Toronto Fire Station #231

12.5 kW_t Solar Water Heating Installation

Final Report – January 2012

Technology

Monitoring

Best Practices

SolarCity Partnership

PROJECT SNAPSHOT

Address:	740 Markham Road, Toronto ON
Building Type and Use:	Fire Services
Owner:	City of Toronto
Contact:	Joel Arthurs
Phone #:	416-392-5177
Email:	jarthur@toronto.ca
System type:	Solar Domestic Hot Water
Array Angle:	45 degrees from horizontal
Azimuth:	15 degrees East
System Configuration:	Drain-back with 6 collectors in parallel
Collector Manufacturer:	Thermo Dynamics
Collector Model:	G32-P
Number of Collectors:	6
Thermal Storage Tank Manufacturer:	Rheem
Thermal Storage Tank Model:	ST120 (435 litres)
Number of Thermal Storage Tanks:	2
Collector Fluid:	Water
System Size (kW thermal):	12.5
Total Gross Collector Area (sq. meters):	17.892
Installation Date:	December 2006

PERFORMANCE

2008/2009 Energy Delivered to Solar Tanks:	654 kWh_t/kW
2008/2009 Modified RETScreen:	648 kWh_t/kW
2008/2009 WATSUN Energy Delivered to Solar Tanks:	737 kWh_t/kW

FINANCIAL

Installed Cost (taxes included):	$40,631
External Funding:	$20,484 from Natural Resources Canada's Renewable Energy Deployment Initiative
2008/2009 Annual Savings:	$335
Simple Payback (excluding external funding):	121 years
Cost per kW_t (excluding external funding):	$3,251

Photos provided by Lucio Mesquita

MONITORING

Monitoring equipment installed:	Yes
Overview of the monitoring plan:	Two Kamstrup Multical 601 heat meters. One installed on DHW line between solar tanks and auxiliary heater (Solar Energy Delivered) and the other on the piping connecting solar tanks to the solar heat exchanger (Solar Energy Collected).
Cost of M&V (% of total project):	10% (of total project cost)
Who is analyzing the data?	City of Toronto Energy & Waste Management Office
Is there a dedicated staff person responsible for system operation management?	No

SUMMARY

The City of Toronto's 12.5 kW_t solar thermal system at Fire Hall 231 generated approximately 654 kWh_t/kW in 2008/2009, which was 13% below the RETScreen simulated yield and 11% lower than WATSUN simulated yield. Designed to reduce the Fire Hall's use of natural gas for water heating, the system was installed in 2006 for $40,631. Based on 2008/2009 performance, the project will achieve a simple payback in 121 years before external grants and 60 years after.

Hot water usage was significantly lower than estimated during the design phase of the project which resulted in the system delivering much less energy than initially predicted. However, when the actual hot water usage is taking into consideration, the results indicate that the system performed as expected for 2008/2009.

Although performance indicated normal operation for 2008/2009, both hot water consumption and delivered energy were reduced at Fire Hall 231 for 2010 and 2011. The system performed particularly poorly during the 2010/2011 winter, both when comparing the results with 2008/2009 and with WATSUN simulations for 2010. The reduction in hot water consumption along with reduction in delivered energy should be investigated further.

Differences between energy collected and energy delivered in 2010 raises questions regarding the accuracy of the delivered energy metering. Further investigation should be undertaken to evaluate the accuracy of heat meters for domestic water heating measurements.

RETScreen is known to be conservative for solar thermal applications and the use of a more sophisticated software tool, such as WATSUN, is highly recommended.

PERFORMANCE ANALYSIS

This report will evaluate the performance of the solar thermal system from April 2008 to March 2009. Data from 2010 and 2011 indicate a large drop in hot water consumption and energy delivered. The cause of which should be investigated.

Actual Performance vs. Original RETScreen Simulation

The original RESTScreen analysis (Appendix A) predicts an annual energy delivery of 10.19 MWh. Actual energy delivered was 7.1 MWh, significantly below the prediction. However, the original analysis estimated a much larger usage volume than was measured. Measured usage for 2008/2009 was only 78% of the initial estimate. Thus, it is possible that the system did not reach the expected production because it operated under a much smaller heat load than it was designed for. With a smaller load, the average water temperature in the system rises, and the solar collector efficiency is reduced.

Actual Performance vs. RETScreen and WATSUN Simulations

The initial RETScreen inputs were modified to account for measured ambient temperatures, solar radiation, and hot water consumption. Modifications made can be found in Appendix B.

With the modified inputs, the estimated energy delivered was reduced to 8.1 MWh/year, while the measured delivered energy was 7.1 MWh. Therefore, the system would have delivered 13% below the estimated RETScreen simulations using the measured heat load.

RETScreen is known to give a conservative estimation of energy delivered by solar heating systems (see Appendix C for more discussion), which is why a more accurate software tool, WATSUN, was used to evaluate the performance of the system.

WATSUN algorithms were developed at the University of Waterloo and it performs a full yearly analysis using hourly data. It has been shown to provide accurate results and it allows the modification of weather data inputs, which is very valuable for performance verification, as in this case. As with RETScreen, WATSUN is available free of charge by Natural Resources Canada.

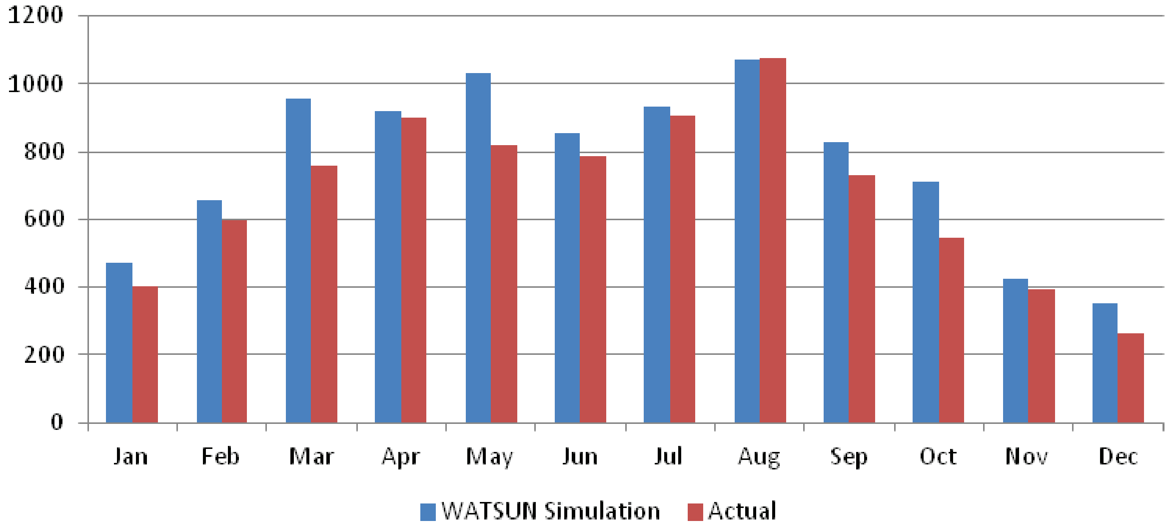
Since not all hourly data was available as an input for WATSUN, a fixed daily hot water usage profile was used, based on the average profile of November 2010 to January 2011 (Appendix D). The average monthly hot water draw was also adjusted and factors were applied to WATSUNs solar radiation and ambient temperature data to be similar to the measured values from a University of Toronto meteorological station.

WATSUN estimated energy delivered to the auxiliary tanks to be 9,655 kWh_t, while the measured delivered energy was 7,076 kWh_t. Therefore, the system would have delivered 25.5% below the estimated WATSUN simulations using the measured heat load. See Appendix E for a comparison of WATSUN simulations to actual performance.

Since there was a large difference between the energy delivered predicted by the WATSUN simulation and the measured delivered energy, the analysis was expanded to include the energy delivered (Qdt) to the solar tanks, which is the energy collected minus piping losses between the solar storage tanks and the collectors.

WATSUN estimated energy delivered to the solar tanks to be 9,215 kWh_t, while the measured delivered energy to the solar tanks was 8,178 kWh_t. Therefore, the system would have delivered 12.68% below the estimated WATSUN simulations. Figure 1 compares the WATSUN simulation to the actual performance.

Figure 1: 2008/2009 Energy Delivered to Solar Tanks - WATSUN Simulation vs. Actual Performance



The difference between estimated and measured energy delivered to the solar tanks is smaller than the values obtained when comparing energy delivered to the auxiliary heating tanks and it is within expected accuracy of the simulations. The simulation indicated normal operation for 2008/2009.

Table 1 shows the difference between measured values of energy delivered to the solar tanks (Qdst) and the energy delivered to the auxiliary heating tank (Qdel). The 13.5% difference is in part due to tank heat losses, but some of it is likely due to metering issues (see Appendix F for a discussion of metering issues).

Table 1: Energy delivered to solar tanks (Qdst) and energy delivered to auxiliary heating tank (Qdel)

Qdst	Qdel	Qdst-Qdel/Qdst
8178.7	7076.0	13.48%

2010 and 2011 Performance

Although performance indicated normal operation for 2008/2009, both hot water consumption and delivered energy were reduced at Fire Hall 231 for 2010 and 2011. The system performed particularly poorly during the 2010/2011 winter, both when comparing the results with 2008/2009 and with WATSUN simulations for 2010.

Some of the performance reduction is due to a 30% reduction in hot water consumption and consequently a reduction in heat load between 2008/2009 and 2010. The 30% reduction in hot water consumption along with reduction in delivered energy should be investigated further.

Figures 2 and 3 illustrate the decrease in hot water consumption and energy delivered, respectively. August was the last month of recorded data for 2011.

Figure 2: Average Hot Water Consumption

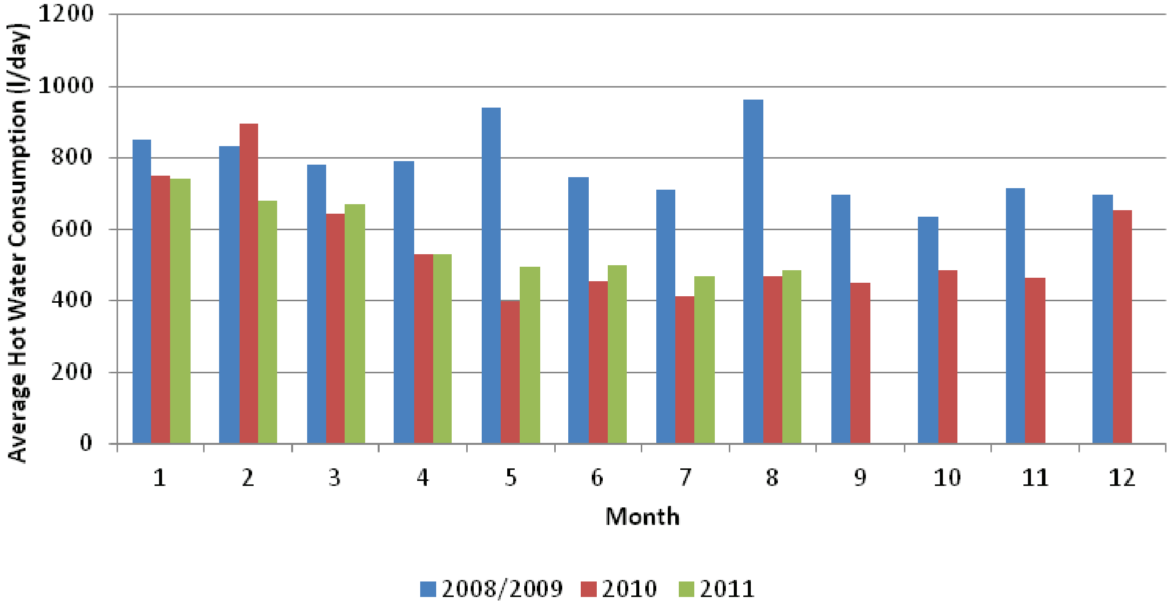
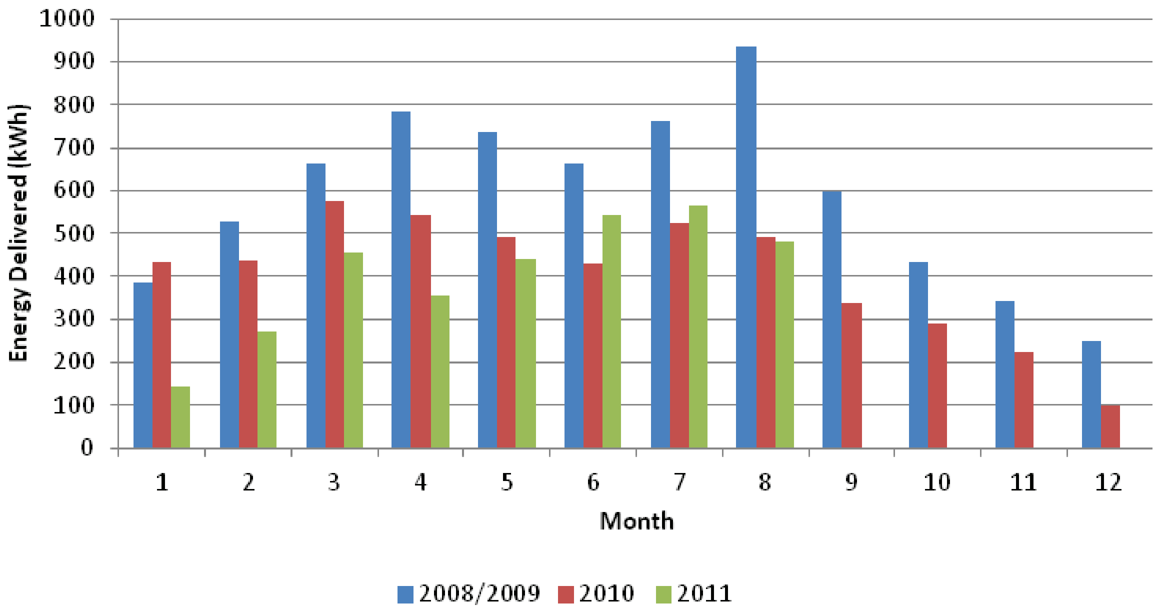


Figure 3: Energy Delivered



A new set of WATSUN simulation data was generated to account for the conditions present during 2010, including reduced consumption. Table 2 presents the comparison between simulated and measured performance. The differences between simulated and measured performance are significant and warrant further investigation. The performance was particularly reduced during the last 3 months of the 2010.

Table 2: 2010 WATSUN Simulation

	WATSUN Results	Measured	
Month	Q delivered	Q delivered	Difference Delivered Energy
	kWh	kWh	(Estimated-Measured)/Measured
Jan	361.3	431.0	-16.17%
Feb	423.2	435.0	-2.72%
Mar	777.5	574.0	35.46%
Apr	824.7	542.0	52.16%
May	639.6	492.0	29.99%
Jun	597.1	428.0	39.51%
Jul	666.4	525.0	26.94%
Aug	664.4	491.0	35.33%
Sep	523.8	338.0	54.97%
Oct	513.8	290.0	77.17%
Nov	468.7	223.0	110.16%
Dec	305.0	98.0	211.25%
Total	6765.5	4867.0	39.01%

BUSINESS CASE

Table 3 presents the business case for the Fire Hall 231 Solar Thermal Project. This analysis uses he 2008/2009 delivered energy to the auxiliary tank of 7,076 kWh_t/yr, which would save approximately $335 per year, assuming a natural gas price of 35¢/m^3. The simple payback for this scenario would be 121 years before grants and 60 years after. The business case should be updated once the causes of the 2010 and 2011 underperformance have been identifed.

Installed System Costs

The breakdown of installed system costs are shown in Table 4. The total cost of the system was $40,631, or $3,251 per kW installed. Materials accounted for approximately 67% of the total cost. Natural Resources Canada's Renewable Energy Deployment Initiative provided a grant of $20,484 for the project, bringing the final project cost down to $20,147, or $1,612 per kW installed.

Table 3: Fire Hall 231 Solar Thermal Project: Business Case for 2008/2009

	Total Cost Installed	Grants	Array Output (kWh_t/yr)	Dollars Saved*	Simple Payback (years)	Payback after grants (years)
Adjusted Feasibility Study	$40,631	$20,484	7,076	$335	121	60

*Assumes a 70% burner efficiency and a burner-tip natural gas price of $0.35 per m^3.

Table 4: As-Built Cost Breakdown

FH#231	**Material**	**Installation**	**Total**
Solar collectors	$5,400.00	$900.00	$6,300.00
Collector rack/support, fasteners	$2,054.00	$1,600.00	$3,654.00
Piping from collector array to solar storage tank and to conventional hot water tank	$1,734.00	$900.00	$2,634.00
Pipe and solar storage tank insulation	$770.00	$450.00	$1,220.00
Solar heat exchanger	$700.00	$300.00	$1,000.00
Solar heat storage tank(s)	$3,050.00	$450.00	$3,500.00
Pump(s) (collector-side)	$1,070.00	$450.00	$1,520.00
Solar system controller	$600.00	$750.00	$1,350.00
Design and supervision	$0.00	$1,900.00	$1,900.00
Shipping	$1,450.00	$0.00	$1,450.00
Metering	$2,660.93	$1,375.00	$4,035.93
Commissioning	$0.00	$0.00	$0.00
Other Additional Structural Work	$7,566.99	$4,500.00	$12,066.99
Total (tax included)	**$27,055.92**	**$13,575.00**	**$40,630.92**
External funding			$20,484
FINAL TOTAL			**$20,147**

APPENDIX A: ORIGINAL RETSCREEN ANALYSIS

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

Site Latitude and Collector Orientation		Estimate	Notes/Range
Nearest location for weather data		Toronto Int'l. A, ON	See Weather Database
Latitude of project location	°N	43.7	-90.0 to 90.0
Slope of solar collector	°	45.0	0.0 to 90.0
Azimuth of solar collector	°	10.0	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	1.64	-5.9		4.9	3.19
February	1.00	2.57	-5.2		4.5	4.23
March	1.00	3.67	-0.5		4.7	4.58
April	1.00	4.74	6.5		4.8	4.84
May	1.00	5.76	13.1		3.9	5.17
June	1.00	6.31	17.7		3.7	5.34
July	1.00	6.24	21.0		3.3	5.42
August	1.00	5.22	19.8		3.0	5.04
September	1.00	3.92	15.1		3.3	4.46
October	1.00	2.64	8.5		3.7	3.74
November	1.00	1.51	3.3		4.3	2.46
December	1.00	1.25	-2.9		4.4	2.37

		Annual	Season of Use
Solar radiation (horizontal)	MWh/m²	1.39	1.39
Solar radiation (tilted surface)	MWh/m²	1.55	1.55
Average temperature	°C	7.5	7.5
Average wind speed	m/s	4.0	4.0

Water Heating Load Calculation		Estimate	Notes/Range
Application type	-	Service hot water	
System configuration	-	With storage	
Building or load type	-	Industrial	
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	1,000	
Desired water temperature	°C	52	
Days per week system is used	d	7	1 to 7
Cold water temperature	-	Auto	
Minimum	°C	2.8	1.0 to 10.0
Maximum	°C	12.3	5.0 to 15.0
Months SWH system in use	month	12.00	
Energy demand for months analysed	MWh	18.92	
	GJ	68.11	

Return to Energy Model sheet

RETScreen® Energy Model - Solar Water Heating Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		Fire Hall #231	See Online Manual
Project location		740 Markham Road, Toronto	
Nearest location for weather data		Toronto Int'l. A, ON	Complete SR&HL sheet
Annual solar radiation (tilted surface)	MWh/m²	1.55	
Annual average temperature	°C	7.5	-20.0 to 30.0
Annual average wind speed	m/s	4.0	
Desired load temperature	°C	52	
Hot water use	L/d	1,000	
Number of months analysed	month	12.00	
Energy demand for months analysed	MWh	18.92	

System Characteristics		Estimate	Notes/Range
Application type		Service hot water (with storage)	
Base Case Water Heating System			
Heating fuel type	-	Natural gas - m³	
Heating system seasonal efficiency	%	60%	55% to 350%
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-P	
Area per collector	m²	3.00	1.00 to 5.00
Fr (tau alpha) coefficient	-	0.74	0.50 to 0.90
Fr UL coefficient	(W/m²)/°C	5.25	3.50 to 6.00
Suggested number of collectors		5	
Number of collectors		6	
Total collector area	m²	18.0	
Storage			
Ratio of storage capacity to coll. area	L/m²	50.0	37.5 to 100.0
Storage capacity	L	900	
Balance of System			
Heat exchanger/antifreeze protection	yes/no	Yes	
Heat exchanger effectiveness	%	90%	50% to 85%
Suggested pipe diameter	mm	13	8 to 25 or PVC 35 to 50
Pipe diameter	mm	19	8 to 25 or PVC 35 to 50
Pumping power per collector area	W/m²	21	3 to 22, or 0
Piping and solar tank losses	%	3%	1% to 10%
Losses due to snow and/or dirt	%	3%	2% to 10%
Horz. dist. from mech. room to collector	m	5	5 to 20
# of floors from mech. room to collector	-	3	0 to 20

Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
Pumping energy (electricity)	MWh	**0.69**	
Specific yield	kWh/m²	566	
System efficiency	%	37%	
Solar fraction	%	54%	
Renewable energy delivered	MWh	**10.19**	
	GJ	36.70	
			Complete Cost Analysis sheet

APPENDIX B: MODIFIED RETSCREEN INPUTS AND SOURCES

Small changes were made to the RETScreen analysis to account for more realistic inputs. First, the heat exchanger effectiveness was lowered to 70%, which lower the predicted delivered energy to 9.8 MWh, then the azimuth was corrected to 15°. This changed the output to 9.76 MWh/year. The next step was to introduce the measured solar radiation and average ambient temperature. With the new values, the estimated energy delivered rose to 10.0 MWh/year. This number was still much higher than the measured heat delivered. The next step was to modify the hot water demand to reflect the volume and temperature level that the system had experienced. The heat load changes from 18.9 MWh/year to 17.1 MWh/year. With the new load, the estimated energy delivered was reduced to 8.1 MWh/year, while the measured delivered energy was 7.1 MWh, and therefore the system would have delivered 13% below the estimated RETScreen simulations using the measured heat load.

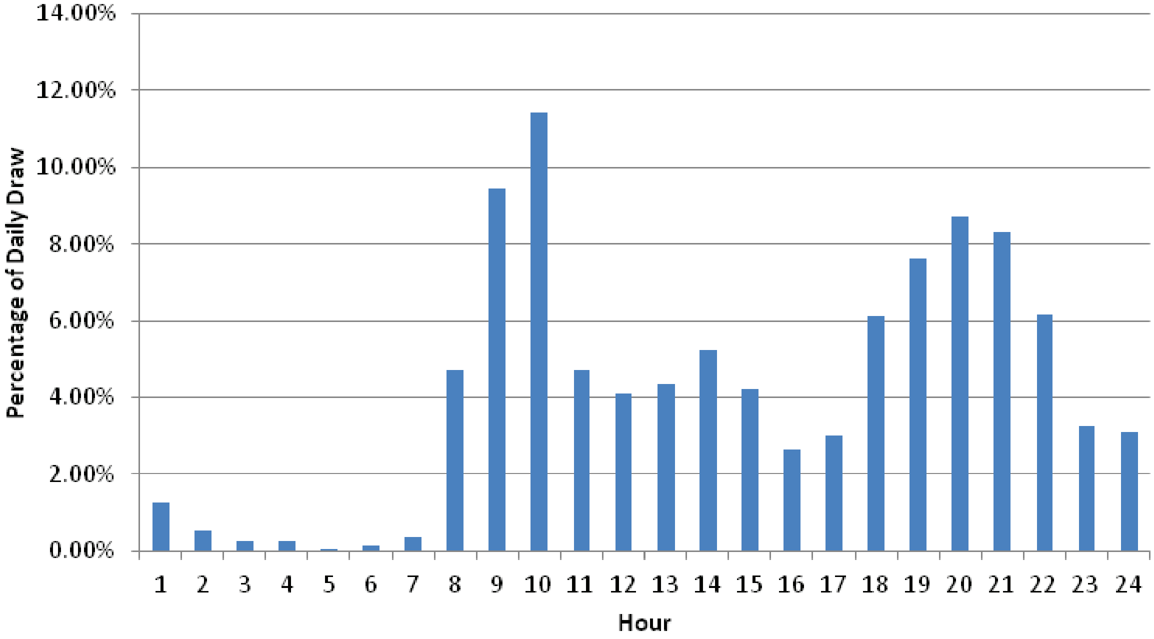
APPENDIX C: RETSCREEN DISCUSSION

RETScreen is based on the f-chart method. The f-chart method was developed by researchers at the University of Wisconsin in the 1970s[1]. F-chart is based on hundreds of simulations using a more sophisticated tool, TRNSYS. From the results of the simulations, simple parametric equations were created which allowed the performance evaluation of solar heating systems even by hand calculations, which was the goal when the method was created. F-chart is known to give conservative estimations of energy delivered by solar water heating systems, which seem to be the case in the present analysis.

1 Beckman et al, "Solar Heating Design, by the F-chart Method", Wiley-Interscience, 1977.

APPENDIX D: HOT WATER CONSUMPTION PROFILE

Figure D1: Fixed daily hot water usage profile used for WATSUN simulation



APPENDIX E: WATSUN 2008/2009 SIMULATION

Table E1: WATSUN Predictions vs. Actual Energy Delivered To Auxiliary Tank

	WATSUN Results			Actual	
Month	Heat collected	Heat Losses	Heat delivered	Heat delivered	Difference Delivered Energy
	kWh	kWh	kWh	kWh	(Watsun-Actual)/Actual
Jan	488.9	8.1	480.9	384.0	25.23%
Feb	684.3	32.9	651.3	527.0	23.59%
Mar	1002.2	69.5	932.7	663.0	40.67%
Apr	962.0	71.5	890.6	786.0	13.30%
May	1075.1	77.9	997.2	738.0	35.12%
Jun	897.9	85.7	812.2	662.0	22.69%
Jul	990.3	114.5	875.8	762.0	14.93%
Aug	1123.7	102.5	1021.2	933.0	9.45%
Sep	878.1	104.8	773.3	598.0	29.31%
Oct	750.9	81.2	669.7	433.0	54.67%
Nov	441.4	22.0	419.4	341.0	23.00%
Dec	360.5	3.1	357.4	249.0	43.52%
Total	**9655.3**	**773.7**	**8881.5**	**7076.0**	**25.52%**

Table E2: Energy Delivered to Solar Tanks

	WATSUN Results	Measurements	Difference Qdst
Month	Qdst	Qdst	(Watsun-Meas.)/Meas.
	kWh	kWh	
Jan	472.6	401.3	17.77%
Feb	657.8	595.7	10.42%
Mar	958.3	759.7	26.15%
Apr	921.5	901.4	2.22%
May	1031.3	820.2	25.74%
Jun	854.9	787.1	8.62%
Jul	933.8	904.5	3.23%
Aug	1071.7	1075.9	-0.39%
Sep	828.4	730.8	13.36%
Oct	711.2	546.5	30.14%
Nov	424.6	391.8	8.37%
Dec	349.7	263.8	32.58%
Total	**9215.8**	**8178.7**	**12.68%**

Table E3: Energy Delivered to Solar Tanks (Qdst) vs. Energy Delivered to Auxiliary Tanks (Qdel)

	Qdst	**Qdel**	**Qdst-Qdel/Qdst**
Month	**kWh**	**kWh**	
Jan	401.3	384.0	4.31%
Feb	595.7	527.0	11.53%
Mar	759.7	663.0	12.73%
Apr	901.4	786.0	12.80%
May	820.2	738.0	10.02%
Jun	787.1	662.0	15.89%
Jul	904.5	762.0	15.75%
Aug	1075.9	933.0	13.28%
Sep	730.8	598.0	18.17%
Oct	546.5	433.0	20.77%
Nov	391.8	341.0	12.97%
Dec	263.8	249.0	5.61%
Total	**8178.7**	**7076.0**	**13.48%**

APPENDIX F: HEAT MEASUREMENT ACCURACY

One observation should be made regarding the measurement of the hot water delivered by the solar system. Most heat meters are designed for fairly steady operation, mostly for heat distribution networks. They do not fare as well under dynamic loads, such as domestic hot water applications, especially under short draws, which can lead to an under reporting of energy delivered.

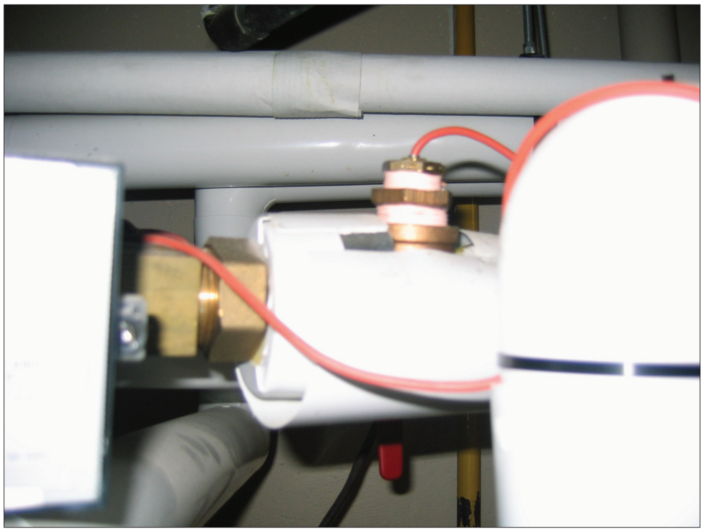
One of the reasons for the reduced accuracy is the fact that, to preserve battery charge, the meter calculator only checks the flow rate at discrete intervals. A recent study[2] tested heat meters under short dynamic loads, with 30 seconds of flow at 0.2 l/s and 300 seconds with no flow. The cycles are repeated until a total measured load equals 20 kWh. The tests were conducted with well know heat meter models and the results are presented in Table F1.

Table F1: Measurement Device Accuracy

Manufacturer	Model	Flow Meter Type	Error in Test (%)
Kamstrup	Multical Compact	Ultrasonic	-13.8
Kamstrup	Multical 66C92F0312	Ultrasonic	-10.8
Enermet	10EVL	Inductive	-3.8
ABB	F3	Ultrasonic	-2.59
Siemens	2WR5	Ultrasonic	-35.35
Actaris	CF Echo	Ultrasonic	-8.06

From those tests it is apparent that all models measured energy below what was really delivered. Of course, domestic hot water loads are not composed only by short bursts, but some of the energy would not be measured under those conditions.

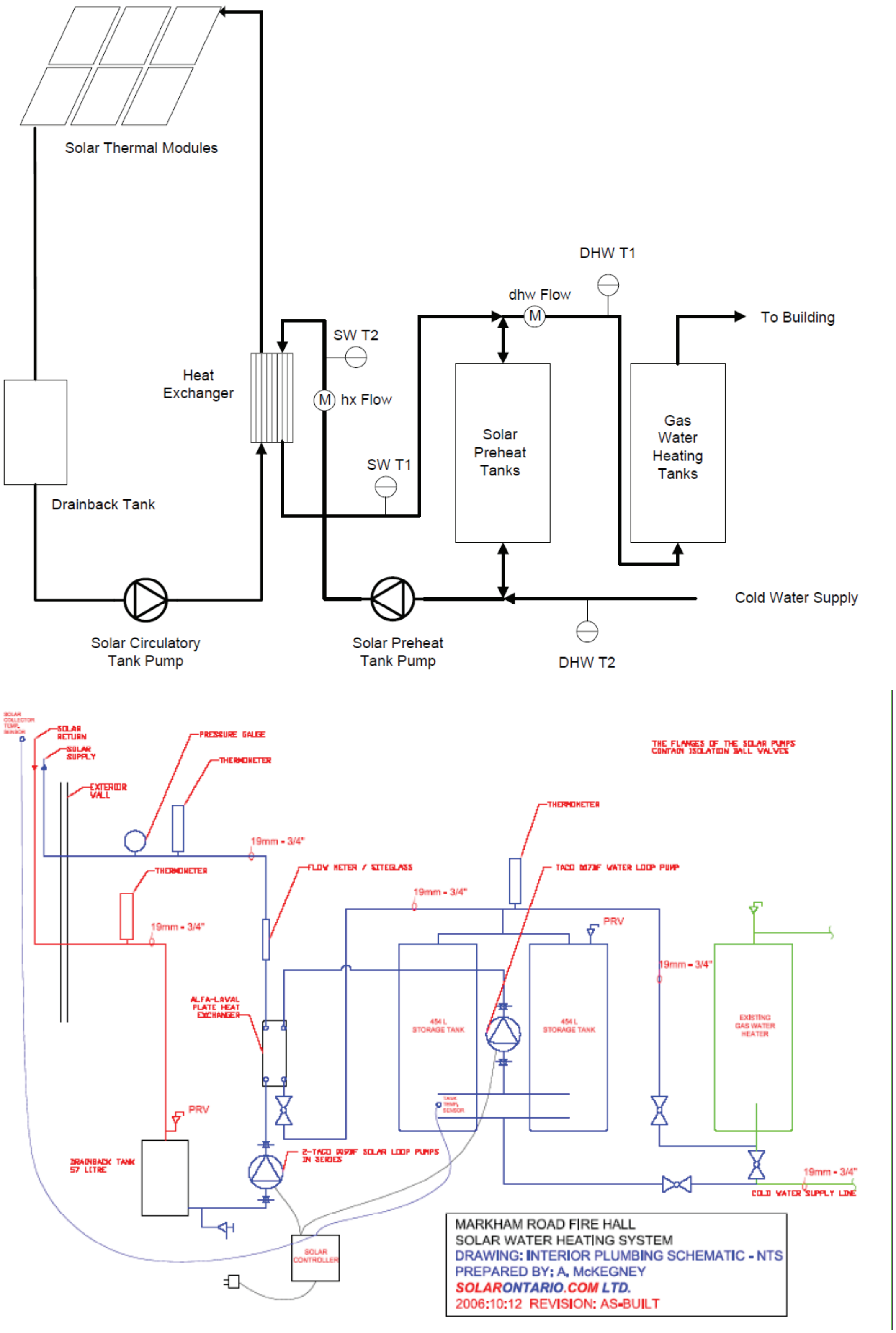
Figure F1: Detail of sensor installation at Fire Hall 231



2 Jomni, Y.,"Improving Heat Measurement Accuracy in District Heating Substations", , 2006, Doctoral Thesis, Lulea University of Technology, Sweden.

APPENDIX G: SYSTEM SCHEMATICS

Figure G1: Solar Domestic Water Heating Schematic



About the SolarCity Partnership

The SolarCity Partnership is a joint initiative of the Toronto Atmospheric Fund, Toronto and Region Conservation Authority and the City of Toronto designed to promote best practices and careful monitoring of large solar installations. SolarCity Partnership is an information-sharing hub for both public and private organizations involved in deploying solar power. Our **SolarCityPartnership.ca** website provides case studies, research, and solar weather data to help with the effective use of zero emissions energy from the sun.

We want to hear from you!

If you have further best practices recommendations, insights into system design, deployment or maintenance or a project to profile, please get involved with the SolarCity Partnership! Contact us at:

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