Solar Heating in the Thermo Dynamics Factory

In November 2002, Thermo Dynamics Ltd. (TDL) moved into a new 840-m^2 (9,000 ft^2) manufacturing facility in Dartmouth, Nova Scotia. This building is state-of-the-art, complete with solar heating, which supplies most of the space heating requirements in the factory. The building is also designed for maximum passive solar gain and natural lighting.

Solar Collectors

The vertical south-facing[1] wall of the factory is covered with 30 Thermo Dynamics (TDL) G32 solar collectors (89 m^2 gross collector area; 83 m^2 aperture area). The solar collectors are the liquid-flat-plate type, with low-iron tempered glass and Sunstrip™ absorber plate. The solar collectors are arranged in three arrays of ten solar collectors, each array in parallel with the other arrays. Within each array, there are two sub-arrays of five solar collectors, each sub-array plumbed in series with the another. The arrays are plumbed independently, and valved to allow for servicing of one array.

The solar collectors are "built into" the south wall of the building in order to make an aesthetically pleasing solar wall. The building is in the new section of Dartmouth's highly successful Burnside Industrial Park and is in a high profile location. The glazing of the solar collectors is flush with the remainder of the wall to maintain the aesthetically pleasing appearance and to reduce thermal losses.

A solution of propylene glycol and water (40:60) is circulated in the solar collectors. Each solar collector array is supplied with glycol via 3/4" (nominal) copper tubing. The hot solar return from each array is also 3/4", eventually collected by 1-1/2" (nominal) copper tubing and then supplied to 1-1/2" headers to the floor zones. There are no external piping runs; all distribution of glycol to/from the solar collectors is inside the building envelope. There is no insulation on the interior piping. Heat loss from the piping is not an absolute loss, and in addition the system runs at low temperature. A Valmet energy meter, complete with RTD temperature probes is installed in the solar loop to permit the direct measurement of the solar energy delivered from the solar collectors and to measure the flow rate of the glycol in the solar loop. The solar loop is fitted with pressure gauges, pressure relief valves and temperature measuring equipment to allow for the safe and efficient operation of the solar system

[1] The precise orientation of the solar collectors is 17° east of true south.

Solar Pumps™ and Photovoltaic Modules

The propylene glycol solution is circulated through the solar collectors by three TDL P118330 Solar Pumps™. Each pump circulates the glycol in a single array of ten solar collector. The pumps are powered by a six Free Energy Europe 12-W_{peak} photovoltaic module. Two PV modules, wired in parallel, drive each pump. The amorphous silicon PV modules are rated at 0.75 amperes at 15 VDC operation. The PV modules are mounted on the south-facing vertical wall in the same plane as the solar collectors. The Thermo Dynamics Jolter™, a linear current booster, is wired between each pair of PV modules and the permanent magnet DC motor that drives the pump. The TDL Jolters™ provide for pump start-up and continuous running at low levels of solar radiation (approximately 100 W/m^2). At full sun the PV modules produce a flow rate of over one liter per minute per solar collector.

Solar Thermal Storage

The solar-heated glycol circulates through 5,000 meters (16,000 feet) of tubing buried in the concrete slab. The 150-mm thick (6 inches) slab provides the heat delivery mechanism and the thermal storage. The slab has a mass of 260 tonnes and can store 64 kWh_t for each degree Celcius temperature rise in the average temperature of the slab. In addition, the walls contain 210 tonnes of concrete, inside the 75-mm thick insulation, adding another 51 kWh_t/°C heat capacity to thermal storage capacity of the building. The heating load of the building is estimated to be 100 kWh_t, on a daily basis, over and above the heat input to the building from other sources, e.g., lights and machinery.

The floor tubing is 5/8” OD Kitec tube (15.9 mm OD). There are 64 loops, each 75 m (250 feet) in length. The building is divided into three zones: two large zones for the factory floor and one smaller zone for the office area. The factory zones are supplied by 1” Kitec (1-1/8” OD); the office area is supplied by 3/4” (7/8” OD) Kitec piping. The zones are each supplied with glycol via 1.5” headers to ensure a uniform distribution of flow in the entire system.

The roof, walls and footings of the building are heavily insulated to reduce heat loss and to maximise the solar heating fraction. Skylights and high-performance glazing on the east and south sides of the building provide for a high degree of natural lighting.

Auxiliary Heater

The original back-up/auxiliary heating system for the factory was a 5-20-kW electric boiler. This is plumbed in parallel with the solar collectors. The electric boiler heats water, which circulates through a

TDL shell-and-tube heat exchanger. This prevents the glycol in the floor loops from coming in contact with the electric heating elements, which can be detrimental to glycol quality. There is no heat exchanger between the floor heating loops and the solar collectors in order to maximise solar loop solar collection efficiency. Electricity for the auxiliary heater is only used at night time, when the factory is not in operation, to prevent an increase in peak electrical demand in the factory and in order to take advantage of lower cost electricity. Other than during the coldest weeks of the winter, 10 kW_e of heating overnight was sufficient to maintain the temperature in the building, when there has been no delivery of solar energy to the building due to very inclement weather. The electricity consumed by this heater was measured by a separate kilowatt-hour meter.

In February 2005, in order to use a cleaner form of auxiliary energy, a high-efficiency gas-fired boiler was installed. This has a seasonal efficiency of 85%. Electricity in Nova Scotia is, for the most part, generated in coal-fired power plants. In consuming 20,000 kilowatt-hours of electricity each year for heating (see details below), TDL was responsible for 30 tonnes of CO2 emissions every year. The introduction of the natural gas boiler will reduce the emissions of CO2, associated with heating the TDL factory, to 7 tonnes of CO2 each year, from 30 tonnes per year.

Measure and Predicted Performance: 09 December 2002

On 09 December 2002 the performance of the system was checked. The outside temperature was between –6 and –9°C. It was a very cold, but sunny day. At 12:55 PM, the azimuthal solar angle with respect to the solar collectors was 30°. The angle of incidence of solar radiation on the solar collectors was 36°. The total flow rate in the solar loop, measured with the Valmet flow meter, was 30 L/min. The three solar pumps were running at 15.2 to 15.5 VDC, and each was drawing from 1.32 to 1.39 amperes from the PV modules. The glycol temperature to the solar collectors was 15°C and the return temperature was 44°C. This represents a heat delivery rate of 55 kW_t.

The performance of the system was analysed for 09 December 2002, using a computer model developed by Thermo Dynamics. On 09 December the sun rose at 7:45 AM and set at 4:30 PM. During this period the angle of incidence on the solar collectors varies from 40° at sunrise to a minimum of 20° at 10:40 AM, to 74° at sunset. This skewed pattern is due to the fact that the solar collectors face 17° east of true south. On a clear 09 December day the radiation incident on the solar collectors varies from 50 W/m^2 at sunrise to a maximum of 940 W/m^2 at 11:30 AM and then falls off to 50 W/m^2 at sunset. Taking into account optical losses, the solar collector absorber plate sees radiation that varies from about 50 W/m^2 to

760 W/m^2 over this sunny day. This was based on a ground reflectance of 0.6 for snow-covered surfaces. The solar collectors see undeveloped land, which was snow covered on 09 December 2002.

For 09 December 2002, the temperature of the return glycol from the floor heating loop was 15°C, which is the temperature at the inlet to the solar collectors. The return glycol temperatures were predicted to vary from 34 to 40°C, due to the variable flow rate of the solar pumps, and the variable input of solar radiation. As the level of radiation on the PV modules the flow rate varies from a low of 1.2 L/m at sunrise/sunset to a maximum of 33 L/m at full sun. Actual measured return temperatures reached 44°C at 1:00 PM; the predicted temperature was 36°C. The measured rate of heat delivery was 55 kW_t, whereas the predicted was only 41 kW_t.

Measure and Predicted Performance: 13 December 2002

Due to the discrepancy in the measured and predicted values for 09 December 2002, another set of measurements were made on 13 December 2002. The outside temperature was 2°C. It was a mild, very sunny, day. At 11:00 A, the azimuthal solar angle with respect to the solar collectors was 0°. The angle of incidence of solar radiation on the solar collectors was 20°. The flow rate in the solar loop was 30 L/min. The three solar pumps were running at 17 VDC, and each was drawing from 1.32 to 1.39 amperes from the PV modules. The glycol temperature to the solar collectors was 21°C and the return temperature was 44°C. This represents a heat delivery rate of 44 kW_t.

On a clear 13 December day the radiation incident on the solar collectors varies from 50 W/m^2 at sunrise to a maximum of 940 W/m^2 at 11:30 AM and then falls off to 50 W/m^2 at sunset. Taking into account optical losses, the solar collector absorber plate sees radiation that varies from aout 50 W/m^2 to 780 W/m^2 over this typical sunny day. This was based on a ground reflectance of 0.6 for snow-covered surfaces. The solar collectors see undeveloped land, which was snow covered on 13 December 2002.

For 13 December 2002, the temperature of the return glycol from the floor was 21°C, which is the temperature at the inlet to the solar collectors. The return glycol temperatures was predicted to vary from 40 to 46°C, due to the variable flow rate of the solar pumps, and the variable input of solar radiation. Actual measured return temperatures was 44°C at 11:00 AM; the predicted temperature was 46°C. The measured rate of heat delivery was 44 kW_t, whereas the predicted was 47 kW_t.

We suspect that the flow rate readings made on 09 December were high. On 09 December motor voltages were 15.5 VDC and total flow rate was 30 L/min. On 13 December we had the same flow rate, checked many times, but motor voltages were 17 VDC. Flow rate is proportional to pump RPM and pump RPM/motor RPM is directly proportional to motor voltage. We believe that the flow rate on 09 December was only 27 L/min, which means a 10% reduction in the measured rate of heat delivery from about 55 kW_t to 50 kW_t.

Operation over the First Heating Season (2002-2003)

The electric auxiliary heating system in the new factory was activated from 27 November 2002 to 03 April 2003. Heating continued after 03 April 2003, however, heating was 100% solar after 03 April 2003. In the 127 days from 27 November to 03 April, 13,237 kilowatt-hours (kWh_e) of electricity (47.6 GJ) were consumed for space heating. The average daily demand for electric heat was 104 kWh_e (or 104 kWh_t). The cost of this energy was $700, using a blended price of $0.0636[2] and $0.0485[3] for one kilowatt-hour of electricity.

During the same period, the solar energy incident on the solar collectors was 29,000 kWh_t. It is estimated that 50% of this energy was captured and delivered to the factory, for a solar contribution of 15,000 kWh_t. Therefore, 50% of the total heating load over the 127 days was supplied by solar. The total heating load was 220 kWh_t/day, during the core heating season[4].

The heating season in Nova Scotia extends into mid-May. From early April throughout May, 100% of the heat for the building was supplied by solar. The total solar energy delivered over the entire 2002-2003 heating season by the solar collectors was 25,500 kWh_t, or 850 kWh_t/solar collector (285 kWh_t/m^2). The building was completed in early October 2002, and the heating load for the first year is expected to be high, due to the large quantities of water that must be evaporated from the concrete.

Summer Operation

The system performance was checked using the computer model for 09 July. On a typical summer day the angles of incidence on the solar collectors are high, ranging from 90° to a minimum of 65°. The maximum solar radiation incident on the solar collectors on a clear, sunny day is 560 W/m^2. However,

[2] The price of electrical energy in the first block of consumption, as per Nova Scotia Power.
[3] The price of electrical energy in the second block of consumption, as per Nova Scotia Power.
[4] The core heating season is December through March.

due to the high optical losses associated with the high angles of incidence, the solar collector absorber will only see 400 W/m^2, at a maximum, and stagnation temperatures will be relatively low. The temperature rise of the solar collector absorber plate, given stagnation conditions, is $\Delta T = G_T (\tau\alpha)/U_L = 400\ W/m^2 / 4.0\ W/m^2\cdot K = 100°C$. Therefore, there should be no problems associated with shutting down the solar loop in the summer when temperatures inside the building are above a satisfactory level.

Operation over the Second Heating Season (2003-2004)

From 03 April 2003 until 04 December 2003 (244 days) all space heat was supplied by the solar collectors. During this period the heating load for the 105 days when heating was required, was estimated to be 100 kWh_t/day, for a total of 10,500 kWh_t, all supplied by solar thermal energy. The electric heating system was activated on 04 December 2003. The electricity consumed for heating the building was 11,148 kilowatt-hours, from 04 December 2003 to 08 April 2004. Most of this was consumed at the high rate of 6.36¢/kilowatt-hour. The total cost to heat the building for the year was $710.

Operation over the Third Heating Season (2004-2005)

All required space heat was supplied by the solar collectors from 08 April 2004 until 16 November 2004. The electric heating system was activated on 16 November 2004. The electricity consumed for heating the building was 6,887 kilowatt-hours, from 16 November 2004 to 22 February 2005. Most of this was consumed at the high rate of 6.36¢/kilowatt-hour. The total cost to heat the building in this period was $440. On 22 February 2005, a high-efficiency natural gas fired boiler was installed and the electric boiler was shut down. From 22 February 2005 to 11 April 2005, 669 cubic meters of gas (26.9 GJ, or 7,478 $kWh_{t\text{-}gas}$) were consumed, at a total cost of $410. The total cost to heat the building for the heating season was $850.

Using a boiler efficiency of 85%, the heat supplied to the building using electricity and natural gas was 6,887 kWh_e + 6,356 kWh_t, a total of 13,243 kilowatt-hours.

Operation over the Fourth Heating Season (2005-2006)

The natural gas boiler heating system was activated on 24 November 2005. All required space heat was supplied by the solar collectors from 11 April 2005 until 24 November 2005. The natural gas consumed for heating the building was 1514 m^3 (62.1 GJ or 17,260 $kWh_{t,gas}$), from 26 November 2005 to 10 March

2006. Assuming a boiler efficiency of 85%, the heat supplied to the building was 14,700 kWh_t. The total cost to heat the building in this period was $980.

Operation over the Fifth and Sixth Heating Seasons (2006-2007 and 2006-2007)

The operation of the space heating system was similar to the operation in 2005-2006, however, the heating requirements were higher (about 20,000 kWht) than in previous years (about 15,000 to 17,000 kWht). The heating figures for these two years are set out in the table below.

Summary of heating costs from 2002 - 2008

Heating season	Fuel	Units Consumed	Cost per unit	Total Cost (HST out)
2002-03	electricity	13,237 kWh_e	$0.053	$700
2003-04	electricity	11,148 kWh_e	$0.064	$710
2004-05	electricity	6,887 kWh_e	$0.064	$440
2004-05	natural gas	7,478 kWht	$0.055	$410 ($850 in total for 04-05)
2005-06	natural gas	17,260 kWht	$0.057	$980
2006-07	natural gas	20,252 kWht	$0.052	$1053
2007-08	natural gas	20,100 kWht	$0.055	$1105

Solar DHW System

A Thermo Dynamics Solar Boiler™ solar water heater was installed in 2002. This system consists of two Thermo Dynamics S-series solar collector. The solar collectors are mounted on the ground on the south-side of the factory. There is a 70-foot (21 m) run of pipe from the solar collectors to the Solar Boiler™ module. This run of pipe consists of two 3/8" OD soft copper tube, inside 2" (50 mm) of elastomeric insulation. The bundle of insulated pipe runs inside a 6" (150 mm) diameter flexible plastic tube placed 2 feet (0.6 m) below grade. The solar collectors deliver solar heated glycol to the Solar Boiler™ module, which consists of the pump/motor assembly and the heat exchanger/reservoir/drain/fill assembly. This unit is attached to the solar storage tank, a 270-L glass-lined and insulated water storage tank. The Solar Pump™ is the experimental TDL pump driven by a brushless DC motor. The motor is driven by a Siemens module (10 W_p) through an electronic circuit, of proprietary design, which regulates the current from the PV module and commutates the brushless motor.

Maintenance and Comfort

Since 2002 there has been negligible maintenance of the two solar heating systems. One of the P118330 pumps on the space heating seasons became difficult to start and it was removed and repaired in 2003. There has been no maintenance on the solar DHW system other than one minor repair to the experimental brushless DC motor/pump installed in 2006.

Thermo Dynamics has been in business since 1981 and has occupied 5 different buildings since 1981. The first four buildings were heated by ceiling slung forced air heaters. The fifth building is the solar-heated building. The comfort level in the solar-heated building, with heated floors, is significantly higher than in the other buildings. In addition the higher level of comfort is achieved with lower air temperatures in the building.