RESEARCH REPORT

Performance Monitoring of a Bubble Pumped Solar Domestic Hot Water System

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PERFORMANCE MONITORING OF A

BUBBLE PUMPED SOLAR DOMESTIC

HOT WATER SYSTEM

By Solar Calorimetry Laboratory

For Bubble Action Pumps Limited

CMHC Project Officer: Michael Macpherson

This project was carried out with the assistance of a grant from Canada Mortgage and Housing Corporation under the terms of the Housing Technology Incentives Program (CMHC CR File 6521-24/90). The views expressed are those of the authors and do not represent the official views of the Corporation.

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Performance Monitoring of a Bubble Pumped Solar Domestic Hot Water System

Final Report

The Solar Calorimetry Laboratory
Queen's University
Kingston, Ontario, K7L 3N6
December 1995

Performance Monitoring of a Bubble Pumped Solar Domestic Hot Water System

Final Report

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Executive Summary

The bubble pump developed by Bubble Action Pumps Ltd. is a concept that has the potential to be inherently reliable. It is unique in its design in that it has no moving parts and during operation requires no external electrical or mechanical input to operate. It is self regulating, in that it circulates anti-freeze, transporting heat from an elevated thermal source to a lower elevation.

An ideal application for this technology is the transport of heat from roof mounted solar collectors to a thermal storage located at a lower level. This configuration exists in solar domestic hot water (SDHW) systems located in cold climates. In this application, solar collectors are usually roof mounted and a thermal storage is placed in the building's basement to avoid freezing during the winter.

Self pumping systems of this type have received increased attention due to their potential for improved reliability, low maintenance and independence of electricity. During 1987 and 1992 prototypes were tested in the Solar Calorimetry Laboratory under controlled conditions. Since that time, a number of significant modifications and improvements have been made in the design to increase its performance and ease of manufacture.

In response to the continued refinement and development of the bubble pump, it was considered important to evaluate its performance on a real installation located outside of the laboratory environment. Consequently, a bubble pumped SDHW system was installed on a municipally owned row house and was instrumented with a remote data acquisition system to evaluate its performance. A variety of commissioning problems were overcome and data was collected from Sept. 1993 to Aug. 1994. This report describes the monitoring and evaluation of this system.

During the monitoring period, the system delivered of 1.17 MWh of solar energy to the load, however, system efficiency was lower than expected because of low hot water load. Performance was observed to increase toward the end of the monitored period as hot water demand and solar insolation increased.

Estimates, based on six of the monitored months, indicated that annual system efficiencies and solar fractions of 19% and 41% are representative of the system's operation under modest load conditions, i.e., 180 to 245 L/day. It is expected that overall system efficiency will increase as daily hot-water-demand increases toward the design value of 300 L/day.

RÉSUMÉ

La pompe à bulles, conçue par Bubble Action Pumps Ltd., est un concept pouvant être essentiellement fiable. Ses pièces fixes et son fonctionnement sans alimentation électrique ou prise de mouvement mécanique en font un produit de conception unique. Cette pompe est autoréglable, car l'antigel y circulant transporte vers le bas la chaleur provenant d'une source de chaleur surélevée.

L'application idéale de cette technologie consiste à transporter la chaleur retenue par des capteurs solaires montés sur le toit vers un accumulateur thermique situé à un niveau plus bas. Cette configuration existe dans les chauffe-eau solaires résidentiels conçus pour les climats froids. Dans cette application, les capteurs solaires sont généralement montés sur le toit, et l'accumulateur thermique est placé au sous-sol du bâtiment pour le protéger contre le gel en hiver.

On s'intéresse de plus en plus aux systèmes de pompage autonomes de ce type, car ils peuvent être très fiables, nécessitent peu d'entretien et fonctionnent sans électricité. Au cours des années 1987 et 1992, le laboratoire Solar Calorimetry a testé des prototypes sous des conditions dirigées de température. On a depuis apporté de nombreuses modifications et améliorations importantes à la conception des systèmes de pompage pour améliorer leur rendement et faciliter leur fabrication.

Une étape primordiale pour la mise au point de la pompe à bulles consistait à évaluer le rendement de celle-ci dans une installation en dehors du laboratoire. Par conséquent, on a installé un chauffe-eau solaire résidentiel avec pompe à bulles dans une maison en rangée municipale, et un système d'acquisition de données à distance y a été intégré pour évaluer le rendement du chauffe-eau. Divers problèmes liés à la mise en service ont été réglés, et on a pu recueillir des données de septembre 1993 à août 1994. Le présent rapport expose les résultats de la surveillance et de l'évaluation du chauffe-eau solaire en question.

Au cours de la période de surveillance, le chauffe-eau solaire a produit 1,17 mWh d'énergie solaire par charge liquide; cependant, le système n'a pas été aussi efficace que l'on s'y attendait en raison de la faible charge d'eau chaude. On a remarqué que le rendement du chauffe-eau s'est amélioré vers la fin de la période de surveillance en raison de la demande accrue en eau chaude et parce qu'il s'agissait d'une période plus ensoleillée.

Des évaluations, effectuées sur six mois de la période de surveillance, ont indiqué qu'un rendement annuel et un apport solaire de 19 p. 100 et 41 p. 100 respectivement représentent un chauffe-eau qui fonctionne dans des conditions de charge liquide modérées, c'est-à-dire qu'il peut fournir 180 à 245 litres d'eau par jour. Le rendement global du chauffe-eau s'améliorerait s'il était conçu pour fournir près de 300 litres d'eau chaude par jour.

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Performance Monitoring of a Bubble Pumped Solar Domestic Hot Water System

1. Introduction

A bubble pumped SDHW system that is self pumping and self regulating has been described [1]. A potential application for this technology is the transport of heat from roof mounted solar collectors to a thermal storage located at a lower level. Such an application exists in solar domestic hot water (SDHW) systems located in cold climates. In this application, solar collectors are usually roof mounted and a thermal storage is placed in the building's basement to avoid freezing during the winter. An anti-freeze solution is circulated, in a closed loop, through the solar collector to a heat exchanger located adjacent to the storage tank. In a conventional system, the anti-freeze solution (i.e., heat transfer fluid) is circulated by a photo-voltaic or AC powered pump that is controlled by a differential controller. The use of these conventionally pumped and controlled systems has resulted in both mechanical and electronic failures in the past, and when combined with the cost of these components, has prompted the investigation of alternative concepts for system control and heat transport.

The bubble pump developed by Bubble Action Pumps Ltd. is one concept that has the potential to be inherently reliable. It is unique in its design in that it has no moving parts and during operation requires no external electrical or mechanical input to operate. It is self regulating, in that it circulates anti-freeze, transporting heat from the solar collectors to the storage tank, only when there is available solar radiation.

During 1987 and 1992 prototypes were tested in the Solar Calorimetry Laboratory under controlled conditions [2, 3]. Since that time a number of significant modifications and improvements have been made in the design to increase its performance and ease of manufacture.

In response to the continued refinement and development of the bubble pump, it was considered important to evaluate its performance on a real installation, outside of the laboratory environment. Consequently, a bubble pumped SDHW system was installed on a typical row house owned by Townhomes Kingston (a municipally owned corporation) and was instrumented with a remote data acquisition system [4] to evaluate its performance. During the monitoring period a number of tenants occupied the home, presenting a diverse hot water load for the solar system. This report describes the monitoring and evaluation of this new system.

2. Bubble Pumped Solar Domestic Hot Water System

The system evaluated was installed on a municipally owned townhouse located in Kingston, Ontario (located at 44.14°N latitude and 76.30°W longitude) by Bubble Action Pumps Ltd.

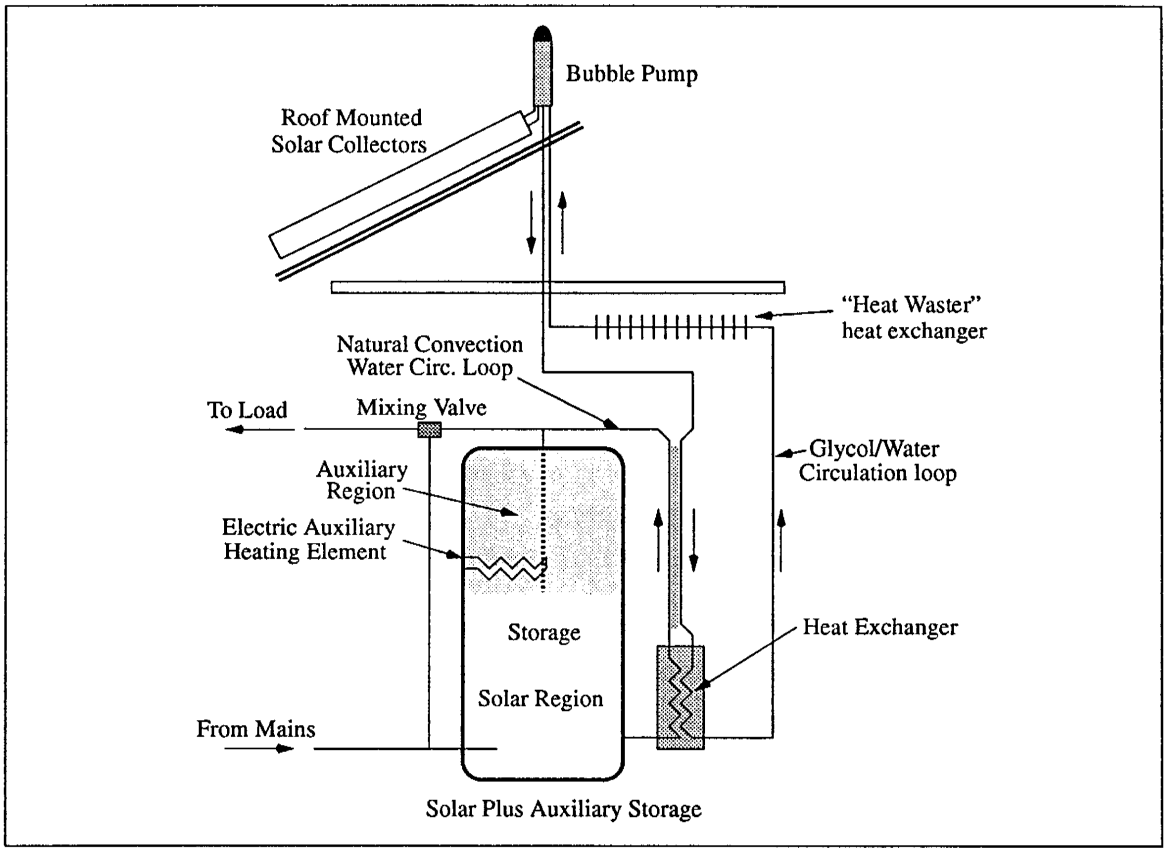

Figure 1. Schematic of the bubble pumped solar domestic hot water system.

2.1 System Description

Two solar collector panels and a SOL-Perpetua™ bubble pump were installed on a single family unit in the townhouse (shown on the cover of this report). Copper piping was run from the roof mounted bubble pump, through the attic space and walls of the building, to a hot water storage tank located in the basement. The complete solar domestic hot water (SDHW) system (Figure 1) consisted of: two Solcan 2100W solar collectors, a bubble pump, a compact plate-type heat exchanger, associated piping and insulation, a "heat waster", and a hot water storage tank.

The hot water storage used was a commercial electric water heater with a nominal 80 gallon (imp.) capacity. The tank was "glass lined" steel and was insulated with fiberglass.

Table 1: SDHW System Technical Specifications

Collectors	2 Solcan 2100W (4 ft. x 8 ft.) solar collectors.
Heat Exchanger	Alfa-Laval counter flow plate type heat exchanger, (Model CB 12-20).
Heat Transfer Fluid	50/50% mixture propylene glycol and water.
Piping	Insulated 1/2 in. and 3/8 in. copper.
Storage	John Wood, Commercial Electric Water Heater, Model JW-1002A.
Pump	SOL-Perpetua™ bubble pump, glass, rubber, copper and plastic construction.
Heat Waster	Natural convection operation, aluminum fin (4 in. x 4 in.) on 3/4 in. copper tube (12 ft. length).

The bottom element in the tank was disconnected to allow the bottom half of the storage to act as a solar storage. The upper portion of the storage was maintained at 60°C by a thermostatically controlled electric immersion heater element.

A freeze resistant 50% water/50% propylene glycol mixture was circulated to transport heat from the collectors to the heat exchanger located at the bottom of the tank. During "solar" charging, domestic water was circulated through it by natural convection.

The "heat waster", a "fin-on-tube", liquid-to-air heat exchanger, was intended to prevent the glycol working fluid from overheating when the storage tank became fully charged with hot water. Excess heat was transferred from the circulation loop to the basement room-air.

Specifications for the BAP system are given in Table 1 and product literature is included in Appendix A

2.2 Basis of Operation

The conceptual design of the bubble pump unit evaluated in this study is shown in Figure 2. The unit was constructed of glass tubing allowing the percolating action to be observed. Baffles and end caps were constructed from rubber. During operation, the glycol fluid mixture boiled in the solar collectors forming vapour bubbles. The density difference created by these bubbles caused the fluid to flow into the elevated separator. This pumping action was enhanced by initially evacuating the collector loop of air, thereby lowering its pressure. This was accomplished with a small hand vacuum pump and allowed boiling at lower temperatures (typically 70°C).

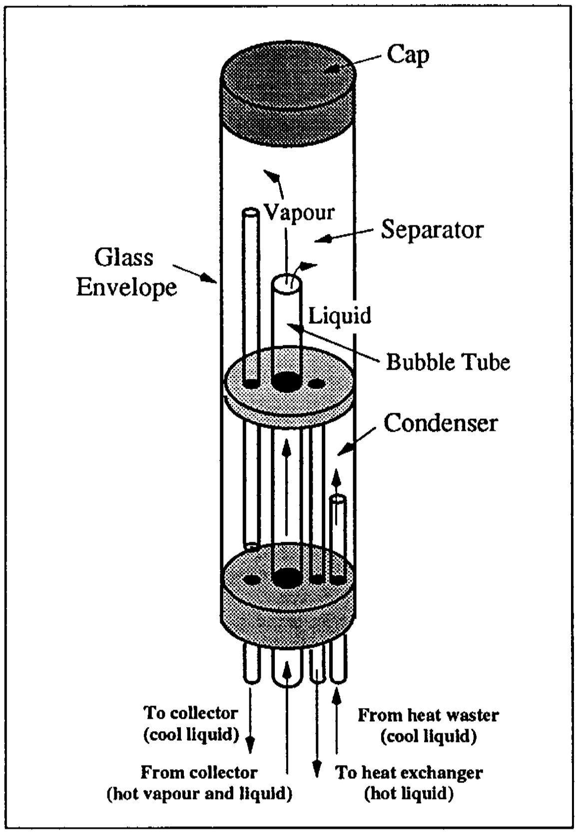

Figure 2. Details of the construction of the Bubble Pump, (not to scale).

The fluid accumulation in the elevated separator produced a pressure head that caused the hot liquid to drain through the heat exchanger located at a lower level where the solar energy was transferred to the storage. For continuous operation, the vapour produced in the solar collectors was condensed before returning to the solar collectors. The vapour was condensed by direct contact with the cooler liquid returning from the storage tank heat exchanger.

The thermodynamic operation of the bubble pump was recently investigated under a separate study conducted at Queen's University. Readers are referred to that documentation for a detailed description of the bubble pump operation [5,6].

3. Monitoring Program

A remote monitoring unit (RMU) was installed on the bubble pumped SDHW system. It included a data acquisition system that collected data from instrumentation attached to the solar system [4]. To reduce both data collection time and intrusions on the residents of the household, the monitoring system operated remotely via telephone dial-up.

The system was equipped with a central processing unit (CPU) to pre-process data and maintain storage on site. The unit continuously measured and calculated energy flows through the hot water tank. Data retrieval hardware and software was then used to download the monitored data to the Solar Calorimetry Laboratory (SCL) at Queen's University using modem communications.

3.1 Measured Quantities

Where possible, measurement instrumentation and analysis procedures used for the project followed the general guidelines of ASHRAE Standard 95, *Methods to Determine the Thermal Performance of Solar Domestic Hot Water Heating Systems* [7], and are described in detail in reference [4]. The quantities recorded are listed in Table 2 and the location of the sensors is shown in the system schematic, Figure 3.

The monitoring system continuously recorded system temperatures, solar radiation levels, water draw volumes and auxiliary electrical energy usage. In addition, integrated energy quantities including the *Solar Radiation* incident on the solar collector surface, the *Energy Delivered* to the load, and the *Total Auxiliary Energy* used, were determined over one-hour intervals.

The *Energy Delivered* to the load, Q_{del}, was determined by summing the incremental energies delivered to the load during discrete scan intervals of the data system[1]. A save interval of one hour was used for this study and the scan interval was set at a relatively high rate (> 10 channels/sec) to minimize errors in the calculation.

1. $Q_{del,i}$ was determined for each scan interval, *i*, by measuring the temperature rise and volume of the main's water as it was drawn through the tank, i.e., the product of the volume of water drawn, v_{load}, the density of the water, ρ, the specific heat, C_p, and the difference in the temperature between the water entering and leaving the tank, $(T_{mains}-T_{del})$. The energy delivered by the system to the load over a "save interval" was then calculated as the sum of the individual "*n*" scans made by the data system during that period, e.g.,

$$Q_{del} = \sum_{i=1}^{n} [v_{load,i} \cdot C_{P,i} \cdot \rho_i \cdot (T_{Mains,i} - T_{del,i})]$$

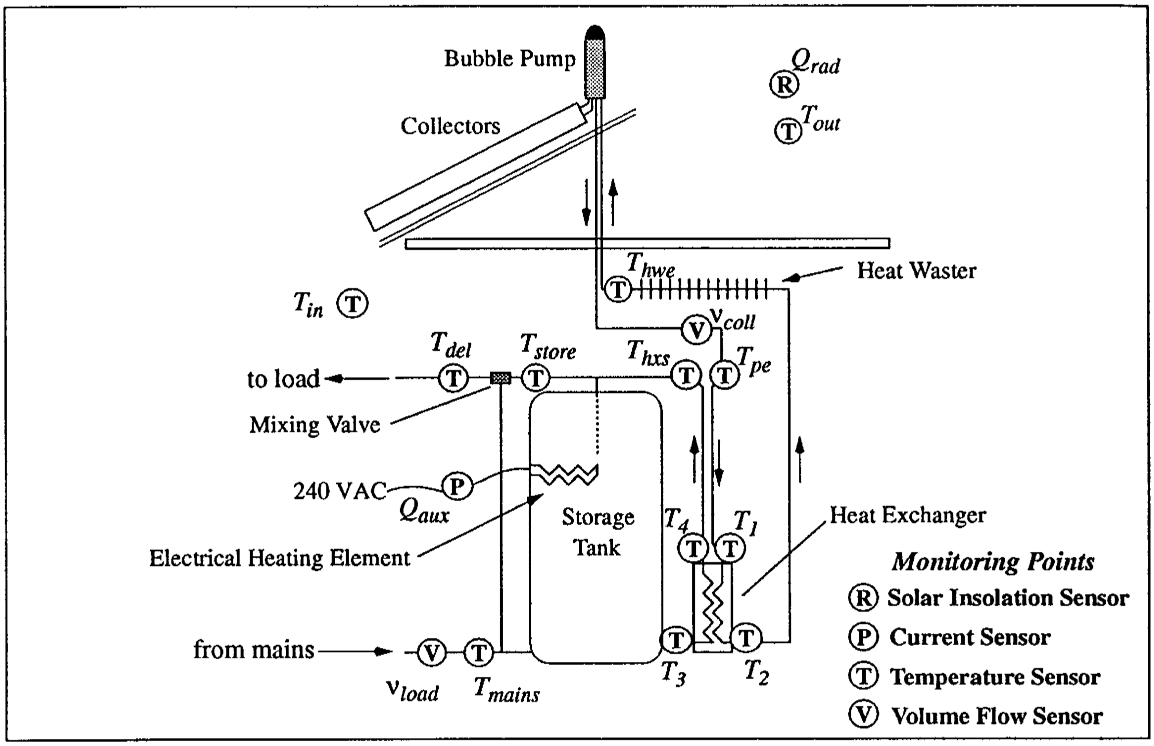

Figure 3. Schematic of the bubble pumped SDHW system showing the monitoring points.

Table 2: List of Measured and Recorded Data.

Variable	Measurement	Sensor Description
Q_{rad}	Insolation in the plane of the collectors	Eppley PSP pyranometer
T_{out}	Outdoor ambient temperature	T-type thermocouple
T_{in}	Indoor ambient temperature	T-type thermocouple
T_{mains}	Mains inlet water temperature	T-type thermocouple
T_{store}	Tank outlet water temperature	T-type thermocouple
T_{del}	Delivery water temperature at mixer outlet	T-type thermocouple
T_{pe}	Glycol/water temperature from the pump	T-type thermocouple
T_1	Glycol/water temperature into heat exchanger	T-type thermocouple
T_2	Glycol/water temperature exiting heat exchanger	T-type thermocouple
T_3	Water temperature into heat exchanger	T-type thermocouple
T_4	Water temperature exiting heat exchanger	T-type thermocouple
T_{hwe}	Water temperature exiting heat waster	T-type thermocouple
T_{hxs}	Water temperature into storage from heat exch.	T-type thermocouple
Q_{aux}	Auxiliary energy consumption	Calculation/toroid current sensor
Q_{del}	Energy delivered to load	Calculation
Q_{sol}	Solar energy delivered to the load	Calculation
V_{load}	Volume of hot water drawn	Badger M25 bronze water meter
V_{coll}	Flow rate in collector loop	Clorius Magnetic flow meter

The volume of hot water used in the home was measured with a utility water meter fitted with a hall-effect counter that closed once for every 26 ml of water drawn from the system. The flow rate of the glycol/water mixture in the collector loop was measured with a magnetic flowmeter so as to introduce a minimal pressure drop on the circulation loop. The flowmeters were calibrated at the SCL using a “gravimetric” flowmeter apparatus.

To determine the *Total Auxiliary Energy* requirements of the hot water tank, Q_{aux}, a toroidal current transformer was used. The power output of auxiliary heater was calculated during a scan interval as the product of the measured current and voltage across the heater element. This value was integrated over time to determine the auxiliary electrical energy used during a “save interval”.

Water temperature measurements were made using type “T” thermocouples inserted into measurement wells installed at various locations in the system. Mixers were placed upstream of the temperature wells to ensure that “bulk” fluid temperatures were measured. Thermocouple sensors were taken from one production run of wire and random samples were chosen and calibrated using a reference temperature bath.

3.2 System Analysis

The SDHW system monitored utilized a single storage tank as a solar storage and auxiliary heater/storage. To analyze its energy performance, a control volume (*CV*) and energy balance approach was used, Figure 4. Under this analysis, energy flows across the *CV* boundary were summed to arrive at net energy contributions. Over specified intervals, the energy crossing the boundary due to solar or auxiliary energy inputs or due to thermal losses and hot water draws, was determined.

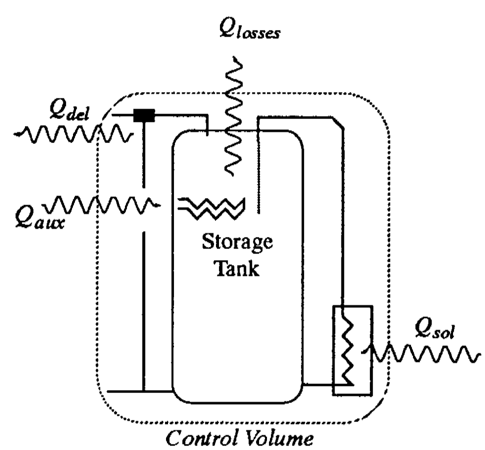

Figure 4. Control volume used for energy balance on the monitored SDHW system showing the energy flows across the boundary.

Using this approach, the net energy stored in the *CV* (effectively the tank), must be equivalent to the difference between the energy entering and leaving the *CV*, i.e.,

$$\frac{d}{dt}(Energy_{CV}) = Q_{sol} + Q_{aux} - Q_{del} - Q_{losses}$$

Over long periods of time the net energy change in the storage can be considered negligible, (i.e., $\frac{d}{dt}(Energy_{CV}) \approx 0$) allowing performance factors to be directly calculated knowing the other values, e.g.,

Solar Energy Delivered, Q_{sol}, was calculated as the *Energy Delivered* to the load plus the tank losses minus the auxiliary energy[2].

$$Q_{sol} = Q_{del} + Q_{losses} - Q_{aux}$$

From the measured and derived results a number of performance factors were determined including,

Total System Energy, Q_{tot}, as presented in this report, represents the total energy used for hot water production including the *Solar Energy Delivered* to the load, Q_{sol}, and the *Total Auxiliary Energy* supplied, Q_{aux}, i.e.,

$$Q_{tot} = Q_{sol} + Q_{aux} = Q_{del} + Q_{losses}$$

The *Solar Fraction* was calculated as the *Solar Energy Delivered* divided by the *Total System Energy*.

$$Solar \cdot Fraction = \frac{Q_{sol}}{Q_{tot}} = \frac{Q_{sol}}{Q_{sol} + Q_{aux}}$$

The value of the *Solar Fraction* is an indication of the percentage of the total hot water heating load that has been met by the solar system.

In addition, the *System Efficiency* was defined as the *Solar Energy Delivered* to the load, Q_{sol}, divided by the total available solar energy in the plane of the solar collectors, Q_{rad}.

$$System \cdot Efficiency = \frac{Q_{sol}}{Q_{rad}}$$

2. For the single tank design, the solar energy collected was considered to contribute to the tank standby losses. Tank losses, Q_{losses}, were estimated using tank manufacturer's data as well as experimental data.

4. System Installation

The SDHW system installation started in the fall of 1992 and the monitoring began soon afterwards. Two solar collectors and the bubble pump unit were installed on the roof of the townhouse. Piping was run through the attic space and walls of the unit, and the storage tank was placed in a wash/utility room located in the basement, approximately 10 m below the bubble pump. Piping runs were insulated.

The data acquisition system and instrumentation were installed but were initially plagued by a number of problems ranging from faulty communications hardware (i.e., local fax switches at the remote site) to programming "bugs" and updates in the remote monitoring unit. Recurring communications problems ultimately led to the elimination of the fax switch and the installation of a dedicated telephone line for the monitoring system.

The prototype SDHW system itself suffered a number of commissioning problems. Most notable were the elimination of leaks in the system. The situation was exacerbated by the instrumentation hardware that significantly increased the number of pipe-fittings in the system. Unfortunately these leaks only become apparent after extended periods of operation and were made evident by an increase in operational temperature of the bubble pump caused by the infiltration of air into the system.

Consequently, the system had to be "pumped down" a number of times and the working fluid changed. During December 1993 and March 1994, a small leak in a valve, which allowed air into the collector system, proved to be very problematic.

The fact that the system was installed on a public housing residence, occupied by relatively indifferent tenants, also made adjustments and maintenance of the SDHW and monitoring systems difficult. Visits to the site could only be arranged after negotiation with the tenants on a convenient time. The tenants occupying the unit also changed a number of times, requiring repeated briefings on the project underway. Periods also existed between tenants when the building was left unoccupied and consequently experienced no hot water load.

Most commissioning problems were corrected and reliable monitoring was started in September of 1993, however, hot water loads varied significantly over most of the remaining monitoring period, often having a detrimental affect on the SDHW system's performance.

5. Monitoring Results

Monthly summaries of the measured data covering the year long period from September 1993 to August 1994 are presented in Appendix B of this report. Average daily values are given for each month of the monitored period. Measured values reported include: incident *Solar Radiation, Outdoor Air Temperature, Hot Water Usage, Total System Energy*, and *Total Auxiliary Energy*. In addition, estimates of *Solar Energy Delivered* to the load and *Solar Fraction* are presented for each month.

5.1 Summary of Monitored Results

Summary plots of the monitored data for the period from September 1993 to August 1994 are shown in Figures 5 to 8.

Values of *Solar Fraction* as determined from the monitored data are shown in Fig. 5 and indicate of the percentage of the total hot water heating load that was provided by solar energy. It is normally not economical for solar domestic hot water systems to be designed to provide all of the hot water load (i.e., solar fraction = 100%). Consequently, annual solar fractions ranging from 20 to 60% are normal design values depending on the local climate, geographic location and the hot water load. The average daily solar fraction for the monitored period was 35%.

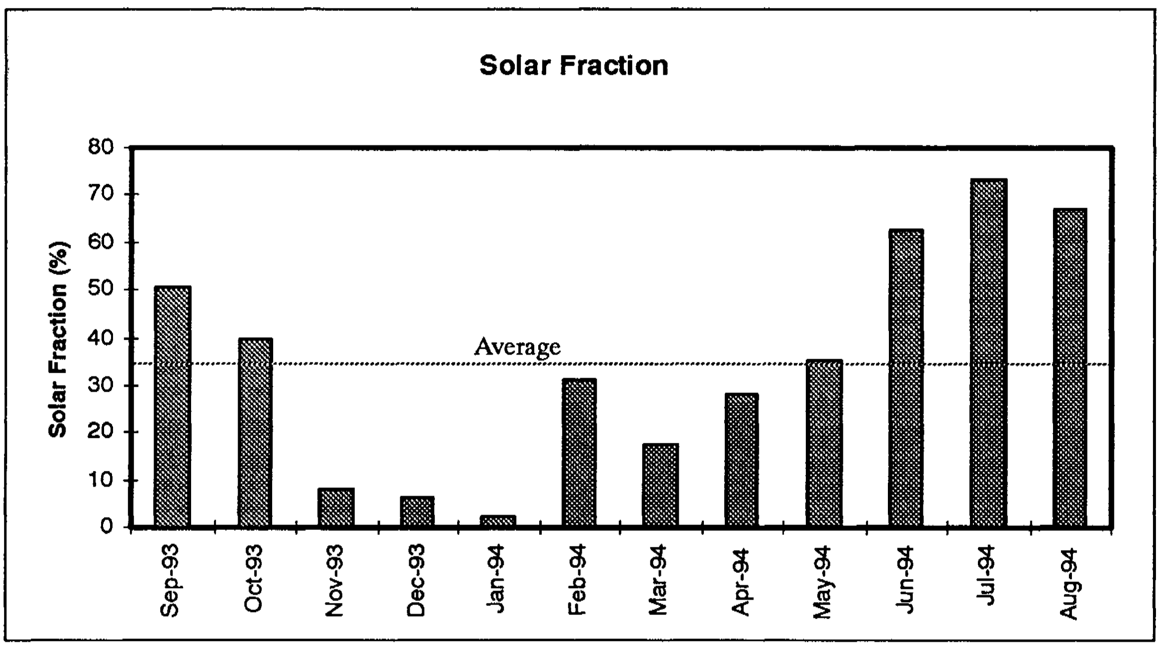

Figure 5. Solar Fraction as determined for the monitored period.

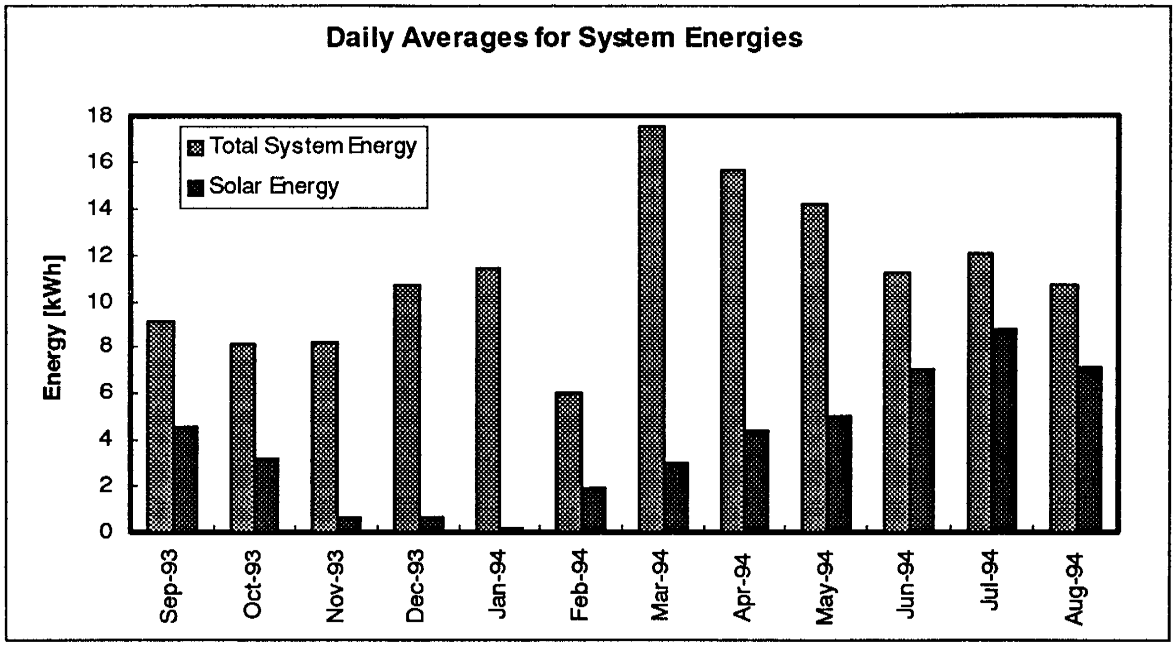

Figure 6. Comparison *of Solar Energy Delivered* and *Total System Energy* used to meet the hot water load during the monitored period.

Monitored results for the *Solar Energy Delivered* and *Total System Energy* used to meet the hot water load are summarized in Fig. 6.

System Efficiency, the solar energy delivered to the load divided by the total solar energy available to the solar collectors, is a measure of the solar system's ability to utilize the

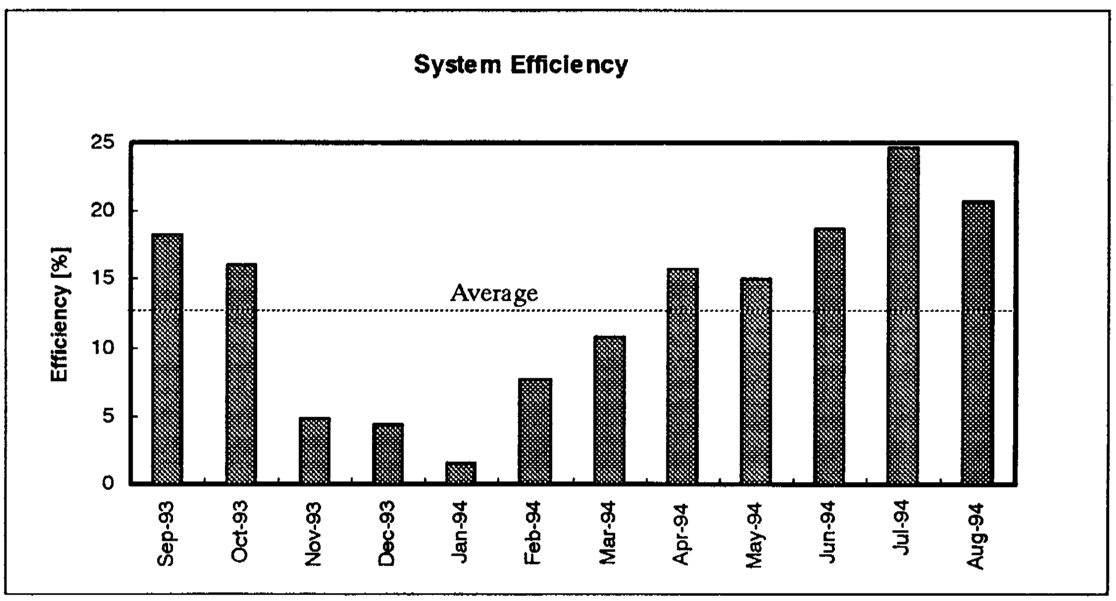

Figure 7. System Efficiency as measured for the monitoring period.

available solar energy. Values of average *System Efficiency* are plotted versus month of the year in Fig. 7. The average system efficiency for the total monitored period was 13.4%.

The volume of hot water drawn from the solar system has a significant effect on its overall performance and in particular its system efficiency. Values of average daily hot water load over the monitored period are shown in Fig. 8.

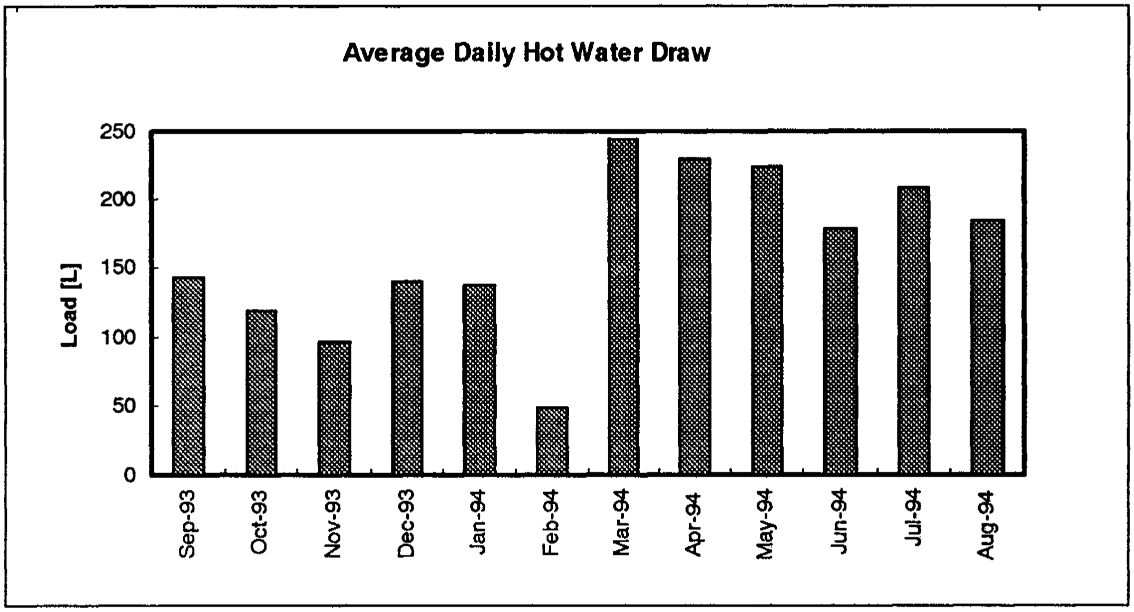

Figure 8. Plot of the average daily hot-water-draw for the monitored period.

5.2 Discussion of Results

It is evident from the data shown in Fig. 6 that the energy solar delivered by the system drops significantly during the winter months. This result is consistent with the operation of conventional solar domestic hot water systems and is a consequence of the lower solar energy available during the winter period.

The system evaluated was also installed directly on the roof surface at low slope to the horizontal. The effect of this was to increase output of the solar system during the summer period when the sun's elevation was high in the sky but also resulted in a significant reduction in available energy during mid-winter. This effect can be reduced somewhat by mounting the solar collectors at a steeper slope, e.g., 45 to 60^{o} to the horizontal. The steeper slope has the added benefit of reducing the potential for snow to accumulate on the collector surface. The winter period monitored was particularly severe and snow accumulation was a contributing factor to the system's lower performance.

In addition, a number of other factors affected the performance of the system. In particular, maintenance of both the SDHW and monitoring systems proved to be difficult as the study was conducted on a public housing residence. From December to March, a small leak in one of the system's valves allowed air into the system. This resulted in increased collector temperatures and system thermal losses during this period. Consequently, measured system efficiencies were lower than expected during this period.

The performance of the system depends on the volume of hot water used. During the first six months of monitoring, the load was well below the design value of 300 litres per day [8] and in the month of February 1994 the unit was unoccupied. Consequently, except for a few days of cleanup during this period, there was very little hot water used. In March of 1994, new tenants moved into the building and the hot water demand increased significantly to daily average values ranging from 180 and 245 L/day.

The system performance was also observed to increased during the final six months of data collection and can be attributed to the elimination of leaks, the increase in hot water demand, and rising solar insolation. An indicator of potential performance can be obtained by looking at the three summer months of that period (i.e., June, July, and August) in which the average system efficiency was 22% and the average solar fraction was 68%.

Further, a more representative estimate of annual system performance can be obtained by combining the six monitored months consisting of Sept. to Dec. 1993, and July and August of 1994. As the yearly variation in performance is effectively symmetrical about June, it can be anticipated that the average system efficiency and solar fraction for this period (19.1% and 40.9%, respectively) are indicative of annual averages.

6. Conclusions and Recommendations

A bubble pumped SDHW system was installed, together with monitoring equipment, at unit 7, 257 Rideau street, a row house owned by Townhomes Kingston. A number of commissioning problems where overcome and data was collected from September 1993 and August 1994. For the period from September 1993 to August 1994, the average daily solar fraction was 32.4% and the average system efficiency was 13.4%. This represents solar energy delivered of 1.17 MWh.

Initial system performance was below expectations due to low hot water demand, however, it was seen to increased toward the end of the monitoring period. This increase in the solar energy delivered was due an increase in hot water demand, improvements to the SDHW system and increased solar insolation.

Based on data collected for six of the months studied, yearly performance is estimated at 19% for system efficiency and 41% for solar fraction. These estimates are based on the average daily hot water draws of 100 to 240 L/day that were measured over the reference period. It is anticipated that the system's performance would increase as average hot water draws increased to the design value of 300L/day. Finally, it is probable that mid-winter performance could be improved somewhat by increasing solar collector slope to a value between 45 and 60^{o} to the horizontal.

The bubble pump has the potential for high reliability, however, successful operation depends on careful installation and the elimination of any potential leaks in the system. It is anticipated that in a normal installation (i.e., one without intrusions for monitoring instrumentation), the system will be leak proof and will function without intervention.

The system monitored demonstrated that it is self regulating and self pumping and has the added feature that its operational status may be immediately identified by observing the bubbling action evident during pumping. This latter point is one of the bubble pump's strongest features.

7. Glossary of Terms

Solar Radiation - the energy incident on the collector surface found by integration of the measured 15 minute or 1 hour average irradiance values.

Solar Energy Delivered - the net solar energy contributed to the total hot water load including storage tank standby losses.

Auxiliary Energy - the additional electrical energy required to produce sufficient hot water to meet the demand when sufficient solar energy was not available.

Total System Energy - the total energy used for hot water production including the solar energy delivered to the load and the auxiliary energy supplied to the storage tank.

Solar Fraction - the percentage of the total hot water heating load that was provided by solar energy.

8. References

1. Sorensen, W., The Bubble Pumped D.H.W. System, presented at the ISES Solar World Congress, Hamburg, F.R.G., (1987).

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4. Usher, E.P. et al., Remote Monitoring of the Solar Domestic Hot Water Systems for the S-2000 Project, Presented at the 18th Annual Conference of the Solar Energy Society of Canada, Edmonton (1992).

5. T.O. Bahomed and S.J. Harrison, Thermal Modelling of A Bubble Pumped Solar Domestic Hot Water System, Solar Calorimetry Laboratory, Queen's University, Kingston, Ontario, Canada, K7L 3N6. Presented at the 1995 ISES Solar World Congress, Harare, Zimbabwe, (1995).

6. T.O. Bahomed, Thermal Modelling of A Bubble Pumped Solar Domestic Hot Water System, M. Sc. Thesis, Queen's University, Kingston, Ontario, (1996).

7. ASHRAE Standard 95, Methods to Determine the Thermal Performance of Solar Domestic Hot Water Heating Systems, ASHRAE, 1791 Tullie Circle, N.E., Atlanta GA (1981).

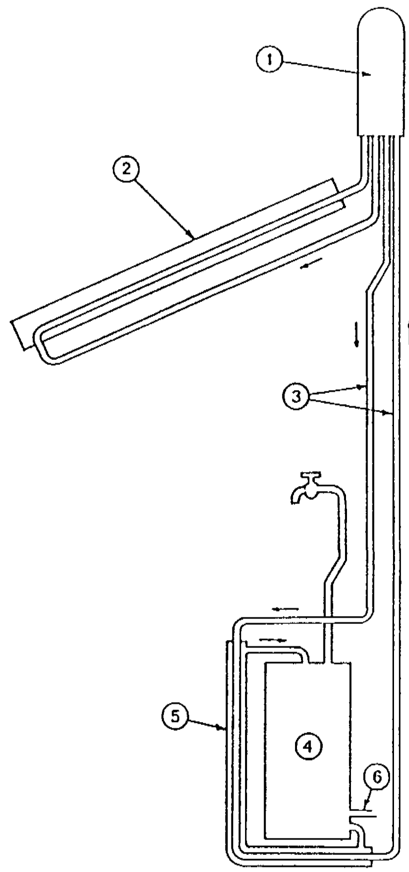
8. Field Monitoring of a Bubble Pumped Solar Domestic Hot Water Package Phase 1 Report: Analysis of System Design and Monitor Requirements, prepared by the Solar Calorimetry Laboratory, Queen's University, (1991).

Appendix A

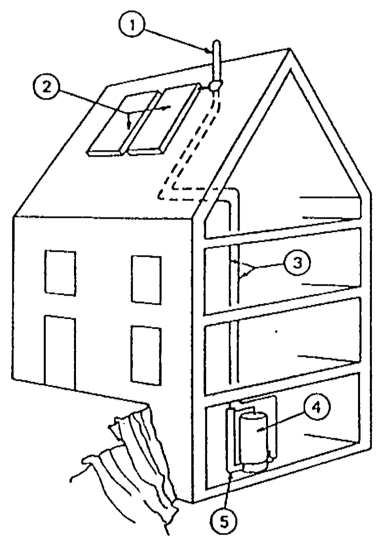
SOL-Perpetua^{TM} Product Literature

BUBBLE ACTION PUMPS LTD.

MAKERS OF ELECTRIC-FREE HOT WATER AND SPACE HEATING SYSTEMS USING SOLAR AND OTHER FUELS



1 Bubble Pump
2 Solar Collectors
3 Risers
4 Hot Water Tank
5 Heat Exchanger
6 Supply Inlet



Schematic of The SOL-Perpetua™ motorless solar water heating system

Some of the many advantages of the Sol-Perpetua™ system:

- No electric power is used: it's passive but has the advantages normally associated with active systems.
- The bubble pump has no moving parts or motor to wear out.
- No controls to malfunction, it's self-controlling, has no wiring.
- Working fluid is water, freeze protected with propylene glycol.
- There's no drain down and no expansion tank.
- Can be used with almost any collector having metal tubing.
- Pumping rate varies with strength of sun.
- Pump serves one, two or more collectors.
- No tank on the roof. Tank can be 3 storeys below collectors.
- Convective heat exchanger delivers 122 F water to top of tank.
- System is sealed after all corrosion causing gas is removed.
- Pump mounts on top of collector and is transparent. You can see it working.
- Only common plumbing tools needed to install a SOL Perpetua System.

Box 1, 121 Counter Street, Kingston, Ontario, Canada K7K 6C7 Tel (613) 542-4045 Fax (613) 542-0198

Appendix B

Monthly Data Summaries

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
September 1993

Latitude· 44.14 °N Longitude: 76.30 °W Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
22	40.4	16.1	106.5	7.3	1.7	5.6	76.3
23	17.6	17.5	246.1	12.9	4.3	8.6	66.7
24	39.2	15.8	372.8	18.1	7.2	10.9	60.0
25	39.2	16.3	118.8	7.5	3.0	4.5	60.3
26	4.7	16.4	193.5	10.7	6.6	4.1	38.5
27	5.7	14.4	87.1	7.5	7.5	0.0	0.0
28	19.6	13.4	88.3	6.7	5.1	1.6	24.6
29	27.9	10.9	18.3	4.0	1.7	2.3	57.5
30	30.5	8.1	106.6	6.9	3.2	3.7	53.1
Total	224.8		1338	81.6	40.3	41.3	50.6
Mean	25	14.3	148.7	9.1	4.5	4.6	50.6

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
October 1993

Latitude: 44.14 °N   Longitude: 76 30 °W   Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	29.9	11.7	95.9	6.8	1.7	5.0	74.7
2	6.0	12.9	101.9	6.9	5.9	1.0	15.0
3	23.8	10.9	320.1	16.9	12.5	4.3	25.7
4	3.6	9.7	206.0	12.2	12.2	0.0	0.0
5	24.4	8.8	27.1	4.3	4.1	0.1	2.8
6	30.2	14.1	77.8	6.5	3.1	3.3	52.2
7	33.5	18.9	172.1	9.6	1.6	8.0	82.7
8	10.6	11.6	40.1	4.8	3.1	1.6	35.0
9	3.5	6.3	106.0	7.7	6.1	1.5	20.6
10	35.7	4.5	338.5	17.0	8.5	8.4	49.5
11	22.8	8.3	257.6	13.5	7.0	6.4	47.7
12	6.8	10.3	34.8	5.1	5.1	0.0	0.0
13	36.1	5.6	200.6	10.6	5.6	4.9	46.8
14	32.5	7.4	27.6	4.3	1.6	2.7	61.9
15	30.4	11.6	25.6	4.1	1 7	2.3	57.5
16	22.1	16.2	93.9	6.6	1.5	5.0	76.3
17	3.9	14.7	6.0	3.5	1.5	2.0	56.9
18	13.4	11.8	73.2	6.3	4.5	1.8	28.5
19	9.0	9.0	328.8	17.9	14 9	2.9	16.6
20	17.6	11.4	64.9	5.7	4.6	1.0	18.8
21	9.5	12.7	62.5	5.9	4.6	1.2	21.5
22	20.5	10.0	66.7	5.9	4.6	1.2	21.0
23	34.0	9.1	140.7	8.7	3.2	5.5	63.5
24	23.9	14.4	133.3	8.0	3.8	4.2	52.7
25	33.7	8.8	64.3	5.7	1.6	4.1	72.0
26	20.6	10 5	169.5	9.7	5 8	3.8	39.9
27	1.1	11.5	4.5	3.5	0.0	3.5	100.0
Total	540.6		3241.3	219.0	131.7	87.3	39.8
Mean	20.0	10.8	120.0	8.1	4.8	3.2	39.8

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary

November 1993

Latitude: 44.14 °N Longitude: 76.30 °W Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
11	15.9	10.2	6.8	3.6	1.5	2.0	57.7
12	18.6	6.0	39.5	4.9	4.7	0.2	4.3
13	6.0	6.3	77.6	7.4	7.4	0.0	0.0
14	3.8	11.2	62.8	6.1	5.2	0.9	15.2
15	5.1	8.6	68.2	6.3	5.8	0.5	9.2
16	15.6	6.6	349.7	21.3	19.4	1.8	8.8
17	3.3	6.9	46.2	5.4	4.7	0.6	12.5
18	28.6	5.2	90.1	6.9	4.7	2.2	31.5
19	3.1	7.2	10.0	4.4	4.4	0.0	0.0
20	16.2	2.0	126.2	9.0	8.3	0.7	8.1
21	9.0	4.2	141.1	10.2	9.4	0.7	7.2
22	21.8	9.2	68.2	6.2	4.7	1.4	23.5
23	6.8	1.2	323.2	20.3	19.1	1.2	5.9
24	6.9	-1.5	107.8	9.1	9.1	0.0	0.0
25	28.4	-5.8	204.6	14.6	14.6	0.0	0.0
26	12.7	-1.2	63.3	7.6	7.6	0.0	0.0
27	3.1	5.3	21.6	4.3	4.0	0.2	5.3
28	3.6	5.6	30.4	4.7	4.5	0.2	5.4
29	16.1	2.2	84.4	7.2	6.8	0.3	4.8
30	27.3	-1.1	4.6	4.6	4.6	0.0	0.0
Total	252.7		1927.3	165.1	151.4	13.6	8.2
Mean	12.6	4.4	96.3	8.2	7.5	0.6	8 2

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
December 1993

Latitude. 44.14 °N Longitude: 76 30 °W Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	**Solar Radiation kWhr**	**Outdoor Air Temp. °C**	**Hot Water Usage Litres**	**Total System Energy kWhr**	**Total Auxilary Energy kWhr**	**Solar Energy Delivered kWhr**	**Solar Fraction %**
1	24.8	0.7	283.3	17.7	15.1	2.5	14.3
2	11.0	5.4	163.1	13.6	13.6	0.0	0.0
3	7.8	6.2	148.8	10.4	10.2	0.2	2.3
4	2.7	4.6	127.9	9.5	9.0	0.5	5.4
5	4.9	3.2	376.1	24.0	23.6	0.4	1.8
6	3.8	2.6	68.4	7.7	7.7	0.0	0.0
7	9.7	3.4	50.6	5.6	5.4	0.2	4.5
8	16.6	2.0	153.2	10.8	10 8	0.0	0.2
9	9.2	4.7	111.0	8.7	8.1	0.6	7.6
10	2.5	6.9	59.9	6.2	6 2	0.0	0.0
11	13.1	-5.7	18.9	4.5	4.5	0.0	0.0
12	25.2	-4.9	399.8	26.3	24 4	1.9	7.4
13	19.5	0.3	108.8	8.8	8.8	0.0	0.0
14	23.6	3.5	68.3	6.4	4.6	1.7	27.6
15	16.9	5.4	118.9	8.3	5 6	2.7	32.4
16	25.0	1.5	355.0	19.6	16 1	3.4	17.7
17	21.3	-1.4	139.2	10.0	7.7	2.2	22.3
18	3.5	1.7	89.6	7.8	6.7	1.0	13 1
19	7.2	4.1	103.7	8.2	7 9	0.3	3.7
20	5.4	4.2	193.6	13.0	12.7	0.2	2.2
21	2.1	2.2	65.6	6.4	6.3	0.0	0.8
22	18.0	-0.6	54.7	6.1	6.1	0.0	0.0
23	25.5	-11.5	145.8	10.7	10.7	0.0	0.0
24	4.6	-4.1	37.4	5.7	5 7	0.0	0 0
25	4.4	-0.4	214.8	15.2	13 6	1.6	10 6
26	28.2	-14.2	66.3	7.6	7 6	0.0	0.0
27	14.8	-18.8	102.8	8.7	8 3	0.4	5.0
28	26.1	-14.5	275.6	18.4	18.4	0.0	0.1
29	8.0	-9.3	83.2	8.4	8 4	0.0	0.0
30	28.6	-7.9	136.7	12.1	12.1	0.0	0 0
31	8.1	-2.1	50.5	6.5	6 5	0.0	0.0
Total	423.6		4372.9	334.3	313 6	20.6	6 1
Mean	13.6	-1.0	141 0	10.7	10 1	0 6	6 1

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
January 1994

Latitude: 44.14 °N Longitude: 76.30 °W Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	7.3	2.0	237.4	15.8	15.4	0.3	2.2
2	23.5	-5.5	67.4	7.3	7.3	0.0	0.0
3	18.4	-15.8	275.3	19.1	18.6	0.4	2.5
4	3.5	-11.1	55.9	6.2	6.2	0.0	0.0
5	12.0	-8.2	42.3	5.9	5.9	0.0	0.0
6	9.0	-14.5	151.0	12.2	12.2	0.0	0.0
7	4.7	-10.6	126.9	10.3	9.4	0.8	8.5
8	3.4	-5.9	207.9	15.4	15.0	0.3	2.1
9	4.1	-2.3	315.4	22.3	22.3	0.0	0.0
10	5.0	-3.8	156.6	13.5	13.5	0.0	0.0
11	3.7	-1.9	101.9	9.0	9.0	0.0	0.0
12	5.1	-2.4	65.3	6.7	6.3	0.4	5.9
13	7.9	0.0	50.1	6.2	6.2	0.0	0.0
14	5.5	-4.6	78.2	7.5	6.9	0.6	7.9
15	11.2	-12.3	85.3	8.5	8.5	0.0	0.0
16	12.2	-12.2	383.8	27.1	24.9	2.2	8.1
17	5.1	-5.5	41.2	7.4	7.4	0.0	0.0
18	13.8	-8.4	97.7	8.5	8.4	0.0	0.9
19	13.3	-12.0	146.0	11.5	11.2	0.2	2.4
20	16.0	-7.7	149.2	11.2	11.2	0.0	0.0
21	9.2	-7.3	47.2	7.5	7.5	0.0	0.0
22	16.6	-4.9	88.5	8.2	8.2	0.0	0.0
23	6.4	-10.2	122.0	9.9	9.2	0.6	6.5
24	9.4	-3 2	85.3	8.7	8.7	0.0	0.0
25	15.1	-12.3	216.4	15.8	15.3	0.4	3.0
26	32.0	-16 3	172.6	14.2	14.2	0.0	0 0
27	16.7	-14.7	115.5	9.3	9.2	0.0	0.8
28	4.8	2.4	397.9	27.3	26.9	0.3	1.2
29	32.7	-4.3	171.2	12.3	11.9	0.4	3.7
30	36.5	-15.8	0.7	4.5	4.5	0.0	0.0
31	30.1	-15.9	0.8	3.4	2.8	0.5	17.1
Total	395.6		4254.2	354.1	345.8	8.2	2 3
Mean	12.7	-7.9	137.2	11 4	11 1	0 2	2.3

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
February 1994

Latitude. 44.14 °N Longitude: 76.30 °W Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	22.6	-12.2	0.8	4.4	4.4	0.0	0.0
2	18.2	-8.9	0.8	3.4	2.8	0.5	15.6
3	34.1	-4.8	0.7	3.4	3.0	0.3	10.0
4	9.5	-6.3	1.1	3.4	2.9	0.4	12.8
5	25.9	-5.3	0.6	3.4	2.2	1.1	34.4
6	25.3	-6.8	0.5	3.3	2.3	1.0	30.3
7	36.6	-10.5	0.4	3.3	1.5	1.8	54.9
8	20.1	-16.1	0.6	3.3	3 1	0.2	8.5
9	14.1	-12.3	0.7	3.3	2.9	0.4	12.5
10	36.3	-11.6	0.4	3.3	1.4	1.9	56.2
11	24.3	-10.1	0.6	3.3	3.2	0.1	4.4
12	34.8	-6.4	0.7	3.3	1.4	1.9	57.6
13	22.3	-2.1	0.5	3.3	1.5	1.8	54.8
14	36.7	-9.5	0.5	3.3	1.5	1.8	53.5
15	11.3	-8.8	176.8	12.8	6.4	6.4	50.0
16	37.3	-4.2	143.9	10.2	4.8	5.3	52.4
17	32.8	0.1	163.9	11.5	5.2	6.2	54.2
18	30.5	1.7	150.3	10.3	4.8	5.5	53.4
19	27.2	7.0	0.7	3.3	3.0	0 3	9.8
20	20.7	8.5	0.8	3.3	1.5	1.8	53.5
21	6.4	4.5	0.6	3.3	1.4	1.9	56.2
22	34.6	-2.3	8.5	3.7	1.5	2.2	59.0
23	6.0	-8.4	0.4	3.3	1.5	1.8	53.5
24	2.8	-1.7	0.9	3.4	2.9	0.4	12.7
25	13.3	-0.6	0.7	3.3	1.4	1.9	56.2
26	41 6	-3 3	243.5	17.3	11.9	5 4	31 1
27	39.8	-6.3	261.3	18.8	18.8	0.0	0.0
28	33.4	-6.1	198.5	15.8	15.8	0.0	0.0
Total	699.7		1361.1	169.8	116 5	53 2	31 3
Mean	24.9	-5.1	48.6	6.0	4.1	1 9	31.3

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
March 1994

Latitude: 44.14 °N Longitude: 76.30 °W Tank Setpoint 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	42.0	-3.6	218.6	15.6	14.8	0.7	4.7
2	38.5	-5.4	292.9	19.8	15 5	4 3	21 6
3	25.4	-3.7	372.3	25.1	22.3	2.8	11.1
4	36.3	0.3	175.9	12.6	9.5	3.0	24.2
5	42.6	2.4	293.2	20.0	12.4	7.6	38.0
6	28.6	-0.2	180.8	12.9	10 8	2.1	16 4
7	12.4	3.7	308.5	22.3	22 3	0 0	0 0
8	21.7	1.4	165 9	13 3	13 3	0.0	0 0
9	16.6	-2.8	313 8	22 0	22 0	0 0	0 0
10	4.1	0.5	247.9	18 1	18 1	0 0	0 0
11	35.8	-0.8	332.0	22 9	18 4	4 4	19 5
12	44.0	-2.5	306 2	21.3	13 6	7.6	35 7
13	11.4	2.4	203 1	15 0	14 9	0.0	0 2
14	16.0	0.8	197.0	15.7	15 7	0.0	0.0
15	10.9	4.0	307.7	20.7	20 7	0.0	0 1
16	22.4	-1.9	201.6	14.5	13 8	0 6	4.6
17	38.6	-3.2	202.7	14 4	11 8	2.6	18.2
18	27.7	-2.1	114.7	9.5	9 5	0 0	0.0
19	41.9	2.3	433.2	28.9	18 3	10 5	36 4
20	37.4	1.4	181.7	13.0	8 7	4.3	33.3
21	29.0	3.7	243.3	17 4	14 4	2 9	16 8
22	42 8	7.8	250.9	16.7	10 1	6.6	39.4
23	27.6	7.0	274 4	18.9	12 6	6.3	33.4
24	16 1	6 4	231.1	17 5	17 5	0 0	0 0
25	16.9	3.9	163 5	12 4	12 4	0 0	0 0
26	44 6	2.5	311.4	20.7	11 1	9 6	46.2
27	7 7	2 3	183.4	15.8	15 8	0 0	0 0
28	13.3	4.8	163.6	14 6	14 6	0.0	0.0
29	22.0	3.7	370.4	25 9	22 2	3 7	14.4
30	43 3	3.5	105 2	8 3	6 6	1 7	20.4
31	46.8	4.8	246.6	16 2	4 4	11 7	72.4
Total	865 6		7594 9	543 6	449 7	93 8	17 2
Mean	27 9	1 4	244 9	17 5	14 5	3 0	17 2

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
April 1994

Latitude: 44.14 °N Longitude: 76.30 °W Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	**Solar Radiation kWhr**	**Outdoor Air Temp. °C**	**Hot Water Usage Litres**	**Total System Energy kWhr**	**Total Auxilary Energy kWhr**	**Solar Energy Delivered kWhr**	**Solar Fraction %**
1	24.4	3.8	256.1	17.9	15.1	2.7	15.3
2	19.9	6.3	220.8	15.5	15.5	0.0	0.0
3	7.5	3.6	132.3	11.6	11.6	0.0	0.0
4	38.2	3.6	374.2	24.5	18.7	5.7	23.6
5	20.8	8.1	232.7	16.7	16.3	0.3	2.0
6	2.1	1.0	270.2	18.3	18.3	0.0	0.0
7	32.0	3.3	262.0	18.2	15.0	3.2	17.5
8	48.3	3.8	181.8	12.4	7.8	4.5	36.8
9	23.8	8.0	364.9	25.2	20.5	4.7	18.7
10	37.7	12.0	192.7	13.1	8.4	4.6	35.5
11	41.2	6.7	284.8	18.2	8.9	9.3	51.0
12	24.7	7.5	249.2	17.0	13.5	3.5	20.5
13	13.0	8.7	190.1	13.4	13.4	0.0	0.0
14	17.9	8.2	291.7	18.9	18.9	0.0	0.1
15	42.1	16.6	136.4	9.8	5.4	4.3	44.5
16	27.9	9.1	368.4	24.5	13.9	10.5	43.0
17	14.8	7.2	149.4	11.4	9.9	1.4	12.9
18	0.1	9.4	255.7	14.3	1.4	12.8	89.9
19	45.6	13.1	272.2	17.8	5.8	11.9	66.9
20	32.7	7.9	115.3	8.8	6.2	2.6	29.4
21	40.0	5.5	165.0	11.1	4.2	6.8	61.7
22	44.2	8.1	153.1	10.7	4.7	6.0	55.9
23	44.3	9.4	373.2	24.0	11.4	12.6	52.4
24	40.8	14.1	165.9	11.1	5.8	5.3	47.8
25	13.0	11.2	188.9	13.2	12.6	0.5	4 4
26	22.1	15.5	357.7	22.8	19 5	3.3	14.7
27	29.9	15.9	135.5	9.8	8 1	1.6	16.8
28	50.2	8.7	155.8	10.4	1.8	8.6	82.2
29	19.2	11.6	232.1	15.4	10.7	4.6	30.0
30	20.5	10.1	165.7	12.6	12.6	0.0	0.0
Total	840.3		6895.1	469.8	337.3	132.5	28.2
Mean	28.0	8.6	229.8	15.6	11.2	4.4	28.2

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary

May 1994

Latitude: 44.14 °N Longitude: 76.30 °W Tank Setpoint. 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	7.0	7.9	344.1	23.1	23.1	0.0	0.0
2	35.5	10.4	128.9	9.3	7.5	1.7	18.7
3	50.4	9.8	305.5	18.9	8.6	10.3	54.5
4	49.3	14.6	161.5	10.9	8.1	2.8	25.8
5	42.4	17.4	286.4	16.5	16.3	0.2	1.3
6	14.0	11.2	95.5	8.2	6.7	1.4	17.6
8	17.7	13.2	588.7	27.1	12.4	14.6	54.2
9	27.4	10.9	366.6	21.7	20.4	1.2	5.7
10	34.2	12.8	158.2	10.9	7.4	3.5	32.0
11	27.0	11.9	134.6	9.8	8.0	1.7	17.5
12	19.9	12.6	207.2	14.8	14.8	0.0	0.0
13	52.5	11.8	177.5	11.3	6.3	5.0	44.4
14	52.2	13.3	298.8	17.7	4.6	13.0	73.7
15	11.3	12.7	153.8	10.9	10.1	0.7	6.7
16	13.7	11.7	167.8	12.4	12.4	0.0	0.0
17	27.5	12.8	248.7	15.4	11.1	4.2	27.6
18	23.1	12.4	189.9	13.2	13.2	0.0	0.0
19	49.6	15.8	130.3	9.0	3.3	5.6	62.9
20	52.1	18.2	210.5	13.3	3.2	10.0	75.6
21	24.9	13.5	260.7	15.7	11.4	4.2	27.1
22	49.6	17.9	141.4	9.6	3.3	6.2	64.9
23	43.7	21.7	394.5	23.2	8.7	14.4	62.2
24	48.9	18.4	157.7	10.1	2.9	7.2	71.5
25	17.8	17.0	267.5	17.0	11.9	5.1	30.0
26	7.3	9.1	93.2	9.0	9.0	0.0	0.0
27	53.1	13.0	148.8	9.7	1.4	8 2	84 7
28	21.0	10.7	285.0	17.8	13.5	4.3	24.2
29	43.8	16.4	184.3	11.0	3.1	7.9	71.4
30	42.1	19.5	173.8	10.6	3.3	7.3	68.8
31	33.0	18.1	285.3	16.9	8.8	8.1	47.9
Total	993.6		6748.3	426.4	276.4	150.0	35.1
Mean	33.1	13 9	224.9	14.2	9 2	5 0	35.1

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
June 1994

Latitude: 44.14 °N Longitude: 76.30 °W Tank Setpoint: 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	33.9	15.9	114.4	8.5	6.3	2.2	26.2
2	38.4	16.1	243.3	14.1	7.7	6.3	45.0
3	51.1	19.4	174.6	11.3	5.1	6.2	54.7
4	50.1	18.1	273.3	16.2	3.0	13.1	80.8
5	41 2	19.8	171.8	10.3	3.2	7.1	68.9
6	11.7	18.1	142.4	9.6	6.8	2.8	29.2
7	30.3	19.7	161.5	9.9	7.1	2.8	28.7
8	52.0	17.3	208.9	12.6	2.1	10.4	83.0
9	50.8	18.7	318.1	18.4	7.7	10.6	57.9
10	51.4	20.4	170.7	10.6	4.7	5.8	55.1
11	30.4	19.9	246.0	15.1	14.5	0.5	3.8
12	33.7	20.9	176.4	12.5	12.5	0.0	0.0
13	29.8	20.5	184.2	10.6	4.7	5.8	55.0
14	35.0	20.3	153.4	9.4	1.9	7.4	79.3
15	46.7	25.8	205.2	13.0	1.5	11.5	88.1
16	43.9	28.4	204.5	12.0	1.6	10.4	86 6
17	45.1	29.1	214.5	14.1	1.6	12.4	88.0
18	46.9	28.6	117.7	8.6	0.0	8.6	100.0
19	46.2	27.5	105.3	8.3	0.0	8.3	100.0
20	37.4	25.1	148.5	10.3	0.0	10.3	100.0
21	39.4	25.6	173.1	10.1	0.0	10.1	100.0
22	43.3	24.3	165.1	10.9	1.6	9.3	85.0
23	42 1	24.1	166.2	10.1	0.0	10.1	100.0
24	9 5	19.1	101.1	7.3	4.2	3 1	42.6
25	20 7	22.4	189.1	11.3	8.6	2.6	23.2
26	44 1	22.1	101.0	7.4	1 4	5.9	80 5
27	6 2	18.0	188.3	11.1	6 4	4.6	41.9
28	32 8	21.4	254.2	13.7	5.2	8.4	61.6
29	36 3	24.0	135.4	8.7	3.2	5.4	62.4
30	38 6	22.0	174.9	10.6	1.9	8.7	81.6
Total	1120 4		5384.6	337.9	125.7	212.1	62.7
Mean	37 3	21.8	179.4	11 2	4 1	7.0	62.7

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
July 1994

Latitude: 44.14 °N   Longitude: 76.30 °W   Tank Setpoint· 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	43.6	21.9	184.7	10.8	1.6	9.2	84.9
2	36.3	24.9	62.8	5.6	1.4	4.2	74.8
3	48.3	23.6	164.3	11.1	0.0	11.1	100.0
4	46.4	25.2	156.4	9.7	0.0	9.7	100.0
5	28.7	25.3	266.4	14.5	2.2	12.2	84.5
6	36.6	26.3	266.6	14.5	7.4	7.1	48.9
7	20.0	24.2	357.9	19.5	18.0	1.4	7.5
8	40.5	28.3	276.8	16.1	5.5	10.6	65.6
9	38.9	26.8	262.3	14.8	10.6	4.2	28.6
10	13.5	22.1	348.4	18.8	6.2	12 6	67.0
11	49.3	22.2	195.7	11 7	1.7	9 9	84.7
12	40.2	23.2	179.8	10 4	1.6	8 8	84.5
13	45.8	26.6	134.3	9.4	0.0	9.4	100.0
14	29.0	22.7	158.9	9.0	1.6	7.4	82.1
15	26.7	24.3	246.6	13.3	5.3	8.0	60.2
16	23.6	24.2	146.5	8.6	4 8	3.7	43.4
17	42.2	25.5	193.2	11.3	1.4	9.9	87.4
18	41.2	26.1	220.1	12.4	1.8	10.6	85.4
19	39.0	25.4	219.5	12.1	1.6	10.5	86.3
20	40.5	27.8	156.4	9.8	0.0	9.8	100.0
21	35.4	28.9	281.4	15.2	3.2	12.0	78.6
22	25.0	26.5	210.3	11 2	4.7	6.5	58.2
23	41.5	26.3	200.8	11.3	4.1	7.1	63.0
24	42.8	26.0	282.6	15.8	1.6	14.2	89.5
25	43 5	26.1	150.4	9.5	1.9	7.5	79.1
26	33.2	23.9	182 2	10.1	1.7	8.4	83.0
27	37.7	22.7	198.3	10.7	3.3	7.4	69.3
28	38.4	24.5	214.1	12.7	1.6	11.1	87.1
29	46.4	24.5	204.8	12.9	1.6	11.2	87 3
30	15 4	21.5	26.2	4 2	1 5	2.7	64.1
31	17.1	26 2	328.8	17.2	1.4	15 7	91.4
Total	1107.8		6479 0	376.0	100 4	275 5	73 2
Mean	35.7	25 0	209 0	12 1	3 2	8 8	73 2

Solar Calorimetry Laboratory
Queens University
Kingston, Ontario

Bubble Action Pumps Ltd
121 Counter Street
Kingston, Ontario

Monthly Performance Summary
August 1994

Latitude: 44.14 °N Longitude: 76.30 °W Tank Setpoint· 60 °C

	Weather		Water Heater			Solar System	
Date	Solar Radiation kWhr	Outdoor Air Temp. °C	Hot Water Usage Litres	Total System Energy kWhr	Total Auxilary Energy kWhr	Solar Energy Delivered kWhr	Solar Fraction %
1	42.4	26.5	198.9	11.1	1.9	9.1	82.4
2	12.1	22.4	106.9	7.0	4.7	2.2	32.0
3	36.7	23.6	163.3	9.9	1.9	8.0	80.8
4	15.4	23.6	155.2	9.2	4.7	4.4	48.1
5	30.8	16.9	209.1	11.1	6.5	4.5	41.0
6	47.8	20.1	272.5	15.3	5.4	9.9	64.6
7	48.2	21.4	183.5	11.4	3.9	7.5	65.3
8	47.0	23.4	235.4	13.3	0.0	13.3	100.0
9	20.5	23.1	140.5	8 4	4.4	3.9	46.9
10	41.8	20.2	176.2	10.1	1.4	8.6	85.4
Total	343.1		1841.9	107 3	35.3	71.9	67.0
Mean	34.3	22.1	184.1	10.7	3.5	7.1	67.0