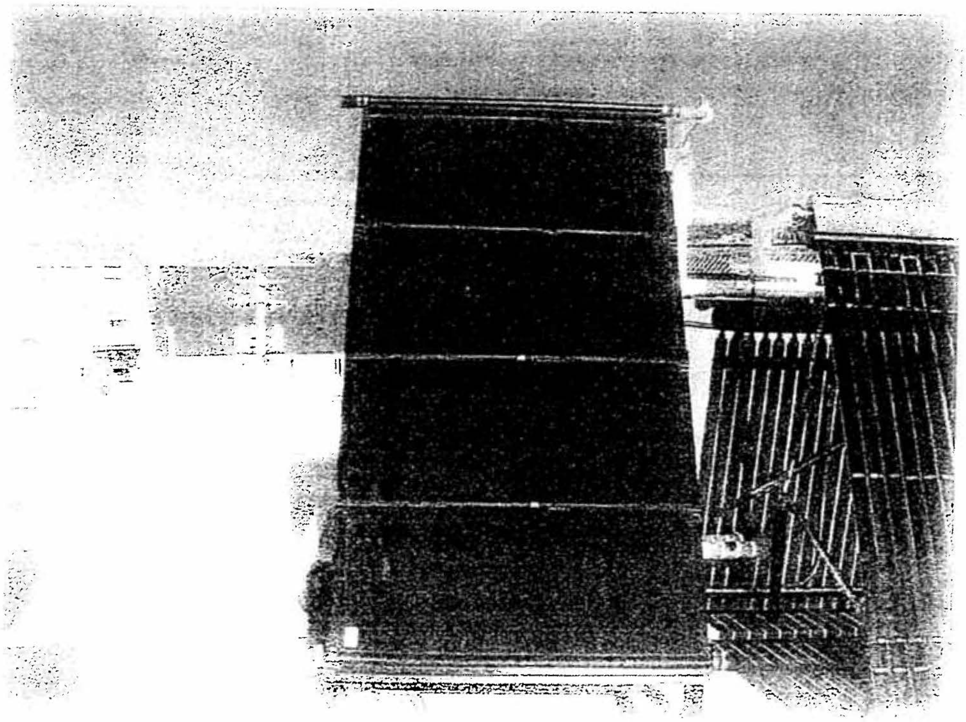


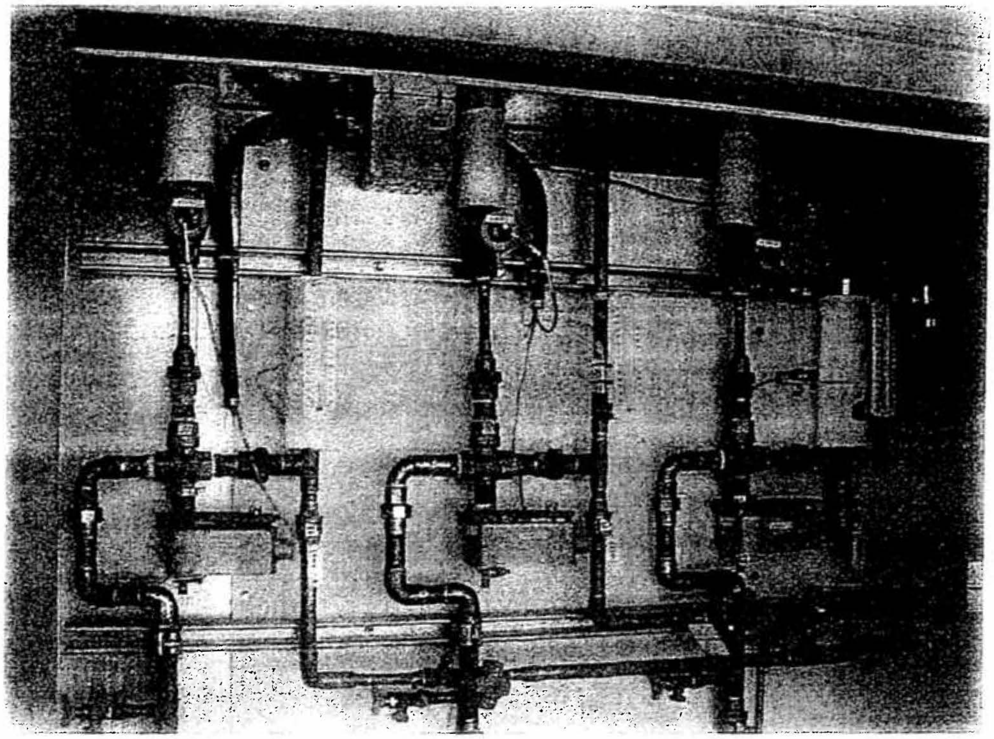
Three Solar Collectors Installed on the Roof Energy Solutions Centre,
Lowe Street, Whitehorse, Yukon Territory



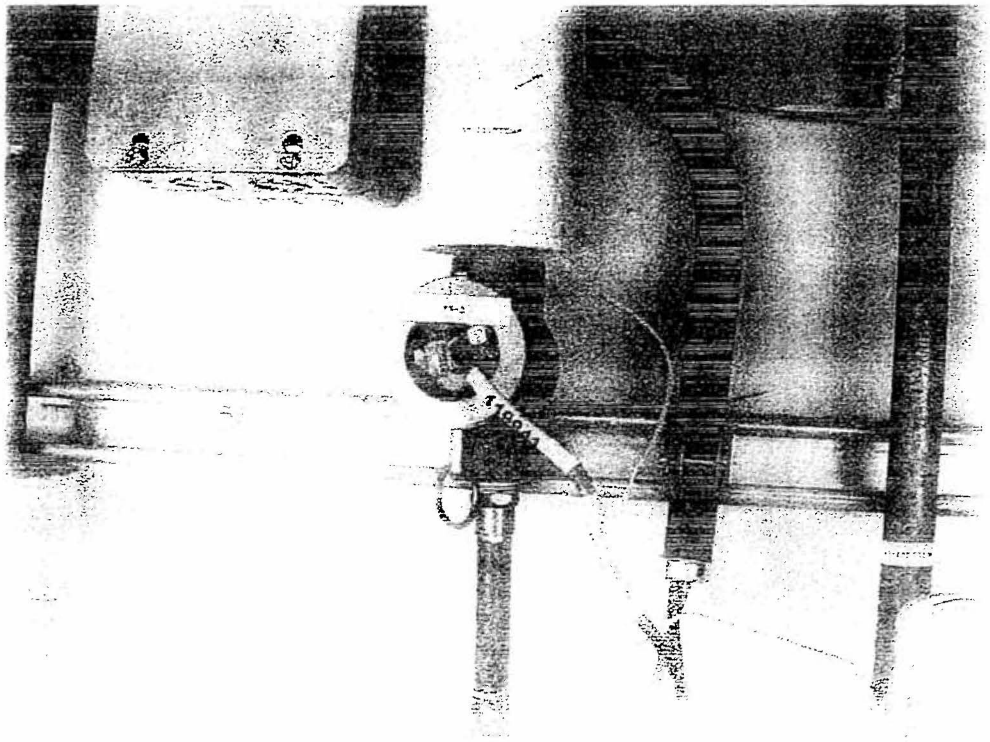


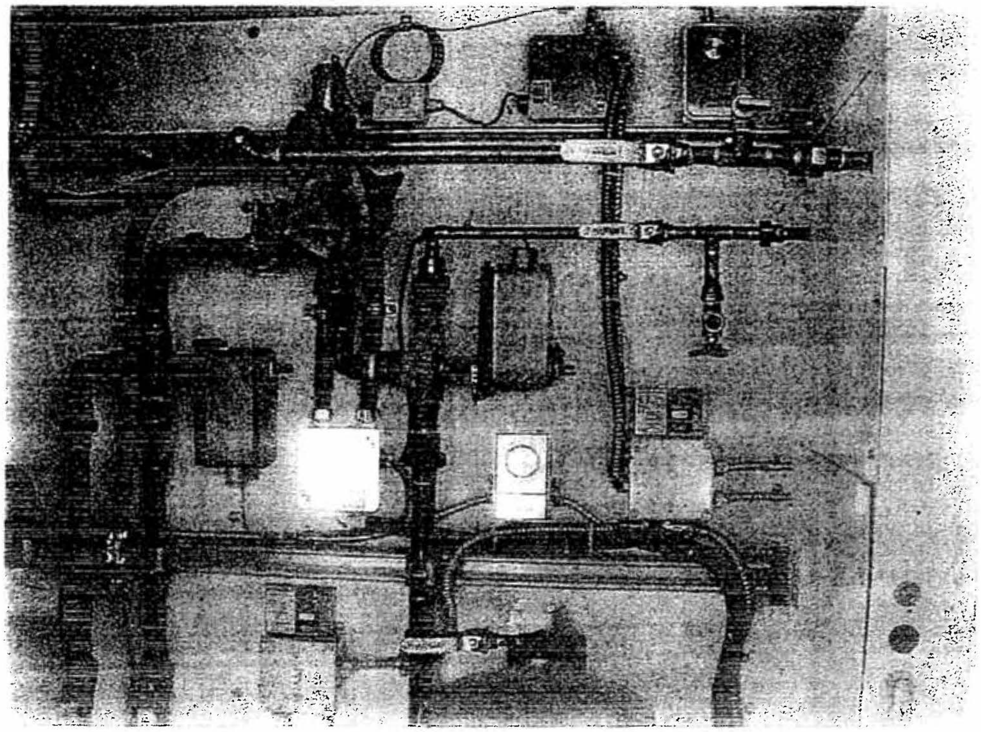
Thermomax Solamax - Evacuated Tube Solar Energy Collector (SP-2)





Heat Transfer Fluid Circulation System for the Solar Collectors





The Overheating Protection System with Dry Fluid Cooler

APPENDIX F

Data

Solar Wall System Monthly Temperature Data During 2004-2005 Heating Season

Month	Ave Temp Gain (°C)	Ave Daytime Outdoor Temperature (°C)	Average Air Temperature Delivered to Building (°C)
Oct-04	23.1	3.9	27
Nov-04	17.2	-5.6	11.6
Dec-04	12.9	-8.5	4.4
Jan-05	12	-11.5	0.5
Feb-05	13.8	-6	7.8
Mar-05	16.3	0.1	16.4

Solar Wall System Average Monthly Savings During 2004-2005 Heating Season

Month	Average Energy Saving (kJ)	Average Energy Saving (kW*h)
Oct-04	2512456	698
Nov-04	2175419	604
Dec-04	1664639	462
Jan-05	1568475	436
Feb-05	2743286	484
Mar-05	1870886	520
Total	**12535161**	**3204**

Lowe Street Site Solar Radiation Data	
th	Total Available Solar Radiation (kW*h/m^2)
1	31
2	
3	
4	176
5	207
6	206
7	222
8	206
9	170
10	123
11	57
12	34

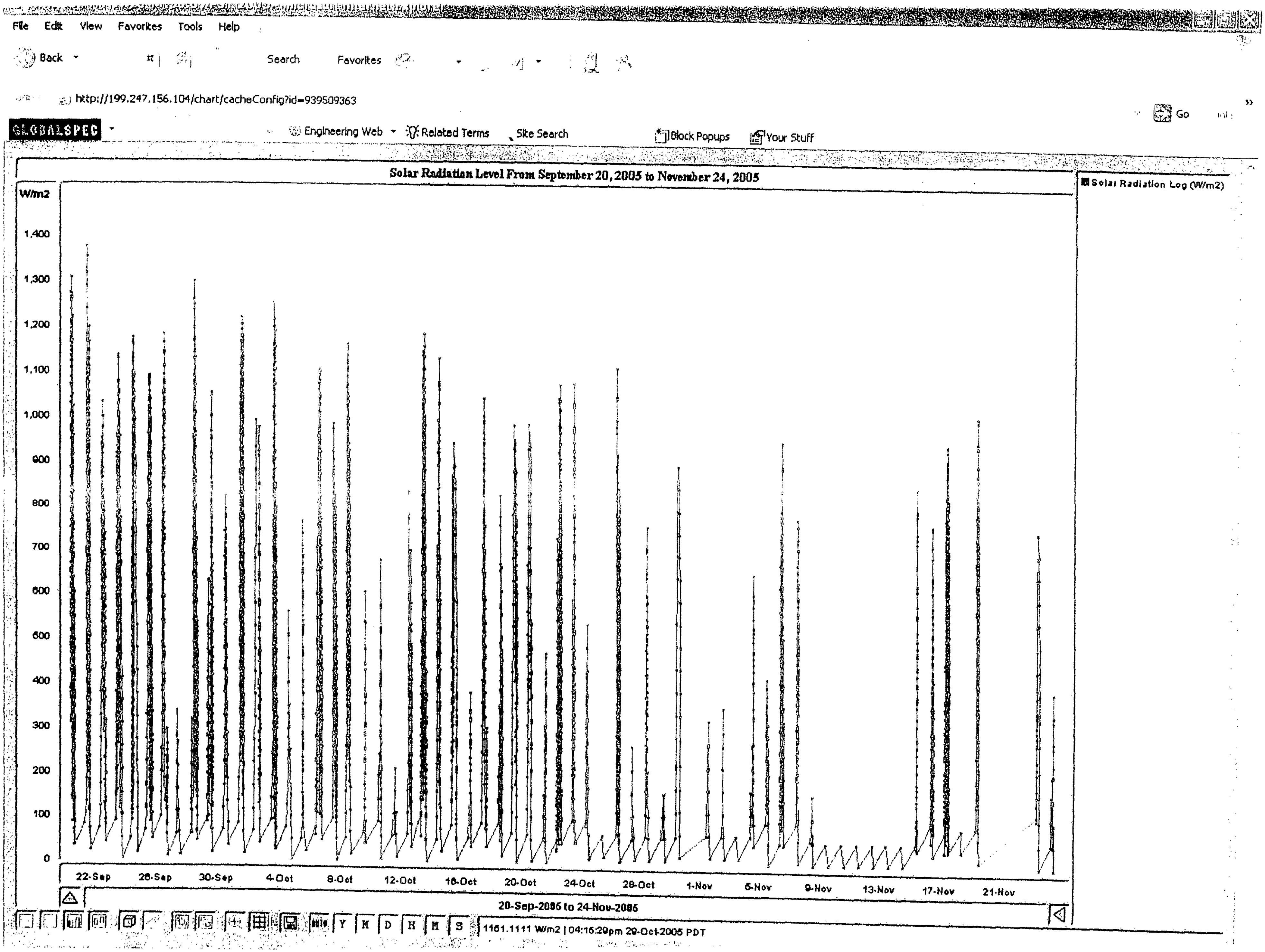
Solar Panel One Monthly Energy Collected			
th	Energy Collected (kW*h)	Total Energy Available to Collector (kW*h)	Efficency (% Radiation Energy Delivered to Glycol)
Jan-04		83.08	
Feb-04			
Mar-04			
Apr-05		471.68	
May-05	1.89	554.76	0.34
Jun-05	2.88	552.08	0.52
Jul-05	5.11	597.96	0.85
Aug-05	4.99	552.08	0.90
Sep-05	1.20	455.6	0.26
Oct-05	1.10	329.64	0.33
Nov-03		152.76	
Dec-03		80.92	

Solar Panel Two Monthly Energy Collected			
th	Energy Collected (kW*h)	Total Energy Available to Collector (kW*h)	Efficency (% Radiation Energy Delivered to Glycol)
Jan-04		62	
Feb-04			
Mar-04	3.13		
Apr-05	0.19	352	0.05
May-05	0.66	414	0.16
Jun-05	1.83	412	0.44
Jul-05	0.51	444	0.12
Aug-05	0.37	412	0.09
Sep-05	0.33	340	0.10
Oct-05	7.69	246	3.13
Nov-03	9.68	104	9.31
Dec-03	0.38	68	0.56

Solar Panel Three Monthly Energy Collected			
th	Energy Collected (kW*h)	Total Energy Available to Collector (kW*h)	Efficency (% Radiation Energy Delivered to Glycol)
Jan-04		91.5	
Feb-04	0.52		
Mar-04	0.23		
Apr-05		519.2	0.00
May-05	0.92	610.7	0.15
Jun-05	6.16	607.7	1.01
Jul-05	6.75	654.9	1.03
Aug-05	3.70	607.7	0.61
Sep-05	0.04	501.5	0.01
Oct-05		362.9	0.00
Nov-03	0.07	168.2	0.04
Dec-03		100.3	

APPENDIX G

Graphs from Online Data Logger



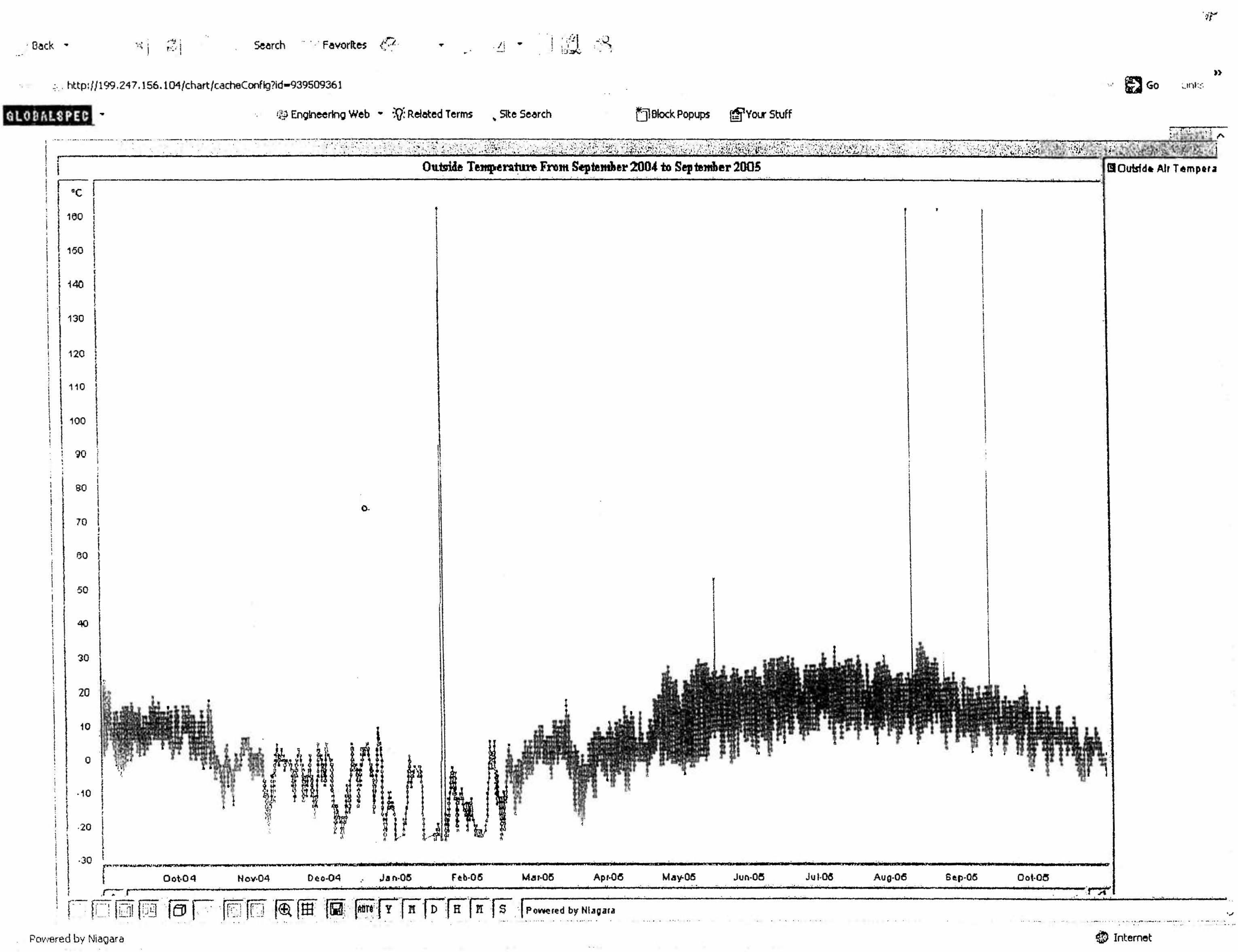
http://199.247.156.104/chart/cacheConfig?id=939509363

Solar Radiation Level From September 20, 2005 to November 24, 2005

■ Solar Radiation Log (W/m2)

20-Sep-2005 to 24-Nov-2005

1161.1111 W/m2 | 04:16:29pm 29-Oct-2005 PDT



http://199.247.156.104/chart/cacheConfig?id=939509361

Outside Temperature From September 2004 to September 2005

APPENDIX H

Warranty Forms

THERMOMAX QUALITY SYSTEM

Warranty Record

Complete this form and return to Thermomax if you are certain that the items are within their warranty period. No claim can be processed until the following information is provided.

Company details:		**Thermomax reference:**	
Company name		**Contact name**	
Contact mobile		Contact telephone	
Contact email		Contact fax.	
Installation details:			
Absorber date code		Manifold serial number (s)	
No of tubes		No of manifolds (20 / 30)	
Type of tubes (TMO 500,600...)		**Typ of manifolds (Thermomax MS,** Solamax, Mazdon ...)	
No of defect tubes		No of defect manifolds (20 / 30)	
Date of installation		**Manifold connector details**	
Date of purchase		Date reported by user	
Installer name		Occupier's name	
Installer location		Occupier's location	
Flat roof		Domestic hot water	
Angled roof		Space heating	
Other roof type		Swimming pool	
System information:			
Manifold Configuration 1		Manifold Configuration 2	
Collector orientation		Frost protection	
Shaded installation		Insulation	°C
Expansion vessel(s)	Litres	Storage vessel	Litres
Static height	Metres	Pipework length	Metres
Pipe material / diameter	mm	Operational pressure	
Safety valve pressure	Bar	Exp. vessel pressure	Bar
Product name / type	Bar	Flushing device	
Serial numbers of vacuum tubes/ manifolds			
Problem details:			
Problem description (Please indicate on sketch, attach own sketch or photograph)			

Additional data:			
Complaint reason		**Driving distance / Serviceman**	km
Work time / serviceman		**Servicecode**	
Type of controller:			

Register data on a clear day (sunshine)

Readings

Current collector temperature _______°C

Current tank temperature _______°C

Current return temperature _______°C

Maximum collector temperature _______°C

Maximum tank temperature _______°C

Maximum return temperature _______°C

Settings

TC________°C TT(1) ______°C TT(2) ______°C

ΔT________ K SΔT________K TF________°C

Accomplished work

____

____

____

____

____

Spare parts

Type of Material	Article number	Number

Decision / Liability:	Tubes	Manifold	Controller
Thermomax			
Installer			
Supplier (Company Name)			
Other (Specify)			

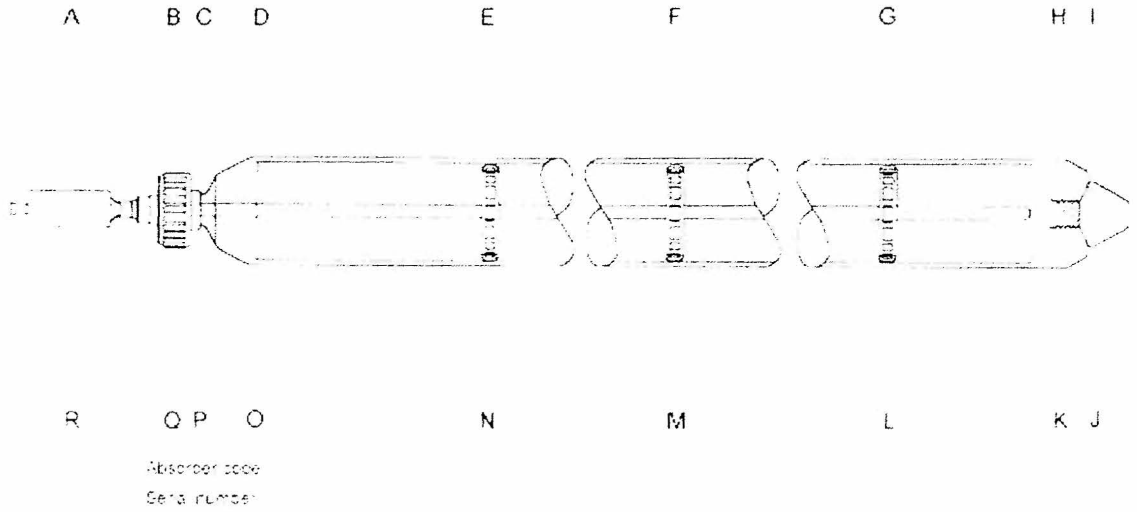
Date

Signature Thermomax

Signature Installer

Signature Supplier

Heat pipe tube



Direct flow tube