Solar Domestic Hot Water Technologies Assessment

Final Report 08-09
July 2008

New York State
Energy Research and
Development Authority

NYSERDA **New York State Energy Research and Development Authority**

The New York State Energy Research and Development Authority (NYSERDA) is a public benefit corporation created in 1975 by the New York State Legislature.

NYSERDA derives its revenues from an annual assessment levied against sales by New York's electric and gas utilities, from public benefit charges paid by New York rate payers, from voluntary annual contributions by the New York Power Authority and the Long Island Power Authority, and from limited corporate funds.

NYSERDA works with businesses, schools, and municipalities to identify existing technologies and equipment to reduce their energy costs. Its responsibilities include:

- Conducting a multifaceted energy and environmental research and development program to meet New York State's diverse economic needs.
- The **New York Energy $mart**SM program provides energy efficiency services, including those directed at the low-income sector, research and development, and environmental protection activities.
- Making energy more affordable for residential and low-income households.
- Helping industries, schools, hospitals, municipalities, not-for-profits, and the residential sector, implement energy-efficiency measures. NYSERDA research projects help the State's businesses and municipalities with their energy and environmental problems.
- Providing objective, credible, and useful energy analysis and planning to guide decisions made by major energy stakeholders in the private and public sectors.
- Since 1990, NYSERDA has developed and brought into use successful innovative, energy-efficient, and environmentally beneficial products, processes, and services.
- Managing the Western New York Nuclear Service Center at West Valley, including: overseeing the State's interests and share of costs at the West Valley Demonstration Project, a federal/State radioactive waste clean-up effort, and managing wastes and maintaining facilities at the shut-down State-Licensed Disposal Area.
- Coordinating the State's activities on energy emergencies and nuclear regulatory matters, and monitoring low-level radioactive waste generation and management in the State.
- Financing energy-related projects, reducing costs for ratepayers.

For more information, contact the Communications unit, NYSERDA, 17 Columbia Circle, Albany, New York 12203-6399; toll-free 1-866-NYSERDA, locally (518) 862-1090, ext. 3250; or on the web at www.nyserda.org

Solar Domestic Hot Water Technologies Assessment

Final Report

Prepared for the

New York State
Energy Research and
Development Authority

Albany, NY
www.nyserda.org

Robert M. Carver, P.E.
Project Manager

Prepared by:

Bright Power, Inc.

New York, NY

Jeffrey Perlman, C.E.M., LEED A.P.
Andrew McNamara, C.E.M., LEED A.P.
Project Managers

NYSERDA Report 08-09 | NYSERDA 10219 | July 2008

NOTICE

ABSTRACT AND KEY WORDS

For this paper, the performance of Solar Domestic Hot Water (SDHW) systems and baseline conventional Domestic Hot Water (DHW) systems is simulated in thirteen regions of New York State using the Transient System Simulation (TRNSYS) hourly simulation tool. The SDHW design factors considered in this assessment include collector type (flat plate, evacuated tube, unglazed building-integrated) and tank configuration (single tank, two tank, external heat exchanger, SDHW tank with instantaneous water heater). These systems also are analyzed with a variety of auxiliary fuel sources (natural gas, electricity, propane, and oil).

SDHW system performance is evaluated against conventional DHW system performance in terms of energy and economics. Metrics used include: energy production, solar fraction, simple payback, net present value, annual maintenance costs, and annual savings. The economic analysis includes the federal and New York State tax credits as of 2009.

The results are rendered into color geographical maps of New York State, where the different colors represent different values of the mapped variable (solar fraction, annual savings, and simple payback) for the selected system.

Keywords: Solar, Thermal, New York, Energy, TRNSYS, SDHW, DHW

ACKNOWLEDGEMENTS

First and foremost, the authors wish to thank four collaborators whose substantial contributions enabled the research and analysis in this paper: Dr. Richard Perez (Atmospheric Sciences Research Center at SUNY Albany) for the satellite-derived weather data, initial brainstorming, and ongoing mentoring; Kyle Benne for the TRNSYS simulations and in-depth knowledge of solar thermal configurations; Mark Beauharnois for the geographical renderings and web-interface at http://sdhw.brightpower.biz; and Robert Carver (NYSERDA) for the consistently thoughtful and constructive criticism, which enabled this paper to achieve a higher level of comprehensiveness and quality. Many individuals and organizations gave their time and resources to provide information necessary for this assessment; in this regard, the authors wish to thank Jim Huggins (The Solar Rating and Certification Corporation (SRCC)), Bill Poleatewich and Katie Poleatewich (Dawn Solar Systems), Alexandra Wexler (Heliodyne), Larry Waitz (Schüco Solar), Dr. Fariborz Mahjouri (Thermomax), Frank Proske (Sun Spot Solar), Noah Tuthill (groSolar), Jeff Irish (Hudson Valley Clean Energy), Ron Kamen (EarthKind Energy), Bob Claridge (Bobcat & Sun Solar), Radco Solar, and the many installers interviewed as part of the assessment. Many thanks to Greg Sherman, Ruth Ayalon, and Sophie Nimmannit for their contributions and help in writing this paper.

TABLE OF CONTENTS

Section Page

FIGURES

TABLES

Table | Page

SUMMARY

Solar thermal technologies convert the sun's radiation into useful heat. In building applications, this heat is commonly used to produce domestic hot water. New York State's climate is not customarily thought to be very suitable for solar thermal applications. Still, recent statistics (2006 EIA market data) show that New York State was ranked fifth in the nation as a destination to which solar thermal collectors were shipped – the equivalent of 24,000 twenty-five square foot collectors arrived in the State. This level of activity is likely explained by the fact that New York State has solar energy tax credits and high energy prices that favor renewable technologies. In light of these facts, the New York State Energy Research and Development Authority (NYSERDA) put forth a competitive solicitation (won by Bright Power) to identify the most promising applications for residential solar domestic hot water systems.

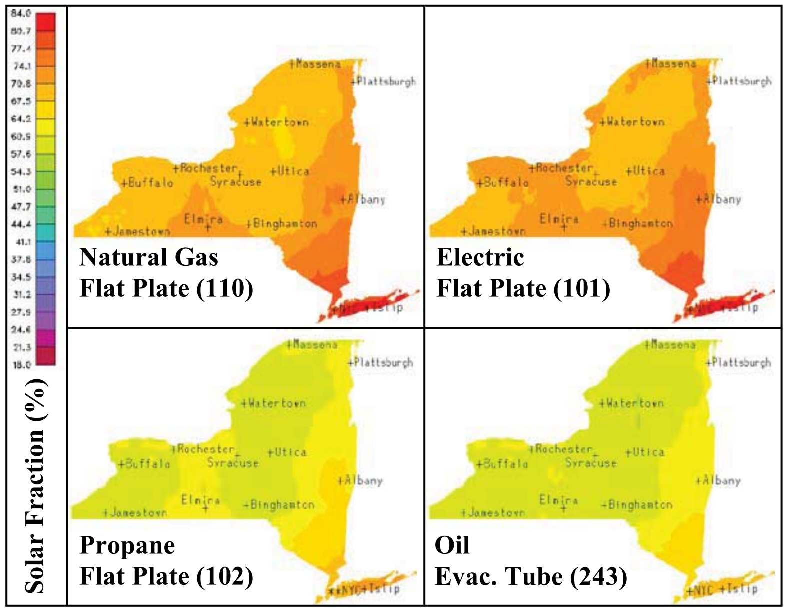

Figure 1. Renderings of Solar Fraction for best performing systems of Each Fuel Type. (Maps for all systems analyzed are available at http://sdhw.brightpower.biz)

In 2001, a total of 2 billion kWh of electricity, 76 billion cubic feet of natural gas, and 295 million gallons of fuel oil were used to heat water in New York households. Water heating accounted for 18% of New York State household energy consumption (Energy Information Administration, 2007). The vast majority of the energy currently used to heat water in homes is derived from fossil fuels, either by burning them directly or by using electricity (in New York State, electricity itself is derived, in majority, from burning fossil fuels). It is possible for a Solar Domesitc Hot Water (SDHW) system to provide over half of the energy needed for water heating in a

Figure 2. Solar Collector Technologies Analyzed in the Assessment; the technologies pictured are (left-to right) flat plate, evacuated tube, and building-integrated

typical New York State home with adequate access to sunlight. Thus, this technology has the potential to substantially reduce dependence on fossil fuels, thereby reducing greenhouse gas emissions and other harmful results of fossil fuel use.

The research described herein will help to identify the most promising solar DHW technologies across different regions of New York State. As Figure 2 indicates, this assessment analyzes three collector types: flat plate, evacuated tube, and building integrated. The systems analyzed in this assessment are systems available on the market today and are based on systems designed by manufacturers and installers. Manufacturers and installers were asked to provide the most cost-effective SDHW system design possible – including solar collectors, tanks, a backup heating source, piping, and pumps. Every system analyzed is capable of providing reliable heated water to a typical family of four in New York State.

A primary component of the evaluation is computer simulations of SDHW systems based on a variety of design factors. The simulations were run in Transient Systems Simulation (TRNSYS) – a powerful energy simulation tool based on hourly computational routines. City-specific, satellite-based climatalogical data for thirteen locations around New York State were used in the simulations to evaluate SDHW system performance across the State.

The simulation results were rendered into color geographical maps of New York State, where the different colors represent different values of the mapped variable (See Figure 1). An example of a mapped variable is "Simple Payback." As seen in Figure 4, each rendering encompasses many of the physical and economic factors that help to determine the viability of a particular technology, including: solar irradiance, system performance, energy prices, installed cost, and tax credits. These color geographical plots enable easy comparison of the different systems, according to different parameters, in different regions of the State. These maps are available at http://sdhw.brightpower.biz.

By analyzing these maps, one is able to determine the viability of each of the SDHW systems across the State. Furthermore, the maps themselves are compelling images that should be comprehensible to people throughout New York State. This publicly available data could serve as a tool in targeting those areas in New York State, most suitable for a particular SDHW technology.

An assessment of possible market, institutional and infrastructure barriers that limit widespread replication of the SDHW systems was also conducted. This assessment is followed by a discussion of potential strategies for overcoming these barriers. Finally, the benefits of a robust SDHW market, including job creation and fossil fuel use reduction, are explored.

KEY CONCLUSIONS OF THE ASSESSMENT

For a typical home in New York State, a Solar Domestic Hot Water (SDHW) system is capable of providing over half of the energy needed to heat water. In the most favorable locations – New York City and Long Island – certain SDHW systems are capable of providing nearly three-quarters of household water heating energy for a typical family. The percentage of water heating energy provided by solar energy is known as "Solar Fraction"; the solar fraction of a given technology type varies primarily with the amount of solar radiation available at a given location. Computer simulations show the following range of solar fractions in Islip, Long Island: 50%-70% for flat plate technologies, 52%-71% for evacuated tube systems, and 34% for building integrated systems. Jamestown, New York was the least efficient in terms of solar fraction; computer simulations show the following range of solar fractions in Jamestown: 41%-59% for flat plate, 43%-59% for evacuated tube, and 30% for building integrated.

Installed costs, or the cost of all materials and labor necessary to install a functioning solar domestic hot water system, were estimated by polling installers across the State; for all systems across the State, installed cost ranged from approximately $9,000 to $15,100. After applying relevant federal and State tax credits and a federal tax rate 25% (i.e., New York tax credit assumed to be subject to federal income tax), the range of installed costs was approximately $4,600 to $7,700. Maintenance costs, including all component replacements during system life, were estimated for each system, depending on which components were included. The range of estimated maintenance costs was $40-$140 annually.

Table 1. NPV for single family SDHW systems (New York State Average)[1, 2]

SDHW Tech:	Flat Plate		Evacuated Tube		Building Integrated	
Backup Fuel ↓	Best-in-class	Average	Best-in-class	Average	Best-in-class	Average
Natural Gas	(1,863)	(2,506)	(2,368)	(2,862)	(3,864)	N/A
Electric	2,928	978	2,424	1,401	1,370	N/A
Propane	994	(272)	451	106	(838)	N/A
Oil	(1,539)	N/A	(1,726)	(1,943)	N/A	N/A

One key conclusion of this assessment is that current government incentives are insufficient to bring the cost of SDHW technology to a level that most consumers would consider cost effective. Consumers using electricity or propane for water heating, who have a tolerance for long-term investments, may find some

[1] The averages in this table are based upon the 34 system types analyzed in this assessment. The table excludes sub-optimal tank types x31 and x32. "N/A" is used for categories when only one relevant system was analyzed.
[2] Fuel costs used in the analysis are city-specific and current to 2007. Average prices are as follows: $1.27 / therm natural gas, $0.138 / kWh electricity, $2.26 / gallon propane, and $2.56/gallon oil, See SECTION 7 and APPENDIX 4 for additional information.

systems to be attractive investments. Most homeowners, however, use natural gas to heat water in New York State. None of the 34 analyzed (System ID 100[3]) had a positive Net Present Value when compared against a conventional gas-fired hot water tank[4]. Unless additional incentives are provided, solar domestic hot water technology is not likely to be an attractive economic investment to the average homeowner. Table 1 presents information on Net Present Value for SDHW Systems across the State.

Currently, high system costs and relatively low energy costs combine to make the economics of solar hot water systems less attractive than they could be. While energy costs have escalated rapidly since 2000, and are projected to increase in the coming years, higher energy costs alone will not drive the SDHW industry. Natural gas prices would need to reach roughly three dollars per therm before the majority of today's SDHW systems would achieve price parity with conventional natural gas water heating. Unlike the successful markets in Hawaii, California, or even Germany, SDHW technology has yet to obtain a solid foothold in New York State and SDHW installation costs remain high. Manufacturers, distributors, and installers are limited in their ability to reduce costs due to volume constraints.

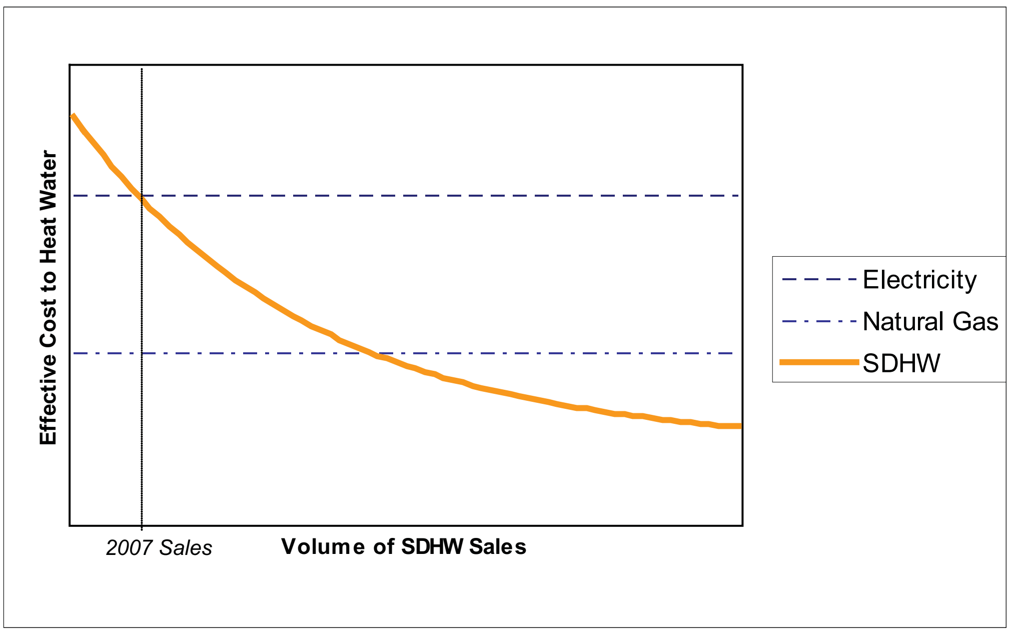

Figure 3. Effective Cost to Heat Water with Solar, Electricity, and Natural Gas[5]

---

[3] See Table 5. Collector and System Properties

[4] Net Present Value was calculated with a discount rate of 4.38% corresponding to a 20-year U.S. Treasury Bill as of January 2008, assumed an energy escalation rate of 3%, was exclusive of maintenance cost, and taken over a time horizon equal to twice the warranty period of the collectors. For all collectors except building integrated (50 year time horizon), the time horizon was 20 years.

[5] This figure is hypothetical and is not to scale.

Consumers are apt to choose the lowest cost option for water heating, which is presently conventional natural gas water heating. An appropriately sized incentive could change this picture, by making the effective cost to heat water with an SDHW system less than that of natural gas. Subsequently, this would grow demand for the technology, which should allow economies of scale to reduce prices. This idea is presented graphically in Figure 3. Incentive levels could be tapered as the price of SDHW technology decreases.

According to this analysis, “flat plate” technology is the most cost-effective collector technology. This is true across all metrics. A flat-plate collector system (e.g., System ID 101, for specifications see Table 5 in the body of the report) installed in New York City with electric resistance backup heating, yielded a simple payback net of tax credits of 8-to-21 years and Net Present Value (NPV) of $2,600 to $6,800 over the course of system life[4]. The expense of electricity as a heating fuel can make these systems a smart investment when compared against the baseline of treasury bills. Best-in-class evacuated tube technology did not lag far behind in either payback or NPV.

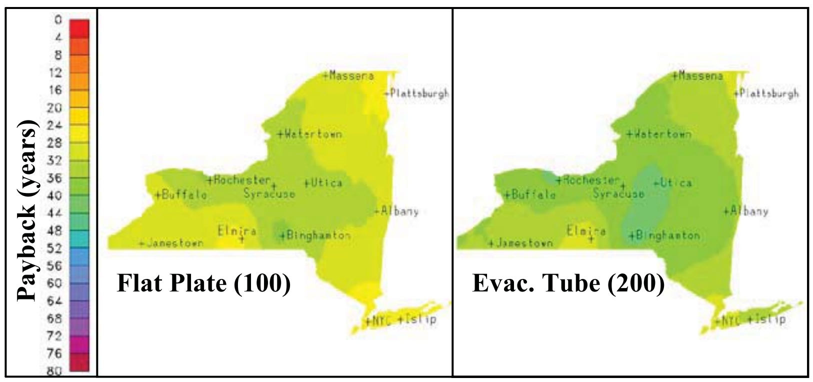

Figure 4. Rendering of Simple Payback of best-in-class systems in two tank arrangement co-fired with natural gas

A solar supplied pre-heat tank coupled with an instantaneous water heater (System ID 101) appears to be the optimal tank configuration, as seen in Figure 1. Systems using electricity as the auxiliary fuel source realize the highest solar fraction; systems using instantaeous gas-fired backup water heaters realize a solar fraction that is nearly as high as the electric systems, yet cost a fraction of the amount to operate. The instantaneous configuration is optimal because the pre-heat tank is able to maintain thermal stratification, and the instantaneous water heater provides the remaining heat on-demand, without standby losses.

There is significant variability in system performance within a technology type. Payback time ranged by about 20 years between the best-in-class and worst-in-class performers for both flat plate and evacuated tube technologies. This indicates that consumers should shop around to obtain a system that is well designed for their homes. The best performing systems used cost-effective collectors, thermally optimal tank configurations (with stratification), and were designed to meet 100% of the average summer load. The worst performing systems analyzed in this assessment were either undersized or had sub-optimal tank configurations. Such non-optimal tank configurations include those in which an external heat exchanger is directly attached to a conventional natural gas or propane hot water heater.

New York City appears to be the most favorable market in New York State for SDHW, due to relatively high energy costs and levels of solar irradiation. For systems with natural gas providing backup heat, the simple payback against a conventional natural gas tank baseline is 22-39 years for flat plate systems, 25-38 years for evacuated tube systems, and 65 years for building integrated systems. The low natural gas costs and lack of solar resource make Binghamton the least favorable market in the State with a simple payback of 36-64 years for flat plate, 39-63 years for evacuated tube, and 106 years for building integrated systems with natural gas fired backup.

Financial incentives would help to bolster the New York State SDHW industry by bringing SDHW technology within reach of cost-conscious homeowners and businesses. A financial incentive would improve the economics of a SDHW system by reducing the payback period and easing the financial burden for interested customers. The NYSERDA-funded solar PV Incentive program has been successful at bolstering the solar photovoltaic (PV) market throughout New York State. A similar incentive program could cultivate the market for SDHW technology in the State. The results of this assessment could be used to craft an incentive policy that would create a positive NPV for SDHW systems backed up with natural gas water heating. According to this analysis, an additional incentive of $1,900 per system would accomplish this. A second issue is reducing the payback time – the best-in-class flat plate system has a simple payback of 29 years for an average location in New York State. Each $150 - $250 in incentives would reduce the payback by one year; therefore, to achieve a payback within the typical waranty period of 10 years, an incentive of roughly $3,300 per system would be required. This incentive would be in addition to thelarger federal tax credit enacted after 2008 and the present State tax credits.

The benefits of a robust SDHW market to New York State include an increase in jobs and a reduction in non-renewable energy use. Assuming that 1.2 million households[6] in New York State will be able to reduce their fossil fuel consumption for DHW by 50% by using SDHW systems, this would yield energy savings of 171 million kWh of electricity, 6.5 billion cubic feet of natural gas, and 25 million gallons of fuel oil annually[7]. Furthermore, a blossoming SDHW industry would create jobs. Estimates of hours per

---

[6] With the portfolio of technologies outlined in the analysis, any home with a sufficient section of unshaded and unobstructed south-facing roof should be able to use the evaluated technologies. As of 2001, there were approximately seven million households in New York State (EIA data). Assuming that half of these are single family homes, and that one-third of those homes have sufficiently well-oriented, unshaded roof space, this suggests about 1.2 million households in New York State that would be able to directly use the results of this research.

[7] Based on 2001 water heating data referenced earlier, assuming the proportional distribution of electricity, gas and oil fired water heating as in the 2001 EIA data.

system are provided in Table 2 below. Contracting and back office work is excluded from job growth figures, although such job growth may be substantial.

Table 2. Estimated time to install & maintain a typical SDHW system

Labor Type	hours
Plumbing	30
SDHW Tech – install collectors on roof	90
SDHW Tech – maintain over life of system	25

Given the estimates in Table 2, estimated jobs created at different SDHW market penetration levels are shown in Table 3 below.

Table 3. Job years created in New York State at various levels of market penetration[6, 8]

Market Penetration Level:	0.1%	0.5%	2.5%
Systems Installed	**1167**	**5833**	**29167**
Plumbing	18	88	438
SDHW Tech - install	53	263	1313
SDHW Tech - maintain	15	73	365
TOTAL	**92**	**458**	**2290**

Even at relatively low levels of market penetration, a significant number of new jobs would be created by the proliferation of SDHW systems across the State. This would involve a combination of a new "green collar" workforce of SDHW Techs as well as an expansion of the existing trades of plumbing and contracting.

[8] Percentages given are of homes eligible to receive installations in New York State.

SECTION 1

NOMENCLATURE

Each Solar Domestic Hot Water (SDHW) system design in this paper is referred to by a three digit number. The first digit or "hundreds" place refers to the collector type, the second digit or "tens" place refers to the tank type, and the third digit or "ones" place refers to the auxiliary fuel type. This nomenclature is defined in Table 4 below.

Table 4. System Design Nomenclature

DIGIT	HUNDREDS	TENS	ONES
	COLLECTOR TYPE	**TANK TYPE**	**FUEL TYPE**
0	Baseline	Solar preheat tank + 40 gal (151 L) Conventional Tank	Natural Gas
1	Flat Plate Model "A" - 3 Collectors	Solar preheat tank + Instantaneous (tankless) heater	Electric
2	Evacuated Tube Model "A" – 24 Evacuated Tubes	Solar preheat tank with External Heat Exchanger + 40 gal (151 L) Conventional Tank	Propane
3	Evacuated Tube Model "B" – 24 Evacuated Tubes	80 gal (303 L) Conventional Tank with External Heat Exchanger	Oil
4	N/A	Double Heat Exchanger Tank	
5	Flat Plate Model "B" - 2 Collectors		
6	Evacuated Tube Model "C" – 24 Evacuated Tubes		
7	600 Square Feet Building Integrated Collector (56 m^2)		

For example, the Flat Plate Model "A" collector system with double heat exchanger tank and fueled by an oil boiler would have a System ID of 143.

SECTION 2

ASSUMPTIONS AND DESIGN FACTORS MODELED IN THE ASSESSMENT

DESCRIPTION OF MODEL NEW YORK STATE HOME

Systems were designed for a typical New York State single family home with the following characteristics: four occupants; basement and attic; two stories tall; sloped roof pitched at 30 degrees towards south; and heating and hot water systems located in basement. Into this home are the following variables:

- Heating system: separate from DHW system (e.g. furnace) or integrated with DHW system (e.g. boiler)
- Solar energy storage in one and/or two tank arrangements

The energy consumption of the whole house is not simulated, rather only the SDHW systems and energy usage related to hot water consumption are simulated.

HOT WATER CONSUMPTION

It was assumed that the hourly DHW usage in the household conforms to the ASHRAE typical family's usage, as shown in Figure 5:

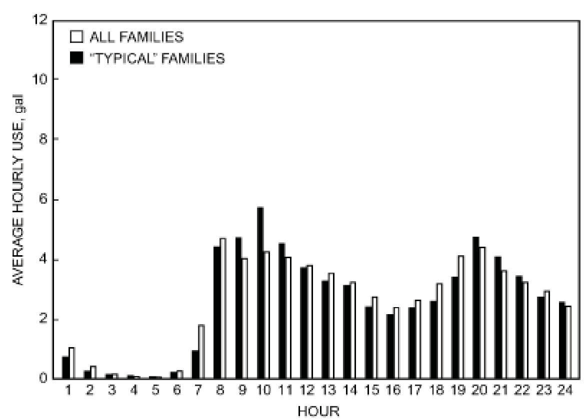

Figure 5. "Typical" Family DHW Use (ASHRAE 2003)

SOLAR DOMESTIC HOT WATER SYSTEM DESIGN FACTORS

Complete system designs were developed for the twenty-eight SDHW systems modeled in the assessment based on the Design Factors below[9].

[9] To determine design factors, a survey of literature relevant to the solar domestic hot water industry was conducted. This included conference proceedings from the American Solar Energy Society (2003 to

Design Factors included in the assessment

- Collector types
  - Flat Plate Glazed Collectors
  - Evacuated Tube
  - Building Integrated/Unglazed
- Tank Types
  - One tank
    - Electric element in the SDHW tank for auxiliary heating
    - Two heat exchangers, the upper one fed by a conventional boiler
    - External Heat Exchanger
  - Two tank: one solar preheat, one conventional, where the auxiliary tank is
    - Conventional tank hot water heater
    - Instantaneous (tankless) hot water heater
    - External Heat Exchanger
- Fuel types
  - Electricity
  - Natural Gas
  - Fuel Oil
  - Propane

For additional information on design factors, see APPENDIX 1.

---

present) as well as the 2005 International Solar Energy Conference proceedings from the American Society of Mechanical Engineers. Manufacturers producing the technologies analyzed in the assessment and those who install SDHW systems in New York State were also consulted.

SECTION 3
DESIGN OF SDHW SYSTEMS

METHODOLOGY

To define the system types, system designs were solicited from manufacturers, requesting that they submit designs they consider to be the most cost-effective solar domestic hot water systems for the typical New York State home. Each manufacturer was asked to submit as many unique system designs as met the criteria established in SECTION 2. Several manufacturers submitted different designs to account for different collector and tank types offered within their product line.

The system designs that follow were chosen by manufacturers as those most cost-effective for the typical New York State home outlined above. Not every system is designed to be the same size; rather, some manufacturers suggested that a smaller solar fraction was more desirable as the system would be less expensive to install.

A total of six collector types, five tank designs, and four backup fuel types are presented in this section. There are 120 potenial combinations of these collectors, tanks, and fuels; only the twenty-eight combinations recommended by manufacturers are analyzed in the assessment.

DEFINITION OF SDHW SYSTEM DESIGNS

The systems analyzed have variations in solar collector type, tank type and arrangement, and fuel type. A three digit number is assigned to each analyzed system to designate which collector, tank, and fuel comprise an analyzed system (see SECTION 1 – Nomenclature). A full listing of the parameters of each system type is available in APPENDIX 2 in Table 39.

Collector Types

The collector types analyzed include: Flat Plate Glazed Collectors (Flat A, Flat B), Evacuated Tube (Evac A, Evac B, Evac C), and Building Integrated/Unglazed (Bldg Int), as shown in Table 5. All collectors are OG-100 certified by the Solar Rating and Certification Corporation (SRCC).

Table 5. Collector and System Properties

System ID	Collector Type	System Net Aperture (ft^2)	Delta T (off) (ºF)	Delta T (on) (ºF)	Pumping Rate (GPM)	Collector Low Limit (ºF)	Tank High Limit (ºF)	Tank 1 Volume (gal)	Tank 1 Volume (L)
1xx	Flat A	69.1	12	8	1.5	N/A	170	105	398
2xx	Evac A	58.4	13.5	5.5	1.5	N/A	175	105	398
3xx	Evac B	58.7	13.5	5.5	1.5	N/A	175	80	303
5xx	Flat B	49.4	18	5	1.5	80	160	80	303
6xx	Evac C	40.4	15	7	2.5	N/A	175	120	454
7xx	Bldg Int.	600.0	12	N/A	2.5	N/A	N/A	80	303

<u>Tank Types</u>

The systems analyzed include both one and two tank arrangements, as well as instantaneous heaters, as shown in Figure 6 through Figure 10.

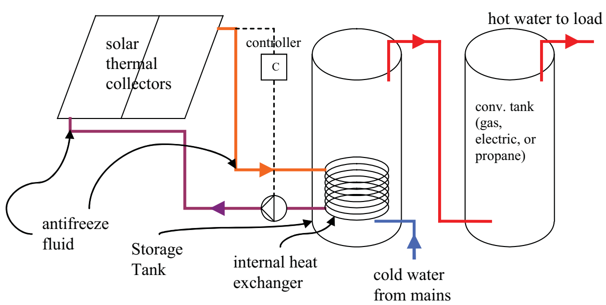

Figure 6. Tank Design x0x - Solar preheat tank + Conventional tank

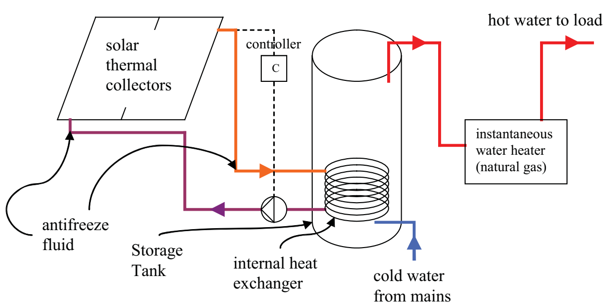

Figure 7. Tank Design x1x - Solar preheat tank + Instantaneous (tankless) heater

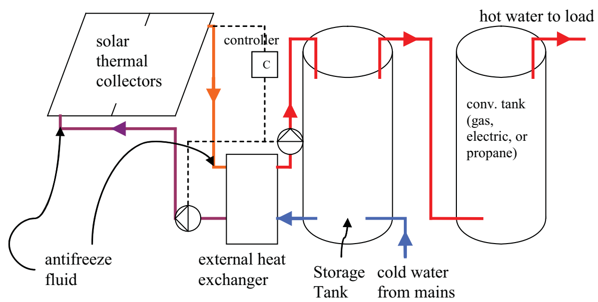

Figure 8. Tank Design x2x - Solar preheat tank with External Heat Exchanger + Conventional Tank

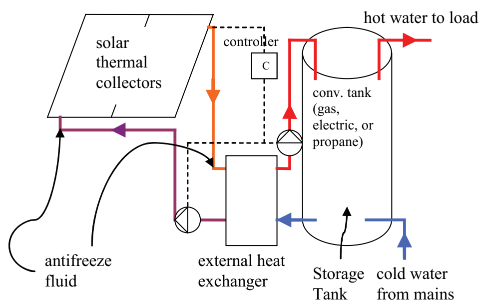

Figure 9. Tank Design x3x - Conventional Tank with External Heat Exchanger

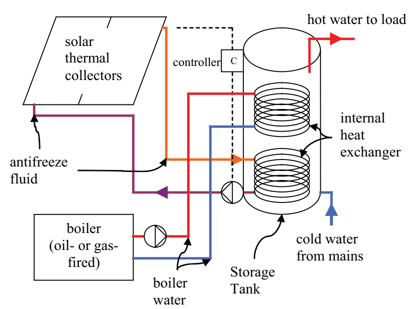

Figure 10. Tank Design x4x - Double Heat Exchanger Tank

Fuel Types

The four fuel types analyzed – natural gas (xx0), electricity (xx1), propane (xx2), and oil (xx3) – account for nearly all of the DHW fuel in the State.

Systems excluded from the assessment

The analysis of every type of system type on the market is outside the scope of this assessment. Most notably, drainback, thermosiphon, and integrated collector storage (ICS) systems were excluded from the assessment. ICS and thermosiphon designs were excluded because they are generally intended for warmer climates and did not meet the freeze protection requirements of New York State. Drainback systems are likewise largely distributed in the warm climate regions of the United States in the form of kits sold directly to homeowners. While many drainback systems did not meet the criteria for freeze protection defined in

APPENDIX 1-F, there were two manufacturers systems that met the criteria, and system designs were solicited from them. Despite repeated requests for information, they were unable to provide system designs for New York State within the required timeframe to be included in this report.

DHW BASELINE COMPARISON

Baseline systems are common conventional water heating systems to which SDHW performance is compared. Each SDHW system has a corresponding conventional hot water heating system baseline. Each baseline system has a tank volume and fuel type identical to that of the auxiliary tank in the associated SDHW system. In the assessment, it is assumed that all heating appliances were installed according to manufacturer's instructions with no additional insulation.

Each SDHW system's performance is compared to the baseline system of the same auxiliary fuel type and tank arrangement. For example, there are three baseline systems fueled by natural gas; a solar hot water system with conventional natural gas backup tanks will be compared to system 000-40 or 000-80, and solar hot water systems with an instantaneous water heater will be compared to system 010. A full listing of baseline systems is shown in Table 6.

Table 6. Baseline Systems Modeled in the Assessment

System ID	Baseline Description
000-40/80	a conventional gas fired water heater - 40 gallon (0.544 EF) or 80 gallon (0.468 EF)
001-40/80/120	a conventional electric resistance water heater – 40 gal. (0.877 EF), 80 gal (0.824 EF), or 120 gal (0.772 EF)
002-40/80	a conventional propane fired water heater - 40 gallon (0.544 EF) or 80 gallon (0.468 EF)
010	a gas fired instantaneous heater. 0.81 EF
043-80/105	a conventional indirect hot water tank with a single lower heat exchanger fueled by an oil boiler 80-gallon (R-12.5 insulated or 105 gallon (R-12.5 insulated)

A wide variety of collector types, tank types, and fuel types prevalent in New York State are represented in this report. The flat plate, evacuated tube and unglazed/building-integrated systems included in this assessment provide representation of the current collector market in the State. Similarly, the tank and fuel types included in the assessment provide good representation of the market. While modeling every combination of collector with every tank and fuel type is beyond the scope of the assessment, this assessment covers SDHW systems applicable to the dominant existing Domestic Hot Water (DHW) system types found in New York State.

SECTION 4
SDHW INSTALLED SYSTEM COSTS

In this section, the SDHW installed system costs were estimated for each system design developed in SECTION 3 at each of the 13 New York State locations.

METHODOLOGY

Total installed system costs (labor, materials, overhead, and profit) of each of the SDHW system designs were estimated by surveying SDHW installers. The status of installers surveyed in the assessment is shown in Table 7.

Table 7. SDHW Installer Survey Status

System Technology	Active NYS Installers	Additional Out-Of-State Installers	Unreachable / Inactive / Unwilling	Successfully Surveyed
Flat A	4	0	0	4
Flat B	4	0	1	4
Evac A / Evac B	5	0	2	4
Evac C	1	2	3	3
Bldg. Int.	0	4	0	4

For calculation purposes, the installed system costs determined in the survey were then divided into two sub-costs: material costs and installation costs. Since installer interviews are the primary source for cost data; the costs presented in this section include any markups that installers may have made. Thus, overhead costs and profit are not analyzed separately, but are a part of both material and installation costs.

Material Costs

Material costs associated with the installation of each of the SDHW system designs were provided by the manufacturer or distributor. Costs include all system components as defined in SECTION 3. The manufacturer's suggested retail price (MSRP) was used to compare costs across SDHW system technologies. For system quotes that do not include the cost of materials for the solar loop (copper piping, pipe fittings, pipe insulation), $500 was added to the quote, based on manufacturer and installer estimates. For systems in which the pre-existing conventional hot water heater (gas, electric, propane, or instantaneous) is capable of being incorporated into the solar hot water system, the material costs for the conventional hot water heater was not included in total system cost. Nevertheless, every system considered in this assessment has at least one tank (either pre-heat or single tank) that is considered a part of the materials cost for the system.

Table 8. Typical SDHW Material Costs

System Technology	Sys ID	Typical Materials Cost[10]
Flat A	1xx	$5,684
Flat B	5xx	$4,953
Evac A	2xx	$5,441
Evac B	3xx	$5,759
Evac C	6xx	$5,950
Bldg. Int.	7xx	$9,000

Installation Costs

Installation costs are considered to be a combination of labor, overhead, and profit, but exclude the cost of materials. Installation cost estimates were calculated by subtracting the materials costs (MSRP) shown in Table 8 from the total installed system cost estimates – this data is presented in Table 9. Since materials cost can differ depending on the installer-manufacturer relationship, MSRP was used in order to normalize for these variations.

Table 9[11]. Installer Survey Results: Installation Costs.

Installer Name	Installation Cost Estimate	Primary Location of Installations	Installation Volume
Flat A Installer 1	$3,616	Long Island	50 / year
Flat A Installer 2	$4,316	Long Island	4 total
Flat A Installer 3	$6,316	New York City	3 total
Flat A Installer 4	$5,316	New York City	8 / year
Flat B Installer 1	$5,539	Binghamton	4 total
Flat B Installer 2	$5,047	Albany	90 / year
Flat B Installer 3	$3,047	Plattsburgh	1 total
Flat B Installer 4	$8,547	New York City	15-20 total
Evac A / Evac B Installer 1	$3,559	Binghamton	1
Evac A / Evac B Installer 2	$3,459	Rochester	2
Evac A / Evac B Installer 3	$5,559	Albany	1

[10] Differences in tank configuration account for variations in cost of $150-$200 that are not reflected in this table. See APPENDIX 5 for a full display of material costs.
[11] NOTE: Table 9 is comprehensive neither in terms of SDHW installers nor cumulative installations.

Evac A / Evac B Installer 4	$9,559	New York	8
Evac C Installer 1	$2,050	Philadelphia County, PA	Unwilling to Share
Evac C Installer 2	$2,550	District of Columbia	75
Evac C Installer 3	$9,050	New York City	3
Bldg. Int. Installer 1	$3,046	Windsor County, VT	2
Bldg. Int. Installer 2	$4,181	Essex County, MA	1
Bldg. Int. Installer 3	$9,883	Fulton County, GA	8
Bldg. Int. Installer 4	$6,281	Ocean County, NJ	3

For certain system types, the surveys did not provide sufficient data to estimate installation costs due to the limited number of active installers in New York State. For Evacuated Tube Manufacturer C (Evac. C) and the Building Integrated (Bldg. Int.) Manufacturer, installers outside of New York were surveyed. Using annual wage data from the US Department of Labor Statistics[12] and the NYS Department of Labor[13] Wage Adjustment Factors were developed and are visible in Table 10 and Table 11.

Table 10. Out-of-State Wage Adjustment Factors

Location: County / State	NY State	Philadelphia / PA	District of Columbia	Essex / MA	Ocean / NJ	Windsor / VT	Fulton / GA
Wage Adjustment Factor (WAF)	1.00	1.09	1.18	1.08	0.96	0.98	1.05

Table 11. In-State Wage Adjustment Factors

Location	NY State	Albany	Binghamton	Buffalo	Elmira	Islip	Jamestown
Wage Adjustment Factor (WAF)	1.00	0.97	0.71	0.96	0.71	1.04	0.96

Location	Massena	NYC	Plattsburgh	Rochester	Syracuse	Utica	Watertown
Wage Adjustment Factor (WAF)	0.85	1.03	0.85	0.97	0.90	0.93	0.85

[12] "Quarterly Census of Employment and Wages," U.S. Department of Labor, Bureau of Labor Statistics, http://data.bls.gov/PDQ/outside.jsp?survey=en

[13] The Wage Adjustment Factors listed in Table 11 were derived from a weighted average consisting of 25% plumber and 75% plumber helper. "Capital District Workforce and Industry Data," New York State Department of Labor, http://www.labor.state.ny.us/workforceindustrydata/index.asp?reg=cap

Each installer interviewed provided quotes at a particular location (L1), which may have been within or outside of New York State; estimated costs at each other location in New York State (L2) were derived according to Equation 1.

$$\textbf{Equation 1.}\ \text{Installation Cost at L2} = \frac{(\text{L2 WAF})}{(\text{L1 WAF})} \times (\text{Installation Cost at L1})$$

For example, a Wage Adjustment Factor of 1.09 (Philadelphia) indicates that labor costs in Philadelphia are 9% higher than the New York State average. It also indicates that they are 12% higher than in Albany, since Albany has a WAF equal to 0.97. If labor costs from a quote in Philadelphia were $5,000, the estimated labor cost in Albany would be calculated as shown in this example.

$$\text{Estimated Installation Cost in Albany} = \frac{(\text{Albany WAF})}{(\text{Philadelphia WAF})} \times (\text{Installation Cost in Philadelphia})$$

Based on conversations with manufacturers, distributors, and contractors, it appears that installation costs remain stable across system designs within a particular technology. One Flat A installer, for example, was not able to provide differentiated installation costs for a two-tank (single heat exchanger) system versus a single tank (double heat exchanger) design. One Flat B installer simply rates system installations as "easy", "medium", and "hard". Since installation costs vary for so many reasons, installers seem to provide quotes based on site-specific conditions more than variations in system design. As such, installation costs presented in Table 12 are uniform within each collector manufacturer for a given location (for full results, see APPENDIX 5).

Table 12. Installation Costs of SDHW Systems in New York State

Location	Flat A	Flat B	Evac A	Evac B	Evac C	Bldg Int.
Albany	$4,593	$6,044	$5,729	$5,729	$4,163	$5,688
Binghamton	$3,357	$4,417	$4,187	$4,187	$3,042	$4,157
Buffalo	$4,541	$5,975	$5,663	$5,663	$4,115	$5,623
Elmira	$3,357	$4,417	$4,187	$4,187	$3,042	$4,157
Islip	$4,932	$6,490	$6,151	$6,151	$4,470	$6,107
Jamestown	$4,541	$5,975	$5,663	$5,663	$4,115	$5,623
Massena	$4,023	$5,293	$5,017	$5,017	$3,646	$4,981
NYC	$4,864	$6,400	$6,066	$6,066	$4,408	$6,023
Plattsburgh	$4,023	$5,293	$5,017	$5,017	$3,646	$4,981
Rochester	$4,594	$6,045	$5,729	$5,729	$4,164	$5,689
Syracuse	$4,242	$5,582	$5,290	$5,290	$3,845	$5,253
Utica	$4,380	$5,763	$5,462	$5,462	$3,969	$5,424
Watertown	$4,023	$5,293	$5,017	$5,017	$3,646	$4,981

In order to validate the calculated installation costs, an estimate for the number of hours was created as a means of checking the labor costs. A rigorous analysis of the number of hours required to install a solar domestic hot water system is outside the scope of this assessment. Still, 30 hours for a plumber and 90 hours for a plumber helper is used as an assumption. The hourly wage data is from the NYS Department of Labor and is based on a 2,000 hour work year.

Table 13. Estimated Labor Costs Based on Hours of Installation

Location	Hourly Wage, Plumber	Hourly Wage, Plumber Helper	Total Labor Cost
Albany	$24	$15	$2,050
Binghamton	$25	$8	$1,498
Buffalo	$26	$14	$2,027
Elmira	$25	$8	$1,498
Islip	$31	$14	$2,201
Jamestown	$26	$14	$2,027
Massena	$24	$12	$1,796
NYC	$29	$14	$2,171
Plattsburgh	$24	$12	$1,796
Rochester	$25	$14	$2,051
Syracuse	$21	$14	$1,893
Utica	$22	$14	$1,955
Watertown	$24	$12	$1,796

The resulting difference between the values calculated in Table 12 and Table 13 can be assumed to represent overhead costs and profits taken by the installer.

RESULTS

The total installed system costs for each system at each of the 13 locations in New York State were calculated by adding the materials costs, presented in Table 8 to the installation costs presented in Table 12. These values are exclusive of State and federal tax credits. Typical Installed System Costs are presented in Table 14. The prices for systems with external heat exchangers (x3x) or double heat exchanger tanks (x4x) are somewhat different. A full display of system costs is available in APPENDIX 5.

Table 14. Typical SDHW Installed System Costs

Location	Flat A	Flat B	Evac A	Evac B	Evac C	Bldg Int.
Albany	$10,277	$10,997	$11,170	$11,488	$10,997	$14,688
Binghamton	$9,041	$9,370	$9,628	$9,946	$9,370	$13,157
Buffalo	$10,225	$10,928	$11,104	$11,422	$10,928	$14,623
Elmira	$9,041	$9,370	$9,628	$9,946	$9,370	$13,157
Islip	$10,616	$11,443	$11,592	$11,910	$11,443	$15,107
Jamestown	$10,225	$10,928	$11,104	$11,422	$10,928	$14,623
Massena	$9,707	$10,246	$10,458	$10,776	$10,246	$13,981
NYC	$10,548	$11,353	$11,507	$11,825	$11,353	$15,023
Plattsburgh	$9,707	$10,246	$10,458	$10,776	$10,246	$13,981
Rochester	$10,278	$10,998	$11,170	$11,488	$10,998	$14,689
Syracuse	$9,926	$10,535	$10,731	$11,049	$10,535	$14,253
Utica	$10,064	$10,716	$10,903	$11,221	$10,716	$14,424
Watertown	$9,707	$10,246	$10,458	$10,776	$10,246	$13,981

CONCLUSIONS

Table 15. Average Total Installed System Costs in Albany, NY

	Flat Plate	Evacuated Tube	Building Integrated
Average Total Installed System Costs	$10,612	$10,818	$14,688
Standard Deviation of quotes by collector type	15%	26%	20%
% Premium above Flat Plate	0%	2%	38%

While the systems analyzed are not all of the same collector capacity, it appears that Flat Plate and Evacuated Tube systems are roughly the same cost. Albany is a relatively average location in terms of cost (the Wage Adjustment Factor is closest to 1.0 of any location), and therefore is used as a basis for comparison. In Albany, Flat Plate systems range from $8,353 to $12,945[14] with a Standard Deviation of 15% amongst the quotes of eight installers surveyed. Evacuated tube technology ranges in cost from $7,785 to $14,64514 with a Standard Deviation of 26% amongst the quotes of seven installers surveyed. Initial results indicate that across technology type and installer type, flat plate collectors are more uniform in terms of installed cost.

Based on the above data, building integrated SDHW systems appear to have the highest fully installed cost of any system. These higher costs are due mostly to their expensive, but durable stainless steel tank specification. This tank comes with an exceptional warranty of 25 years, which matches the warranty length of the entire Building Integrated system.

[14] Numbers are adjusted for local labor rates according to Table 11.

Due to the small number of active SDHW installers in New York State, the installation costs presented above can be considered estimates only. A total of nineteen installers were surveyed. Installers varied in size and activity, ranging from one installation per year to 50 installations per year. Installation companies with a well-developed infrastructure had more precise cost structures and lower installed system costs. Some manufacturers and installers use a rule to estimate that installation cost equals the materials cost. Looking at the data collected, it appears that this crude methodology is relatively accurate.

It is clear that the SDHW installation market is still under development in New York. Generally speaking, solar installers operating in New York choose to focus their energies on solar PV installations rather than SDHW installations due to customer demand and larger contract sizes. Most New York State solar thermal installers have limited experience and cannot provide costs and labor hours with the level of detail and accuracy desired for this SDHW technologies assessment. Costs vary for many reasons and in some areas, SDHW installation is not even offered. Further detail and analysis are presented in SECTION 8: Market, Institutional, and Infrastructure Barriers.

Despite the limited pool of data available, the data presented is a means of estimating typical installed system costs for a SDHW system throughout New York State. In combination with system performance data in SECTION 7, this data will enable a comparison of the economic benefits and costs of each SDHW system design at each of the thirteen locations in New York State.

SECTION 5

SDHW MAINTENANCE COSTS

In this section, costs associated with the maintenance of SDHW systems during their useful life were estimated. The objective was to develop a matrix for maintenance costs for each SDHW system design.

METHODOLOGY

System manuals and installer surveys often suggested that the only SDHW maintenance costs were associated with replacing and recharging the heat transfer fluid[15]. In order to more accurately reflect the costs of owning a system, maintenance costs were estimated based on projected component life for the solar collectors, tank, circulator pump, heat exchanger, and heat transfer fluid. A system is assumed to be retired when the longest lasting piece of equipment fails. For this assessment, the solar collectors determine the lifespan of solar hot water systems. Component life was estimated by doubling the manufacturer's warranty. Heat transfer fluid is not under warranty; therefore, it was given a useful life of eight years, based on manufacturer and installer surveys.

Table 16. System Component Warranty and Life

Manufacturer	System Warranty	Tank Warranty	Pump Warranty	Heat Exchanger Warranty	System Life	Tank Life	Pump Life	Heat Exchanger Life	Heat Transfer Fluid Life
Flat A	10	5	2		20	10	4		8
Evac A&B	10	6	2	5	20	12	4	10	8
Flat B	10	5	2	5	20	10	4	10	8
Evac C	10	6	2		20	12	4		8
Bldg. Int.	25	25	2		50	50	4		8

Next, the number of yearly component replacements over the course of the system life was determined. Table 17 was calculated as follows:

Equation 2.
$$\frac{\text{Component Replacements}}{\text{Year}} = \frac{\text{Component replacements during System Life}}{\text{System Life (years)}}$$

When using this formula, component replacement at system retirement was not included because the system is at the end of its useful life, and the component does not need to be replaced.

[15] Other suggested "no-cost" maintenance measures included visual inspection of the collectors and tank, pump and control hardware to verify structural integrity and operation, checking collector flow rates and solar tank/panel temperatures, and checking supply and return pipes to collector for physical damage to insulation and weather shielding. This is not representative of the true maintenance costs for operating a SDHW system. Many of the installers in New York State have less than five years of experience installing SDHW systems and have little experience estimating ongoing maintenance costs. Systems installed by relative newcomers to the field have not been operating long enough to accurately represent maintenance costs.

Flat B, for example, has a system life of 20 years and the tank life of 10 years. Therefore, the tank would be replaced at 10 years, for a total of one replacement in 20 years, or 0.05 replacements per year. With an assumed Pump Life of four years, the pump would be replaced at 4, 8, 12, and 16 years, for a total of four replacements in 20 years, or 0.20 replacements per year.

Table 17. System Component Replacements Per Year

Manufacturer	Tank	Pump	Heat Exchanger	Heat Transfer Fluid
Flat A	0.05	0.2	0	0.1
Evac A / Evac B	0.05	0.2	0.05	0.1
Flat B	0.05	0.2	0.05	0.1
Evac C	0.05	0.2	0	0.1
Bldg. Int.	0	0.2	0	0.1

The multipliers calculated in Table 17 are used to determine the annual maintenance costs for each system design. The maintenance costs presented in this section have been divided into material maintenance costs and labor maintenance costs.

Material Maintenance Costs

In order to calculate the annual material maintenance costs, the MSRP system component costs were identified. These are presented in Table 18; "HX" refers to the number of heat exchangers in a given tank.

Table 18. MSRP System Component Costs

	Tank - 1HX	Tank - 2HX	Tank - 0HX (Preheat)	Tank - Conventional	External HX	Pump	Heat Transfer Fluid
Flat A	$1,540	$1,700				$100	$150
Flat B			$759	$600	$300	$100	$150
EvacA/ Evac B	$1,350	$1,550		$600	$300	$100	$150
Evac C	$1,000					$100	$150
Bldg. Int.	$2,125					$100	$150

The system component costs were multiplied by the values in Table 17. The annual material maintenance costs are presented in Table 7.

Table 19 . Annual Material Maintenance Costs

System Technology	Sys ID	Typical Material Maintenance Cost[16]
Flat A	1xx	$112
Flat B	5xx	$88
Evac A	2xx	$103
Evac B	3xx	$103
Evac C	6xx	$85
Bldg. Int.	7xx	$35

Labor Maintenance Costs

RS Means was used to estimate the labor hours required to perform the maintenance measures. Labor hours were multiplied by a factor of 0.25 for a plumber and 0.75 for a plumber helper.

Table 20. Labor Hours / Maintenance Measure

	Tank Replacement	Pump Replacement	External Heat Exchanger Replacement	Heat Transfer Fluid Replacement
Plumber	1.25	0.5825	0.625	0
Plumber Helper	3.75	1.7475	1.875	4

Next, labor hours were multiplied by the hourly annual wage data for each of the 13 locations, provided by the NYS Department of Labor[17] (assuming 2,000 hours of annual work).

Table 21. Wage Data

Location	Albany	Binghamton	Buffalo	Elmira	Islip	Jamestown	Massena
Plumber	$24.15	$24.93	$26.01	$24.93	$30.90	$26.01	$23.81
Helper	$14.73	$8.34	$13.85	$8.34	$14.16	$13.85	$12.02

Location	NYC	Plattsburg	Rochester	Syracuse	Utica	Watertown
Plumber	$29.17	$23.81	$25.14	$20.73	$21.88	$23.81
Helper	$14.40	$12.02	$14.41	$14.13	$14.43	$12.02

The resulting labor cost for each measure was then multiplied by the values presented in Table 17 to arrive at labor cost. Maintenance measures associated with each system design were added together to arrive at a

[16] Differences in tank configuration account for variations that are not reflected in this table. System ID numbers x43 cost an estimated $120/yr and x3x systems $50/yr to maintain. See APPENDIX 5, for full display of costs.

[17] "Prevailing Wage Rates for 07/01/2007 – 06/30/2008," New York State Department of Labor, http://wpp.labor.state.ny.us/wpp/viewPrevailingWageSchedule.do?county=87 (April 1, 2008)

final labor maintenance cost. Depending on location and system type, these numbers ranged from approximately $9 - $19 annually. The full results are presented in APPENDIX 5.

RESULTS

Table 22 presents the annual maintenance costs for each system design at each of the 13 locations in New York State. There is additonal variation in cost than what is presented here, as certain tank configurations cost more to maintain. The range of estimated maintenance costs for these systems is $44 - $139. See APPENDIX 5 for a full display of maintenance costs for each system at each location.

Table 22. Typical Annual Maintenance Costs

Location	Flat A	Flat B	Evac A	Evac B	Evac C	Bldg Int.
Albany	$130	$106	$121	$121	$103	$49
Binghamton	$124	$100	$115	$115	$97	$44
Buffalo	$130	$106	$120	$120	$103	$48
Elmira	$124	$100	$115	$115	$97	$44
Islip	$131	$107	$121	$121	$104	$49
Jamestown	$130	$106	$120	$120	$103	$48
Massena	$128	$103	$118	$118	$101	$47
NYC	$131	$107	$121	$121	$104	$49
Plattsburgh	$128	$103	$118	$118	$101	$47
Rochester	$130	$106	$120	$120	$103	$49
Syracuse	$129	$105	$119	$119	$102	$48
Utica	$129	$105	$120	$120	$102	$48
Watertown	$128	$103	$118	$118	$101	$47

CONCLUSIONS

Generally speaking, evacuated tube and flat plate systems have similar maintenance costs. The main differences in maintenance costs are:

1. The building integrated systems cost less to maintain due to the long tank life – half the annual amount according to this analysis.
2. The external heat exchanger systems tend to cost less to maintain, since the replacement cost of the external heat exchanger/tank arrangement is lower than the internal heat exchanger tanks.
3. Maintenance costs are dominated by materials costs; labor costs are secondary according to these estimates.

Actual labor for maintenance may be higher as contractors mark up the cost of labor. Since a market for maintaining SDHW systems is not currently established, we have elected to show labor rates "at cost" to a company maintaining an SDHW system.

SECTION 6
MODELED ENERGY PERFORMANCE AND ENERGY SAVINGS

SIMULATION SOFTWARE

The primary software tool used to estimate the energy performance of the assessed solar thermal technologies was TRNSYS version 16. The hourly simulation routines of TRNSYS and a wide-ranging component library aided in the creation of accurate and verifiable models of each system to be tested in a time-efficient manner. The modular nature of TRNSYS lent flexibility to the modeling process, and facilitated the addition to the program of mathematical models not included in the standard TRNSYS library. This is best exemplified by the inclusion of custom weather files and custom tank profiles. Additionally, there is a great body of knowledge about how to model solar systems in TRNSYS, due to its use by research institutions across the world for modeling solar energy systems. In addition to TRNSYS, RET Screen simulation software results were generated for each collector type at one location. This is a much simpler program, giving an order of magnitude estimate of solar production. It was used to gauge whether the TRNSYS results were reasonable.

SOLAR RADIATION DATA FOR NEW YORK STATE

The climatological irradiance data used as an input to the simulations consist of TMY-2 data (NREL, 1994), which have been adjusted to account for the high-resolution spatial distribution of solar resources derived from geostationary satellites that have recently been incorporated in the updated National Solar Radiation Data Base (Wilcox, S. et al., 2007). The time series generator (Perez, 2000) was used to process original TMY-2 data by adjusting each month's clearness index to reflect the recent satellite observations. The same procedure was also used to extrapolate TMY-2 data at any nearby locations. This methodology was used to generate updated TMY data at the original seven TMY-2 locations -- Albany, Binghamton, Buffalo, Massena, New York, Rochester, and Syracuse -- and to generate extrapolated TMY data for Islip, Elmira, Plattsburgh, Jamestown, Watertown, and Utica.

TRNSYS MODEL

Specifically, in this assessment, all components were modeled using the standard TRNSYS and TESS libraries (TESS, 2007), unless noted otherwise. Annual simulations were performed using a one-hour time step. The climatalogical data set was created in TMY2 format using the aforementioned methodology.

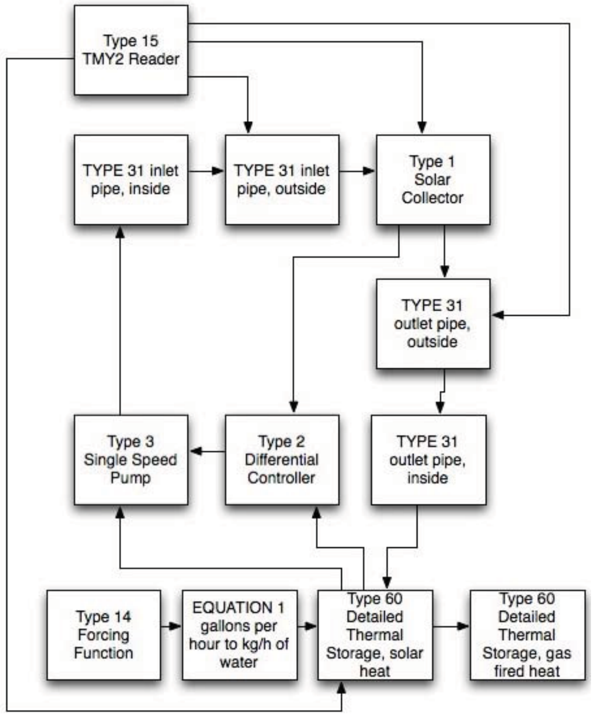

Figure 11. Typical Simulation Input (System ID 100)

COLLECTOR MODEL

The collector model used for flat plate, evacuated tube, and building integrated collectors was the Generic Type 1. This Type uses the quadratic curve of collector efficiency as a function of temperature difference between the collector and the environment and three user-specified coefficients of the function that control the performance of the collector. Performance data were taken from SRCC ratings and collectors were arranged in series.

SYSTEM TYPES

All the pumped, closed-loop systems uses the TRNSYS pump model with a controller to turn the pump on and off and used TRNSYS tank models that included heat exchanger(s), except the Flat C (8xx, 9xx, 10xx) systems. The Flat C systems differ from the others because a custom TRNSYS type provided by the manufacturer was used to model the thermosyphon and heat exchanger. These custom types were validated by a major university and several peer reviewed papers have been published on its performance. Those papers are not given here to protect the identity of the manufacturer. Other than these two components, all components were modeled using the standard TRNSYS and TESS libraries (TESS, 2007).

TANK ARRANGEMENTS

The three tank arrangements were modeled as follows:

1. Single tank arrangements (x3x, x4x) were modeled as one TRNSYS tank with two heat exchangers. From an energy perspective, this simulation treats as equals solar tanks with two heat exchangers (e.g., top and bottom of tank) and solar tanks with an upper electric element and one heat exchanger (e.g., bottom of tank).
2. Two tank arrangements (x0x, x2x) used a TRNSYS tank with single heat exchanger to model a single heat exchanger solar pre-heat tank and used a TRNSYS gas or electric heated primary tank downstream from the solar pre-heat tank.
3. Solar tank plus instantaneous hot water heater models (x1x) used a TRNSYS tank with a single heat exchanger to model single heat exchanger solar pre-heat tank and used a TRNSYS instantaneous DHW type to model auxiliary heater.

COMPONENTS OF THE TRNSYS MODEL

The forcing function (Type 14) was used to prescribe the hot water draw profile, per ASHRAE (see Figure 5). The TMY2 Reader (Type15) provided weather-related inputs to the solar collectors, including the mains-water temperature model, which was used to determine the temperature of the cold water source (TESS, 2007). Detailed Thermal Storage, (Type 60) is the model for all tanks modeled in the assessment – including solar, electric, gas-fired, oil-fired, and propane-fired. The modeled parameters were changed to account for each tank type.

The Fluid Pump (Type3) model was used to simulate the circulation pumps of the SDHW systems. This component models the pumping power using a simple polynomial relationship between power and mass flow rate. In this study all pumps were based on a typical pump using 90 watts of power at a peak flow rate of 9.5 GPM (0.59 l/s). A linear relationship was used to predict the pumping power used at part load[18].

The Differential Controller (Type2) used was a simple on/off controller, programmed to turn on when the differential temperature between the collectors and storage tank rose above a specified setpoint and turn off when the differential temperature became sufficiently small. The setpoint at which the controller turns on and off varied by the manufacturer's recommendations and can be seen in APPENDIX 2.

Inlet pipe (TYPE 31) and outlet pipe (TYPE 31) lengths were based on typical residential construction of 15 ft (4.6 m) of indoor pipe and 10 ft (3 m) of outdoor pipe. This was modeled to account for heat losses in fluid transmission between the storage tank and solar collector. The pipe was modeled as 1 inch (2.54 cm) in diameter with 1 inch (2.54 cm) of polyethylene insulation.

[18] A cubic or squared relationship would have been more accurate in predicting pumping power, but due to limited information from the manufacturers, and the relatively minor role of pumping energy in the energy balance of the SDHW systems, a linear relationship was used. An interesting follow up to this study would be to model pumping energy more precisely.

RESULTS - SIMULATION OUTPUTS

<u>DHW baseline loads</u>

Simulation results show that the baseline load varies depending on system type. As noted above, each baseline system corresponds to one or more SDHW systems – baseline systems are created to match the auxiliary tank designs of the SDHW systems.

All results are presented in "site" energy usage. Since electric resistance tanks have higher levels of insulation according to ASHRAE minimums, electric tanks are more efficient with site energy than the natural gas, propane, and oil tanks. The gas instantaneous heater is the second most efficient system, due to its low level of radiative heat loss.

The lower levels of energy usage by the electric tanks allow SDHW systems using electric backup to achieve higher levels of solar fraction than systems backed up by other fuel types.

The baseline systems were simulated at each of the 13 locations across New York State. For each given baseline system, the difference in energy usage across locales is due to the difference in "Mains Water Temperature" as simulated in TRNSYS. The energy use by each baseline system (E_aux) at each location is presented in APPENDIX 5. The consumption of each baseline system in Albany – a relatively average location in the State in terms of baseline water consumption – is presented below in Table 23.

Table 23. Baseline System Energy Use in Albany

System ID	Energy Usage (kBTU)
000-40	24,466
000-80	27,416
001-40	16,147
001-80	16,928
001-120	17,709
002-40	24,466
002-80	27,416
010	17,613
043-105	19,926
043-80	20,520

It is worth noting that the 043-80 gallon tank uses more energy than the 043-105 gallon tank; this is the only instance in which a smaller tank uses more energy than a larger tank of the same class. This curiosity was investigated and has basis in physical reality. The main factor appears to be the geometry of the tanks: the particular 043-105 gallon tank studied has a surface area that is only slightly larger than the 043-80 gallon tank. The larger volume of the 105 gallon tank and the larger surface area of the heat exchanger inside the 105 gallon tank allow for a greater difference in temperature across the heating coil and thus more efficient heat transfer into the tank. Also, for this assessment, the hot water draw profile is identical for both tanks.

Comparison of the SDHW Systems - Energy Performance

Simulation results of the SDHW Systems are presented in this section. Table 24 shows the annual performance of all analyzed systems in Albany, a relatively average location in the state of New York in terms of solar radiation and temperature. The following are definitions of the variables listed in the table:

- E_aux represents the auxiliary energy used to heat domestic hot water in addition to solar energy. E_aux was calculated by the energy model and is exclusive of pumping energy (analyzed separately).
- E_disp represents the amount of energy displaced by the SDHW system – e.g., the amount of energy contributed to the tank from solar energy. E_disp was calculated by taking the difference between SDHW E_aux and Baseline E_aux. E_disp is exclusive of pumping energy.
- Solar Fraction (SF) is calculated as E_disp divided by baseline E_aux. Pump Energy is excluded from the SF calculation because electricity uses a variable amount of "source energy" at the power plant depending on fuel source, which varies across the State.
- Pump Energy is based on modeled pump run times, and the associated electric consumption (kWh) is included as a cost in the economic analysis of each SDHW system.

Table 24. SDHW Annual Energy Performance in Albany

Collector	Sys ID	E_aux (kBTU)	Pump Energy (kBTU)		E_disp (kBTU)	SF
			Solar	Boiler		
Flat A	100	8668	382		15798	65%
	101	4007	380		12140	75%
	102	8668	382		15798	65%
	110	4517	380		13096	74%
	143	7560	348	55	12312	62%
Evac A	200	8950	453		15517	63%
	201	4069	453		12077	75%
	202	8950	453		15517	63%
	243	7270	413	53	13198	64%
Evac B	300	10415	359		14051	57%
	301	5033	359		11113	69%
	302	10415	359		14051	57%
	310	5706	359		11907	68%
	330	19784	930		7632	28%
	331	7789	626		9140	54%
	332	19784	930		7632	28%

	343	8170	376	59	12292	60%
Flat B	520	13430	630		11036	45%
	521	7587	630		8559	53%
	522	13430	630		11036	45%
	530	20995	776		6421	23%
	531	7818	626		9110	54%
	532	20995	776		6421	23%
Evac C	610	7888	392		9725	55%
	641	8295	340		9414	53%
Bldg Int.	700	16464	201		8002	33%
	701	9778	211		6369	39%
	702	16464	201		8002	33%
Flat C	821	8930	518		7217	45%
Flat C	920	11494	478		12972	53%
	921	5998	478		10148	63%
	922	11494	478		12972	53%
	931	6483	469		9664	60%
Flat C	1021	4668	431		11479	71%

Table 25 shows the performance of two-tank, natural gas fired systems at all simulated locations. When x00 systems were not offered by the manufacturer, the next most relevant system was included or the results were extrapolated – see note below Table 25.

Table 25. Annual Solar Fraction of selected SDHW systems for two tank arrangement co-fired with natural gas[19]

Location	System identification Number								
	100	**200**	**300**	**520**	**600***	**700**	**820***	**920**	**1020***
Albany	65%	63%	57%	45%	47%	33%	38%	53%	60%
Binghamton	60%	59%	52%	41%	42%	30%	34%	48%	55%
Buffalo	61%	60%	54%	43%	44%	31%	36%	50%	56%
Elmira	62%	61%	54%	42%	43%	30%	35%	50%	57%
Islip	71%	70%	64%	50%	52%	34%	42%	59%	66%
Jamestown	59%	59%	52%	41%	43%	30%	34%	49%	55%
Massena	60%	59%	53%	41%	43%	31%	34%	48%	55%
New York City	69%	67%	61%	48%	50%	33%	40%	57%	64%
Plattsburgh	62%	61%	56%	44%	46%	31%	36%	51%	58%

[19] *The 600, 820, and 1020 systems are not offered by the manufacturer. For purposes of equalized comparison in this table, Solar Fraction of these systems was estimated by the following equations:*

$SF_{600} = SF_{300} * SF_{610} / SF_{310}$

$SF_{820} = SF_{920} * SF_{821} / SF_{921}$

$\mathbf{SF_{1020} = SF_{920} * SF_{1021} / SF_{921}}$

Rochester	61%	61%	54%	43%	45%	32%	36%	51%	57%
Syracuse	61%	59%	54%	42%	44%	32%	35%	50%	56%
Utica	60%	59%	53%	42%	43%	31%	35%	49%	56%
Watertown	61%	60%	54%	43%	44%	32%	36%	50%	56%
NYS Average	62%	61%	55%	43%	45%	32%	36%	51%	58%

One result visible in Table 25 is that the two collector 920 system has a higher solar fraction than the two collector 520 system. This is due to a combination of two factors: collector efficiency and a balance of system efficiency. Collector efficiency is straightforward to evaluate from the SRCC ratings of the collectors. The system efficiency is primarily due to the heat exchanger efficiency. In order to better understand the relative weight of these two factors, a special simulation was conducted in which the Flat B collectors of system 520 were replaced with Flat C collectors. In other words, two Flat C collectors from the 920 system were modeled on the 520 system. This special simulation is denoted as 520*C* in Table 25b below. Note that the 520*C* system is not commercially available and is modeled for comparison purposes only.

Table 25b. Detailed comparison of Solar Fraction of the Flat C collector to the Flat B collector

	520 (with Flat B collectors)	520*C* (with Flat C collectors)	920 (with Flat C collectors)
Solar Fraction	43%	49%	51%

It is visible in this table that simply replacing the Flat B collectors with Flat C collectors is responsible for a nominal 6% jump in solar fraction (43% to 49%), while the balance of system is responsible for a nominal 2% jump in solar fraction (49% to 51%). As such, the 920 system is more efficient on both counts, but derives more of its incremental benefit from the collector efficiency than balance of system efficiency.

Table 26. Annual Solar Fraction of selected SDHW systems per square foot

Location	System identification Number								
Sys ID	100	200	300	520	600	700	820	920	1020
Albany	0.9%	1.1%	1.0%	0.9%	1.2%	0.06%	1.3%	0.9%	0.7%
Binghamton	0.9%	1.0%	0.9%	0.8%	1.0%	0.05%	1.2%	0.8%	0.6%
Buffalo	0.9%	1.0%	0.9%	0.9%	1.1%	0.05%	1.2%	0.9%	0.6%
Elmira	0.9%	1.0%	0.9%	0.9%	1.1%	0.05%	1.2%	0.9%	0.7%
Islip	1.0%	1.2%	1.1%	1.0%	1.3%	0.06%	1.4%	1.0%	0.8%
Jamestown	0.9%	1.0%	0.9%	0.8%	1.1%	0.05%	1.2%	0.8%	0.6%
Massena	0.9%	1.0%	0.9%	0.8%	1.1%	0.05%	1.2%	0.8%	0.6%
NYC	1.0%	1.1%	1.0%	1.0%	1.2%	0.06%	1.4%	1.0%	0.7%
Plattsburgh	0.9%	1.0%	1.0%	0.9%	1.1%	0.05%	1.2%	0.9%	0.7%
Rochester	0.9%	1.0%	0.9%	0.9%	1.1%	0.05%	1.3%	0.9%	0.7%
Syracuse	0.9%	1.0%	0.9%	0.9%	1.1%	0.05%	1.2%	0.9%	0.6%
Utica	0.9%	1.0%	0.9%	0.9%	1.1%	0.05%	1.2%	0.8%	0.6%
Watertown	0.9%	1.0%	0.9%	0.9%	1.1%	0.05%	1.2%	0.9%	0.6%
NYS Average	0.9%	1.0%	0.9%	0.9%	1.1%	0.05%	1.2%	0.9%	0.7%

Table 26 displays the annual solar fraction divided by the net aperture area, providing a metric for efficiency of collection. The building integrated system shows the lowest performance of 0.16 – 0.19% per ft^2, flat plate systems (100, 520) range from 2.8%-3.4% per ft^2 while evacuated tube systems (200, 300, 600*) show 3.4%-4.2% per ft^2. Of the two flat-plate systems, system 100 has roughly 50% more collector area than system 520, yet they show very similar performance on an area normalized basis. Evacuated tube systems appear to be the most efficient at collecting solar radiation. Not surprisingly, the 600 ft^2 building integrated system draws in roughly 5% of the solar radiation per unit area, but compensates for this inefficiency by spreading out across the entire roof.

Systems 820, 920, and 1020 display that smaller systems are more efficient per square foot of collector area. These systems all use the same solar collector; 820 is comprised of one collector, 920 of two collectors, and 1020 of three collectors. The reason for the reduced system performance with each additional collector is this: as the temperature of the preheat tank rises, it becomes more difficult to transfer heat to that warmer water. The two collector 920 system shows very similar performance on an area normalized basis to the other two collector systems analyzed in the assessment: the 100 and 520 systems.

<u>Geographical Renderings of Energy Performance</u>

On the following pages are selected statewide geographical renderings of system performance in terms of solar fraction. A full display of simulation outputs is located at http://sdhw.brightpower.biz. Matrices of the results can be seen in APPENDIX 3.

In Figure 12, the best performing system for each fuel type is displayed. The first row (left to right) displays the best performing SDHW system with natural gas fired backup (System ID 110) and with electric backup (System ID 101). The second row (left to right) displays the best performing SDHW system with propane fired backup (System ID 102) and with oil backup (System ID 243). The first three systems displayed are Flat Plate Model "A" and the other is Evacuated Tube Model "A".

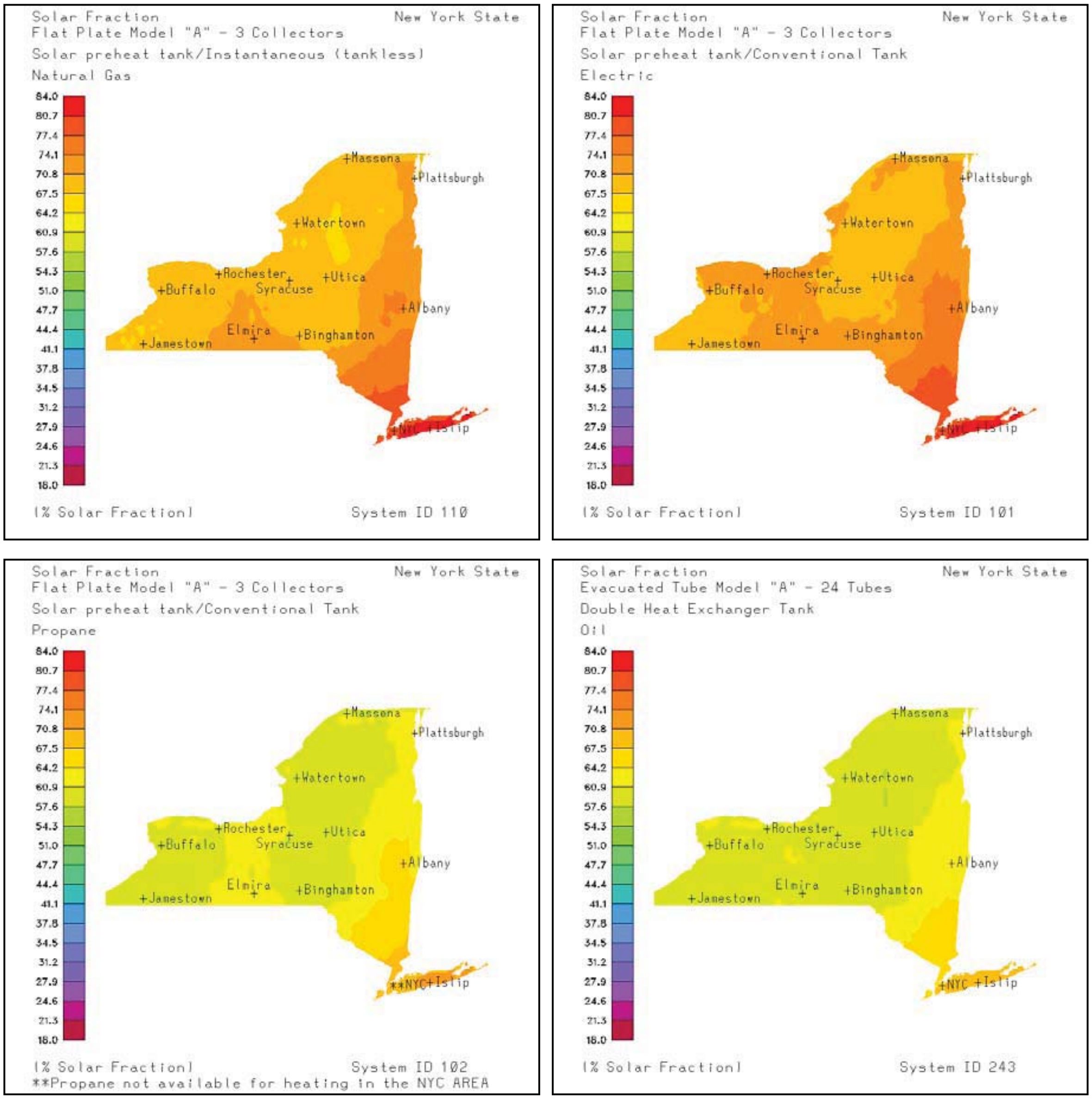

Figure 12. Statewide Renderings of Highest Solar Fraction for each Fuel Type

In Figure 13, the best performing system for each technology type is displayed. The tank type and fuel type are held constant in these plots; systems with the most common tank arrangement (solar preheat tank with conventional backup tank) and fuel type (natural gas) are displayed. The first row (left to right) displays the best performing Flat Plate system (System ID 100), and the best performing Evacuated Tube system (System ID 200). The second row displays the only building integrated system analyzed in the assessment (System ID 700).

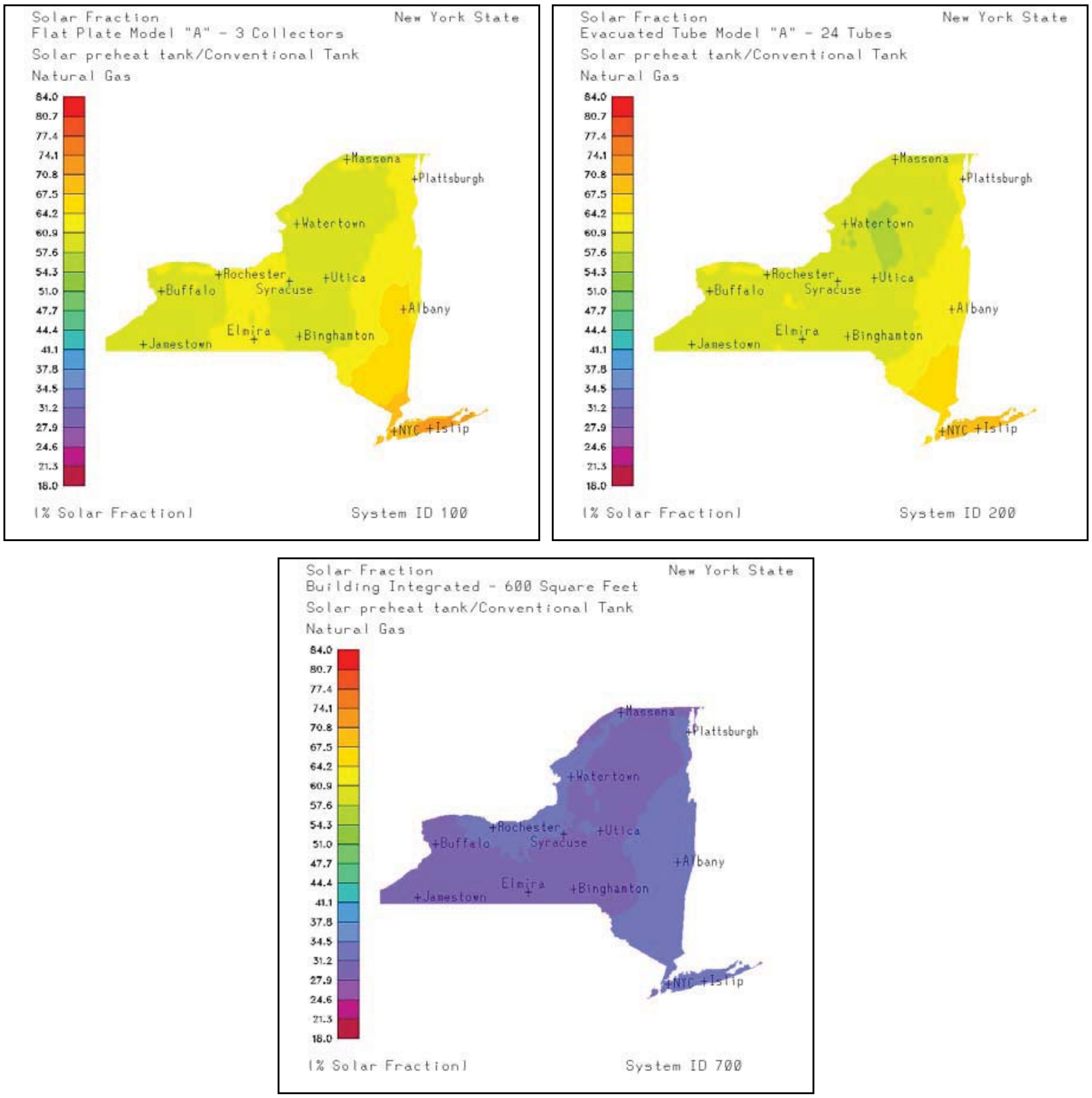

Figure 13. Statewide Renderings of Highest Solar Fraction for each Technology Type[20]

[20] For two tank systems co-fired with natural gas backup

In Figure 14 and Figure 15, renderings of the systems with the most and least variability in system performance across the State are displayed. Systems 110 and 143 (Flat Plate Mode "A") displayed the most variability, and Systems 700 and 702 (Building Integrated) displayed the least variability across the State.

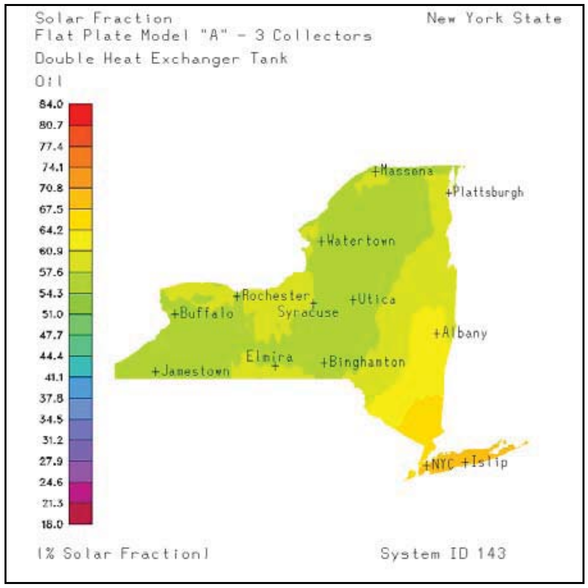

Figure 14. Rendering of System with Most Statewide Variability in Solar Fraction[21]

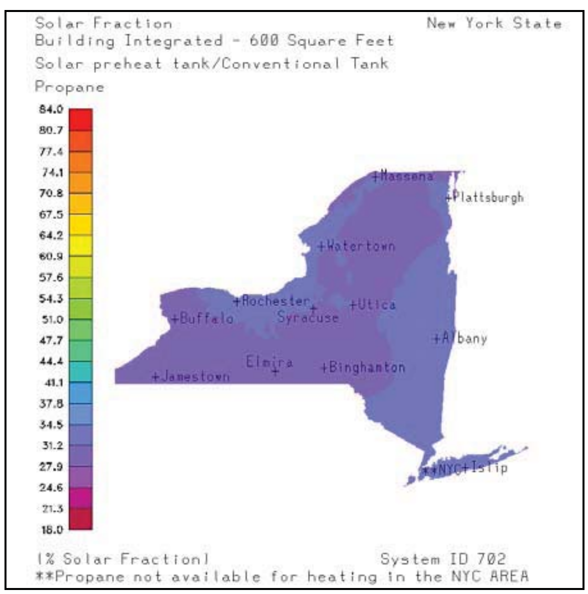

Figure 15. Rendering of System with Least Statewide Variability in Solar Fraction[22]

[21] Equal range of variability as System ID 110, pictured previously

In Figure 16, geographical renderings of the solar fraction of all analyzed systems are presented in thumbnail format. Full size renderings are available at http://sdhw.brightpower.biz.

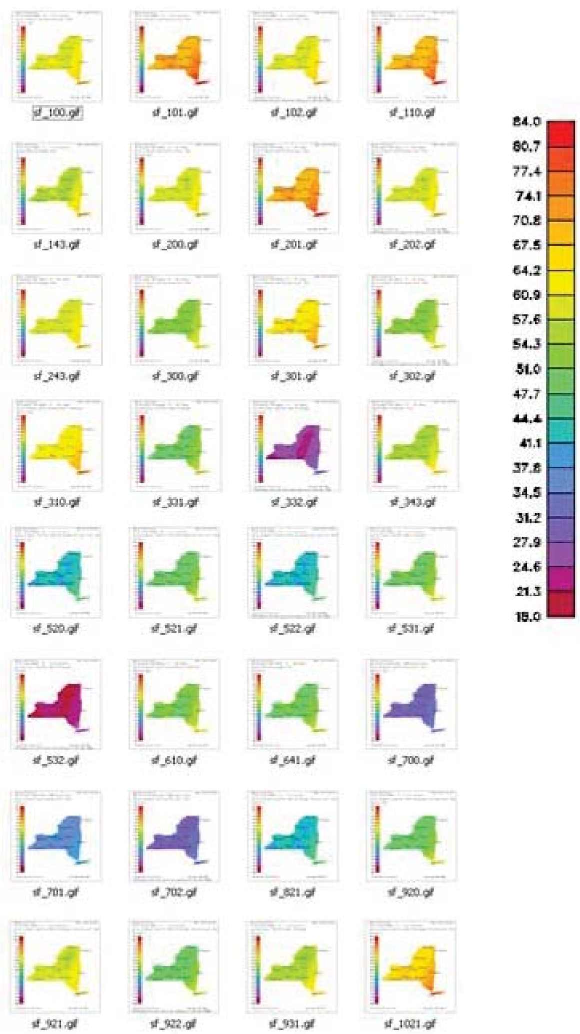

Figure 16. Renderings of Solar Fraction for all analyzed SDHW Systems

[22] Equal range of variability as System ID 700, pictured previously

ANALYSIS OF ENERGY PERFORMANCE RESULTS

Immediately visible on viewing Table 25 and the geographical renderings in Figure 12 through Figure 16 is that climate is an important factor in determining the solar fraction achieved by any system. The coastal areas of New York City and Long Island (Islip) outperform Western and Northern New York areas by 9-12% nominal, while Albany and the Hudson Valley fall between the two extremes.

Systems 820, 920, and 1020 display that smaller systems are more efficient per square foot of collector area, as seen in Table 26. These systems all use the same solar collector; 820 is comprised of one collector, 920 of two collectors, and 1020 of three collectors. The reason for the reduced system performance with each additional collector is this: as the temperature of the preheat tank rises, it becomes more difficult to transfer heat to that warmer water. As such, in the three-collector 1020 system, each square foot of collector is providing roughly half as much usable energy as that same collector in the 820 system (Table 26). The two collector 920 system shows very similar performance on an area normalized basis to the other two collector systems analyzed in the assessment – the 100 and 520 systems.

A solar supplied pre-heat tank coupled with an instantaneous water heater appears to be the optimal tank configuration (see Figure 12). Systems using electricity as the auxiliary fuel source (xx1) realize the highest solar fraction[23]. Systems using instantaeous gas-fired backup water heaters realize a solar fraction that is nearly as high as the electric systems, yet would cost a fraction of the amount to operate. The instantaneous configuration is optimal because the pre-heat tank is able to maintain thermal stratification and the instantaneous water heater provides the remaining heat on-demand, without standby losses.

It appears that an internal heat exchanger pre-heat tank (Systems x0x) is more efficient than an external heat exchanger pre-heat tank (Systems x2x), especially for systems with an annual solar fraction above 50%. For example, the 1020 (Flat C) system has three collectors that are each rated as more productive by SRCC OG-100 than the two collectors of the 100 system (Flat A). Despite this fact, the solar fraction remains 5% (nominal) lower than system 100 as visible in Table 25. This is likely due to the aforementioned difference in heat exchanger configuration between the two systems: the external heat exchanger of the 1020 system is less efficient than the internal heat exchanger of the 100 system.

For a common fuel type, the flat plate systems analyzed in this assessment display the highest solar fraction, edging evacuated tube systems by a few percentage points in terms of solar fraction. Evacuated

---

[23] This is not surprising, because these simulations results are presented in terms of site energy usage – if the analysis were instead performed in terms of "source" energy usage, the electric systems (xx1) would instead be the worst performers in the chart. By this metric, electric systems typically outperform other fuel sources by roughly 10 nominal percentage points, while in fact these systems are usually the most expensive to operate.

tubes are customarily thought to be more efficient, and this discrepency is likely due to the Flat Plate Model "A" system being more appropriately sized for New York State by the manufacturer. Building integrated systems display less than half the solar fraction of the other technologies, but are warrantied for over twice as long, allowing the system additional years of solar collection.

Systems 1xx and 5xx are both flat-plate collectors, but 5xx exhibits much lower solar fraction. This can be attributed to a larger net aperture (collector area) as shown in Table 5. System 520 has a 28.5% smaller collector aperture and 30.4% lower solar fraction than system 100. Systems 6xx similarly realize lower solar fractions than the other evacuated tube systems 2xx and 3xx, Nevertheless, system 600 (see Table 25) has a 31% smaller aperture and a 24% lower solar fraction when compared to system 200, and only a 15% lower solar fraction when compared to system 300.

Single tank external heat exchanger systems (x3x) vary according to the fuel source beyond the aforementioned nominal 10% difference. Tank configurations x30 and x32 realize some of the lowest performance in Table 24 and Figure 16, while x31 systems perform relatively higher. For example, 531 outperforms 530 and 532 by 54% vs. 23% Solar Fraction, or thirty-one nominal percentage points. There is a physical explanation for this. In systems 530 and 532, the position of the natural gas or propane heating element at the bottom of the tank is in close proximity to the heat exchanger carrying the solar heated antifreeze solution. Since the lower portion of the tank is already heated by natural gas or propane, there is a lower difference in temperature between the heat exchanger and the tank water, allowing much less heat transfer. On the other hand, the electric element in system 532 is located in the upper area of the tank. This allows thermal stratification across the vertical dimension of the tank. This thermal stratification in the tank leaves the lower portion of the tank at a much lower temperature, allowing for good heat exchange between the solar fluid and the tank water.

If an external heat exchanger system is to be used with a conventional natural gas or propane tank, it is clear that a two tank arrangement is preferable. This is visible by comparing the performance of 530 and 520. The thermal stratification of the preheat tank in this arrangement allows for good heat transfer in the solar preheat tank, before that water is transferred to the second tank (see Figure 8 for tank diagram).

If an external heat exchanger is to be used with a conventional electric tank, it appears that for the system size simulated in this assessment, consolidatation into a single tank arrangement does not harm system performance. This is visible by comparing systems 531 and 521. Again, this is because the electric element is generally located near the top of the tank, which keeps the bottom of the tank relatively cold and allows heat exchange between the hot solar fluid and the cold tank water.

The Building Integrated/Unglazed SDHW systems (7xx) demonstrate less variability in solar fraction across the State, perhaps because they are well insulated by the roof (See Figure 15). These systems have a nominal range of 4.9% in solar fraction across the State. The Flat Plate Model "A" system with oil-fired boiler backup displays the greatest variability across the State, with a nominal range of 13.3% in solar fraction across the State. Flat plate and evacuated tube systems exhibit a much greater spread in solar fraction, indicating that building integrated systems may be particularly well suited for cold climates. It is worth noting that the unglazed building-integrated collectors show the lowest performance in solar fraction but have the longest system life, which allows savings to accrue over a longer period.

Also, note that the 3xx and 2xx evacuated tube systems are from the same manufacturer. The manufacturer touted 3xx system as the better performer, but these "premium" tubes underperformed the less expensive 2xx in this climate region.

Simulation Result Comparison – TRNSYS vs. RETScreen

In order to roughly check the results of the TRNSYS simulations, a more simple analysis was performed in Renewable Energy Tecnology Screen (RETScreen), a software product developed by the United Nations, the Canadian Government, and others for "pre-feasibility" analysis. As described on the RETScreen website[24]: "The RETScreen International Clean Energy Project Analysis Software is a unique decision support tool developed with the contribution of numerous experts from government, industry, and academia. The software, provided free-of-charge, can be used worldwide to evaluate energy production and savings." As such, it is used to gain a sense for order of magnitude production that can be expected from a Solar Hot Water System at a given location.

As a software tool, RETScreen has considerably less flexibility than TRNSYS – tank efficiency in RETScreen is defined by a single number: Water Heating System Seasonal Efficiency, whereas TRNSYS can account for the effects of thermal stratification, differeing levels of insulation, and different fuels for heating the water. In the nomenclature of this assessment, RETScreen fixes the second digit of the system number as a "0" – corresponding to a natural gas fired tank. Additionally, RETScreen runs on monthly weather data, as opposed to TRNSYS, which runs on hourly weather data. This increases the accuracy of TRNSYS simulations considerably. Another major difference between the two programs is their prediction of household hot water energy consumption. For a household using 66.4 gallons of 125 ºF hot water per day, TRNSYS predicts 24,466 kBTU per year of DHW associated energy, whereas RETScreen predicts 15,720 kBTU per year of DHW associated energy. As a baseline for comparison, the US DOE Energy

[24] "RETScreen International Overview," Natural Resources Canada, http://www.retscreen.net/ang/centre.php

Information Administration (EIA) states that the average household using natural gas as the primary hot water heating fuel used 18,100 kBTU per year for an average family size of 2.5 people[25].

Table 27 and Table 28 display the simulation results of TRNSYS and RETScreen, respectively. The Hot Water (HW) Energy use numbers are not in close agreement, as discussed above. The displaced energy, however, is reasonably close; one would not expect them to match perfectly due to the increased precision of TRNSYS. The higher production values predicted by TRNSYS are due in part to the higher HW Energy Use; if there is more energy used to heat water, there is a greater potential for a SDHW system to contribute additional energy. As such, the Solar Fraction, the quotient of Displaced Energy and HW Energy Use is in reasonably close agreement as well.

Table 27. TRNSYS modeled performance in Albany of systems with common tank and fuel type

Sys ID	100	200	300	520	600*	700	820	920	1020
HW Energy Use (kBTU)	24,466	24,466	24,466	24,466	24,466	24,466	24,466	24,466	24,466
Displaced Energy (kBTU)	15,798	15,517	14,051	11,036	11,476	8,002	9,225	12,972	14,673
Solar Fraction	65%	63%	57%	45%	47%	33%	38%	53%	60%

Table 28. RETScreen modeled performance in Albany of systems with common tank and fuel type

Sys ID	100	200	300	520	600*	700	820	920	1020
HW Energy Use (kBTU)	15,720	15,720	15,720	15,720	15,720	N/A	15,720	15,720	15,720
Displaced Energy (kBTU)	12,291	10,796	10,117	10,346	8,350	N/A	7,019	10,779	12,378
Solar Fraction	78%	69%	64%	66%	53%	N/A	45%	69%	79%

ENERGY PERFORMANCE – CONCLUSION

At a typical home in New York State, a Solar Domestic Hot Water (SDHW) system is capable of providing over half of the energy needed to heat water. In the most favorable locations – New York City and Long Island – certain SDHW systems are capable of providing nearly three-quarters of household water heating energy for a typical family. Computer simulations in TRNSYS show the following range of solar fractions in Islip, Long Island: 50%-70% for flat plate technologies, 52%-71% for evacuated tube systems, and 34% for building integrated systems. Jamestown, New York was the least efficient in terms of solar fraction;

[25] If an ASHRAE "Typical Family" was composed of four people, that would easily explain the discrepency with the EIA data, which has an average family size of 2.5 people. If RETScreen hot water energy estimates are exclusive of tank losses and fuel efficiency, this could also account for the discrepency. Since ASHRAE does not provide information about family size, RETScreen gives no information on the assumed tank efficiency, and EIA does not provide the volume of hot water used, it is not possible to compare the assumptions of these three baselines. NOTE: This assessment used RET Screen version 3.1.

computer simulations show the following range of solar fractions in Jamestown: 41%-59% for flat plate, 43%-59% for evacuated tube, and 30% for building integrated.

It can be seen that SDHW system performance varies by climate, but also by a combination of the interplay between collector type, tank configuration, and auxiliary heating fuel. A few key conclusions:

- Evacuated tube collectors provide the best performance per unit area, flat plate the shortest payback, building integrated the longest life.
- A solar supplied pre-heat tank coupled with an instantaneous water heater appears to be the optimal tank configuration.
- Manufacturer specified system designs are not necessarily optimally sized; obtaining performance data specific to a given climate and system is key.
- An external heat exchanger coupled with a single fossil-fuel fired tank does not perform well.
- Similar technologies of collectors, especially with evacuated tubes, can perform quite differently.
- Unglazed building-integrated collectors have more consisent performance throughout the different climate zones analyzed herein.
- Internal heat exchanger systems outperform external heat exchanger systems in terms of energy performance, especially at solar fractions greater than 50%.
- For a given collector type, there are diminishing returns in terms of solar fraction for each additional collector.

Optimal solar fraction for New York State appears to be 75%, which corresponds to a summer solar fraction of 100%. Economically speaking, a solar fraction below 50% for a single family home is challenging to justify in terms of cost, due to high fixed cost and relatively low marginal cost for additional panel and tank capacity.

SECTION 7
ECONOMIC BENEFITS AND COSTS OF SDHW SYSTEMS

LOCAL FUEL COSTS

The costs used for the analysis are presented in Figure 17 below. Electricity is the most expensive fuel per unit of "site" energy, followed by propane, oil, and natural gas. Fuel costs used in the analysis are city-specific and current to 2007. New York State average prices are as follows: $1.27 / therm natural gas, $0.138 / kWh electricity, $2.26 / gallon propane, $2.56/gallon oil. See APPENDIX 4 for additional information.

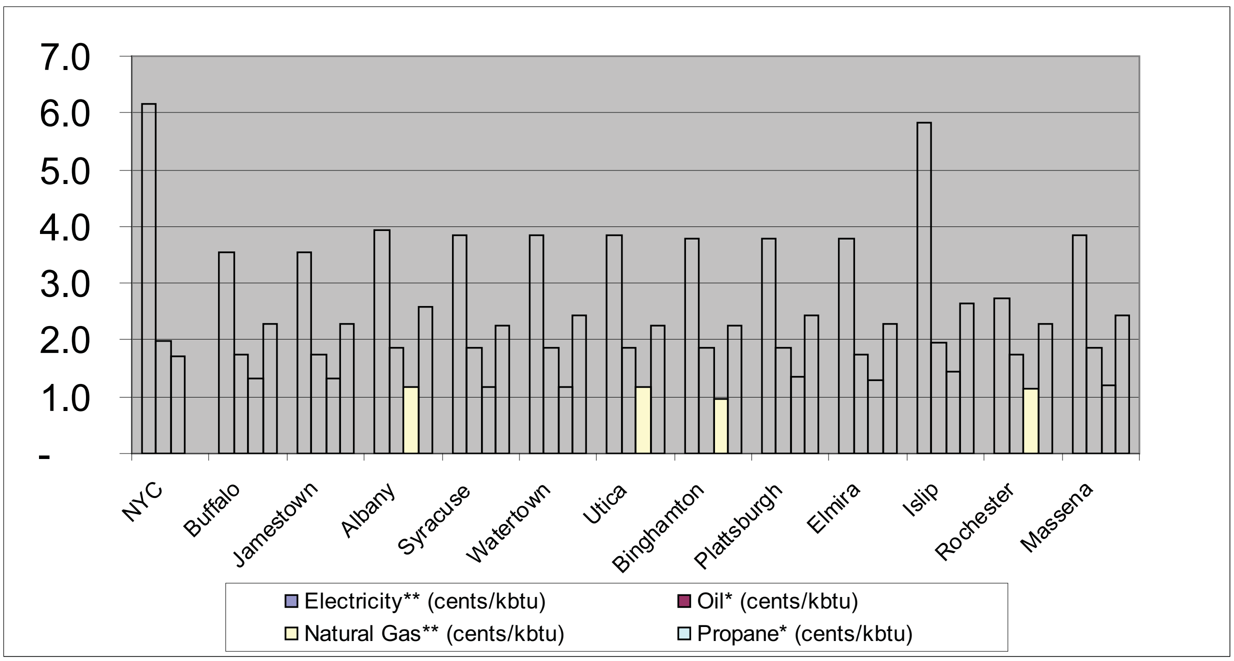

Figure 17 Levelized Residential Cost of Site Energy, in Cents per kBTU

**Note: All Propane and Oil Data is taken from the NYSERDA Historical Weekly Reports for 1/1/07 and Currently Monthly Report for 7/16/07.*

***Note: Electricity and Natural Gas data are taken from the New York State Public Service Commission biannual reports on typical electric and gas bills from the major utilities. The reports include bill data from January 1 and July 1 of each year and are available at (http://www.dps.state.ny.us/TypicalBills.htm). The electric rate for customers in Islip is calculated from the Long Island Power Authority (LIPA) tariff document and information of surcharges from LIPA customer service*

ESTIMATED ECONOMIC BENEFITS

Economic Benefit Matrices are displayed in APPENDIX 5

GEOGRAPHICAL RENDERINGS OF ENERGY PERFORMANCE

On the following pages are selected statewide geographical renderings of economic performance in terms of annual savings and simple payback. A full display of over 70 color maps is available at http://sdhw.brightpower.biz. Matrices of the results can be seen in APPENDIX 5.In Figure 18, the systems generating the highest annual savings for each fuel type are displayed. The first row (left to right) displays the best performing SDHW system with natural gas fired backup (System ID 100) and with electric backup (System ID 101). The second row (left to right) displays the best performing SDHW system with propane fired backup (System ID 102) and with oil backup (system ID 143). All four systems displayed are Flat Plate Model "A".

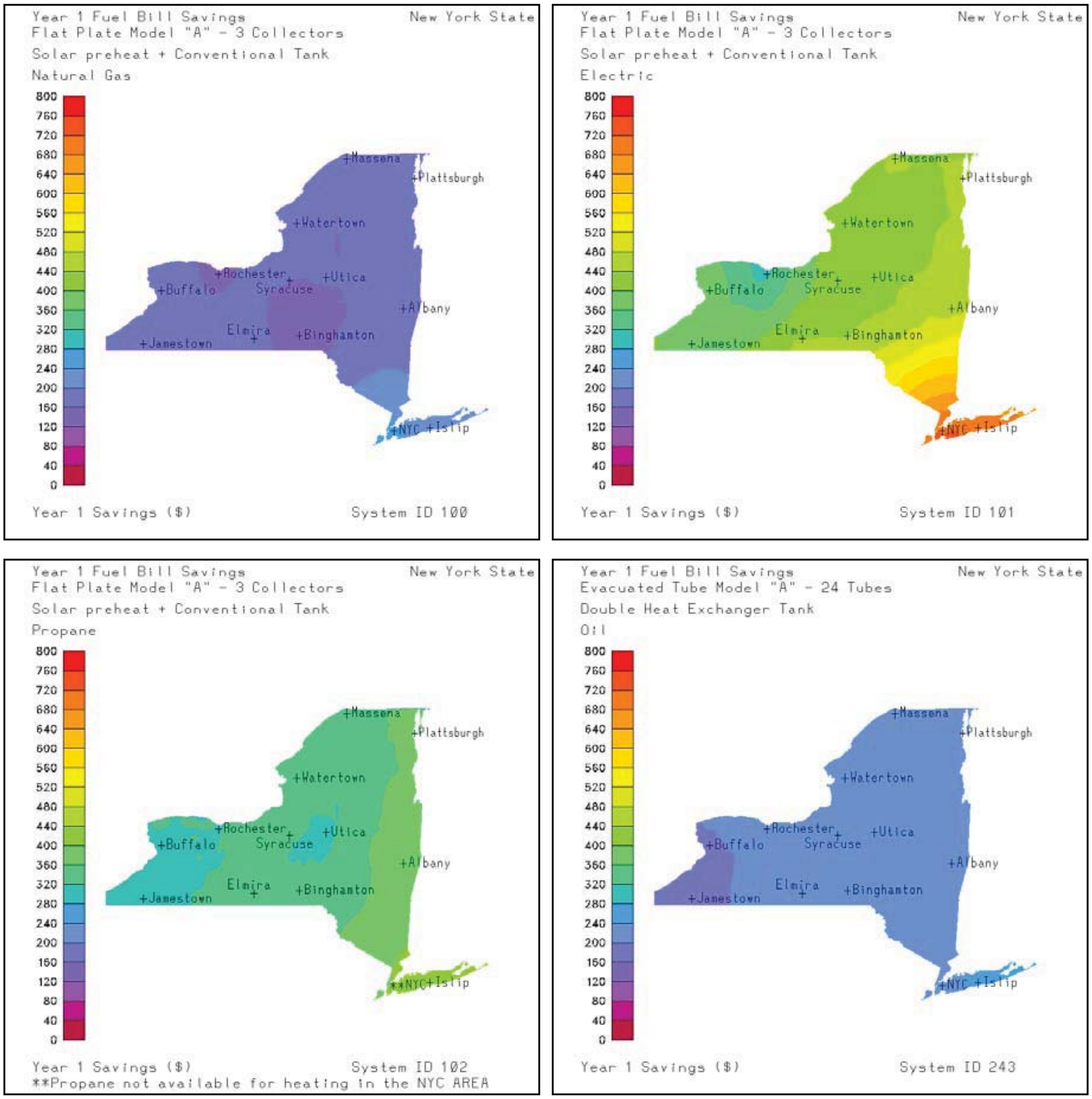

Figure 18. Statewide Renderings of Highest Annual Savings for each Fuel Type

In Figure 19, the systems with the shortest simple payback time (years to recoup investment based solely on fuel bill savings) are displayed. The first row (left to right) displays the best performing SDHW system with natural gas fired backup (System ID 100) and with electric backup (System ID 101). The second row (left to right) displays the best performing SDHW system with propane fired backup (System ID 102) and with oil backup (system ID 143). All four systems displayed are Flat Plate Model "A".

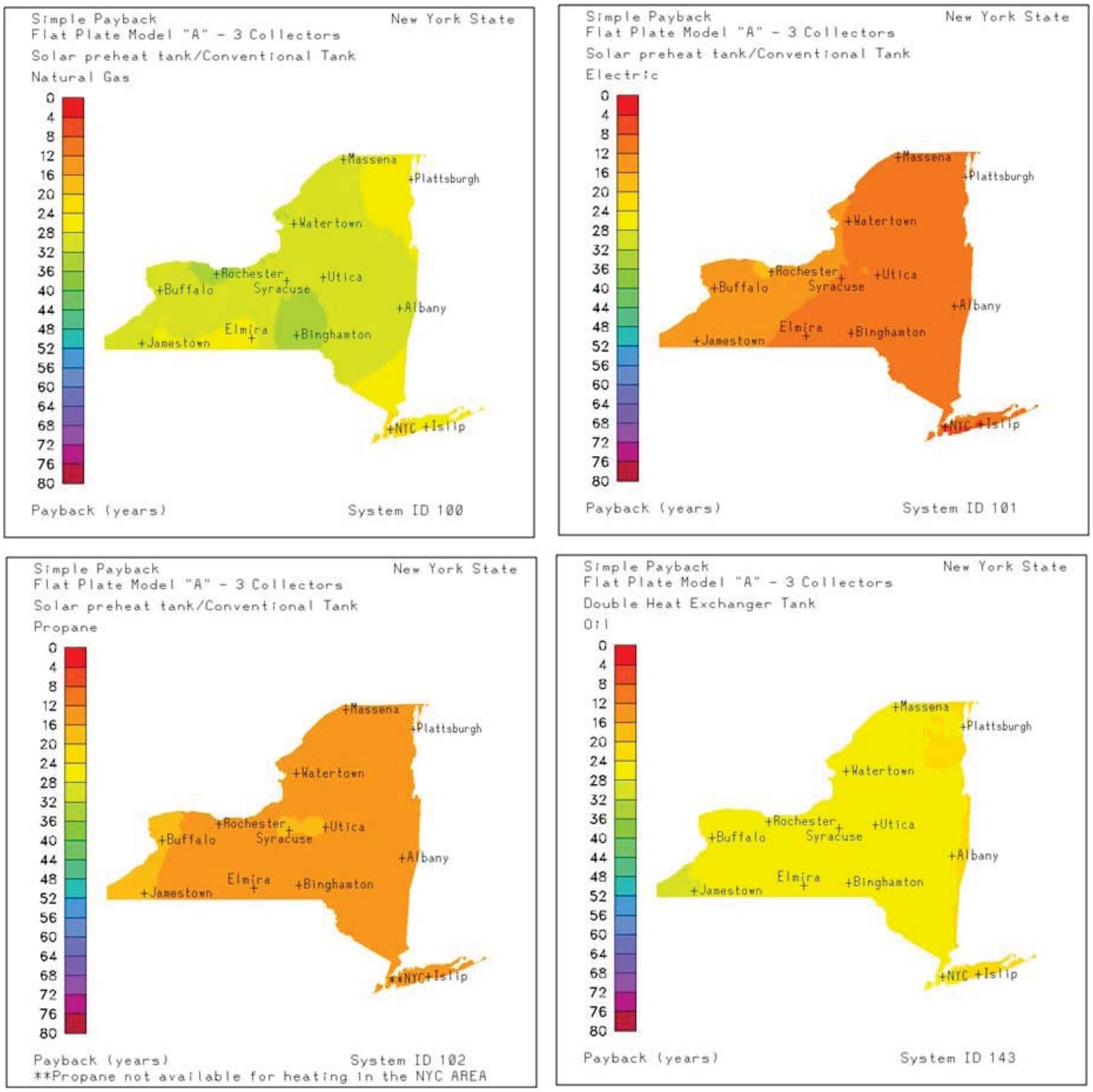

Figure 19. Statewide Renderings of Shortest Payback Time for each Fuel Type

In Figure 20, the highest annual savings for each technology type is displayed. The tank type and fuel type are held constant in these plots; systems with the most common tank arrangement (solar preheat tank with conventional backup tank) and fuel type (natural gas) are displayed. The first row (left to right) displays the best performing Flat Plate system (System ID 100), and the best performing Evacuated Tube system (System ID 200). The second row displays the only building integrated system analyzed in the assessment (System ID 700).

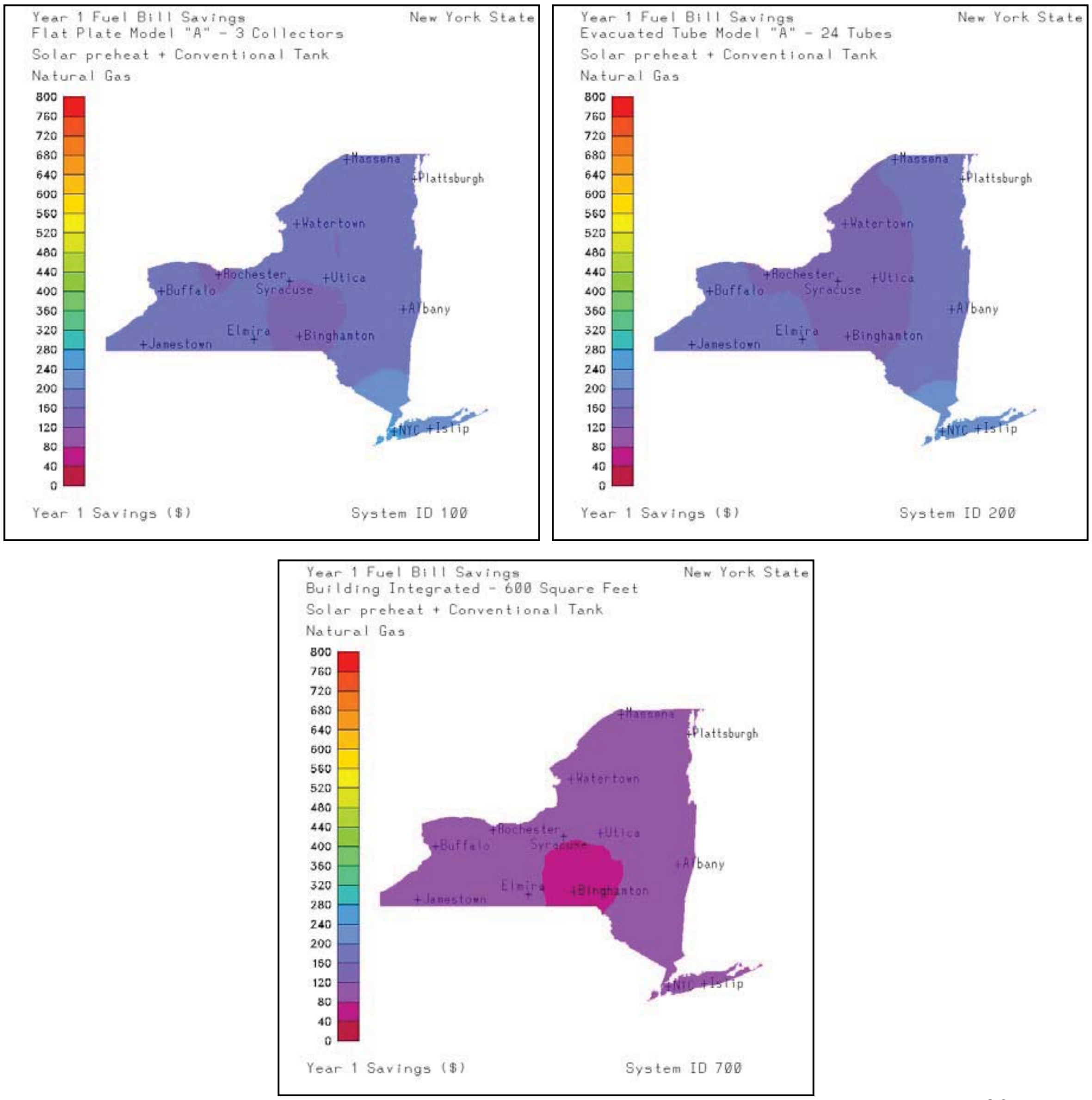

Figure 20. Statewide Renderings of Highest Annual Savings for each Technology Type[26]

[26] For two tank systems co-fired with natural gas backup

In Figure 21, the shortest payback for each technology type is displayed. The tank type and fuel type are held constant in these plots; systems with the most common tank arrangement (solar preheat tank with conventional backup tank) and fuel type (natural gas) are displayed. The first row (left to right) displays the best performing Flat Plate system (System ID 100), and the best performing Evacuated Tube system (System ID 200). The second row displays the only building integrated system analyzed in the assessment (System ID 700)[28].

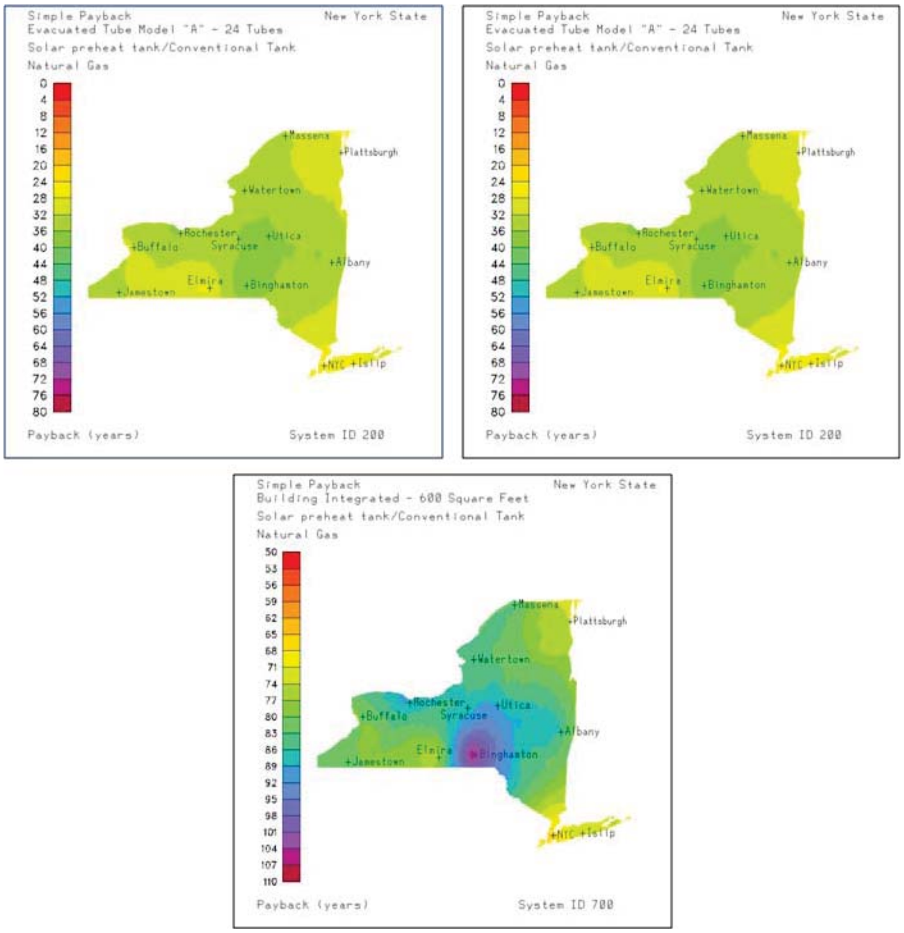

Figure 21. Statewide Renderings of Shortest Payback Time for each Technology Type[27, 28]

ANALYSIS OF ECONOMIC BENEFITS

Economic analysis of the SDHW Systems is presented in this section. Figure 18 and Figure 19 along with Table 29 and Table 30 display the effect of fuel type upon economic performance. Since electricity is the most expensive fuel in terms of cost per on-site unit of energy, SDHW systems with electric backup have the fastest payback and the greatest annual savings. Propane is the second most costly fuel, followed by

---

[27] For two tank systems co-fired with natural gas backup
[28] The rendering of Payback for System ID 700 is the only rendering with a different scale.

oil, and natural gas, and the savings and payback presented below correspond to these costs. These results indicate that homeowners using electricity to heat water are most likely to consider an SDHW system[29].

The systems with the lowest overall annual operating costs are SDHW systems co-fired with natural gas because this is the lowest cost fuel available. System ID 110 realizes the lowest annual operating costs of any system analyzed, due to the particular efficiency of instantaneous water heating.

Table 29. Range of Year 1 Fuel Bill Savings – All Locations, All Systems except 33x, 53x, 7xx

Year 1 Fuel Bill Savings - All Locations				
Fuel Type	**Natural Gas**	**Electric**	**Propane**	**Oil**
Minimum	$73	$204	$207	$181
Maximum	$248	$710	$416	$240

Table 30. Range of Simple Payback – All Locations, All Systems except 33x, 53x, 7xx

Simple Payback (yrs.) - All Locations				
Fuel Type	**Natural Gas**	**Electric**	**Propane**	**Oil**
Shortest	22	8	13	23
Longest	64	28	27	33

The Net Present Value (NPV) for each technology type is displayed in Table 31. None of the twenty-eight systems analyzed (System ID 100) had a positive Net Present Value when compared against a conventional gas-fired hot water tank. Unless additional incentives are provided, solar domestic hot water technology is not likely to be an attractive economic investment to the average homeowner. Table 31 presents information on Net Present Value for SDHW Systems across the State.

Table 31. NPV for single family SDHW systems (New York State Average)[30, 31]

SDHW Tech:	**Flat Plate**		**Evacuated Tube**		**Building Integrated**	
Backup Fuel ↓	Best-in-class	Average	Best-in-class	Average	Best-in-class	Average
Natural Gas	(1,863)	(2,506)	(2,368)	(2,862)	(3,864)	N/A

[29] As discussed above, systems 33x and 55x are non-optimal tank configurations that should not be used in homes; they have been omitted from the below table. The building integrated systems (7xx) have been omitted because their longer payback, and lower annual savings would skew the results since an oil-fired building integrated system was not analyzed.

[30] Net Present Value was calculated with a discount rate of 4.38% (20-year U.S. Treasury Bill as of January 2008), assumed an energy escalation rate of 3%, was exclusive of maintenance cost, and taken over a time horizon equal to twice the warranty period of the collectors. For all collectors except building integrated (50 year time horizon), the time horizon was 20 years. Parentheses indicate negative numbers.

[31] The averages in this table are based upon the twenty-eight system types analyzed in this assessment, excluding sub-optimal tank types x31 and x32. "N/A" is used when only one relevant system is analyzed.

Electric	2,928	978	2,424	1,401	1,370	N/A
Propane	994	(272)	451	106	(838)	N/A
Oil	(1,539)	N/A	(1,726)	(1,943)	N/A	N/A

Table 32 shows the annual performance of all analyzed systems in Albany, a relatively average location in the State in terms of solar radiation and temperature.

Table 32. SDHW Annual Economic Performance in Albany

Collector	Sys ID	Year 1 Savings	Simple Payback (yrs)
Flat A	100	$171	31
	101	$464	11
	102	$392	13
	110	$139	38
	143	$212	25
Evac A	200	$164	35
	201	$459	12
	202	$382	15
	243	$226	26
Evac B	300	$151	39
	301	$424	14
	302	$348	17
	310	$126	47
	330	$53	109
	331	$336	17
	332	$160	36
	343	$210	28
Flat B	520	$105	54
	521	$313	18
	522	$260	22
	530	$45	124
	531	$335	17
	532	$135	41
Evac C	610	$99	52
	641	$358	14
Bldg Int.	700	$86	87
	701	$243	31
	702	$198	38
Flat C	821	$264	17
Flat C	920	$134	38
	921	$382	13
	922	$316	16
	931	$363	17
Flat C	1021	$436	14

Flat Plate Model "A" (Sys ID 100) realizes the highest annual savings and shortest payback for a common tank and fuel type. Within Evacuated Tube collectors, Model "A" is most cost effective, and trails Flat Plate Model "A" only slightly. Figure 20 and Figure 21 along with Table 33 and Table 34 display the economic performance of solar collectors for a common tank and fuel type. With the exception of building integrated systems (7xx systems), there is a strong correlation between the net aperture area of each system and the economic performance, similar to the correlation between solar fraction and net aperture area presented in Table 26. Evacuated tube systems perform somewhat better than flat plate systems, by one to three dollars per square foot. The building integrated system analyzed realizes a lower overall and per square foot fuel bill savings. Still, it is important to remember that the building integrated system has an estimated system life of 50 years, while the other systems have a life of 20 years.

Table 33. Annual Fuel Bill Savings of selected SDHW systems for two tank arrangement co-fired with natural gas

Sys ID	100	200	300	520	600	700	820	920	1020
Albany	$171	$164	$151	$105	$119	$86	$93	$134	$153
Binghamton	$130	$125	$113	$75	$86	$64	$66	$98	$114
Buffalo	$183	$178	$162	$115	$129	$92	$100	$144	$165
Elmira	$186	$181	$162	$113	$126	$91	$97	$143	$166
Islip	$219	$211	$195	$131	$153	$105	$119	$172	$196
Jamestown	$179	$174	$157	$112	$124	$90	$97	$140	$161
Massena	$169	$164	$149	$103	$117	$86	$89	$130	$150
New York City	$248	$237	$218	$150	$171	$119	$135	$194	$221
Plattsburgh	$197	$191	$176	$125	$140	$99	$106	$154	$177
Rochester	$159	$155	$141	$103	$113	$83	$89	$127	$144
Syracuse	$161	$154	$141	$99	$112	$84	$87	$126	$144
Utica	$159	$152	$139	$97	$109	$83	$85	$123	$142
Watertown	$161	$154	$141	$99	$112	$84	$87	$126	$144
NYS Average	$179	$172	$157	$110	$124	$90	$96	$139	$160

Table 34 shows the annual fuel bill savings for a common tank and fuel type (as above), but normalized per square foot of collector. It is interesting to note that the value generated per square foot diminishes with the addition of more collectors – as is visible by comparing 820, 920, and 1020 in the table below.

Table 34. Annual Fuel Bill Savings per square foot of selected SDHW systems for two tank arrangement co-fired with natural gas[32]

Sys ID	100	200	300	520	600	700	820	920	1020
Albany	$2.47	$2.82	$2.57	$2.12	$2.94	$0.14	$3.19	$2.31	$1.76
Binghamton	$1.88	$2.14	$1.92	$1.52	$2.12	$0.11	$2.28	$1.69	$1.31

32 The Systems 600, 820, and 1020 are not offered by the manufacturers. For purposes of levelized comparison in this table, Annual Fuel Bill Savings of these systems was estimated by the following equations:

$Savings_{600} = Savings_{300} * Savings_{610} / Savings_{310}$

$Savings_{820} = Savings_{920} * Savings_{821} / Savings_{921}$

$Savings_{1020} = Savings_{920} * Savings_{1021} / Savings_{921}$

Buffalo	$2.65	$3.05	$2.77	$2.33	$3.19	$0.15	$3.45	$2.49	$1.89
Elmira	$2.70	$3.09	$2.77	$2.28	$3.12	$0.15	$3.34	$2.47	$1.91
Islip	$3.17	$3.61	$3.32	$2.65	$3.78	$0.17	$4.10	$2.96	$2.25
Jamestown	$2.59	$2.97	$2.68	$2.26	$3.08	$0.15	$3.33	$2.42	$1.86
Massena	$2.44	$2.80	$2.54	$2.08	$2.89	$0.14	$3.08	$2.25	$1.72
New York City	$3.58	$4.06	$3.71	$3.04	$4.23	$0.20	$4.64	$3.35	$2.55
Plattsburgh	$2.85	$3.27	$2.99	$2.52	$3.46	$0.16	$3.66	$2.66	$2.03
Rochester	$2.30	$2.66	$2.40	$2.08	$2.80	$0.14	$3.08	$2.20	$1.66
Syracuse	$2.33	$2.64	$2.41	$2.01	$2.77	$0.14	$3.00	$2.17	$1.65
Utica	$2.30	$2.60	$2.36	$1.97	$2.69	$0.14	$2.94	$2.13	$1.63
Watertown	$2.32	$2.64	$2.41	$2.01	$2.77	$0.14	$3.01	$2.17	$1.65
NYS Average	$2.58	$2.95	$2.68	$2.22	$3.06	$0.15	$3.32	$2.41	$1.84

* Estimated Savings, see Equation 4 below Table 33

Table 35 displays the annual fuel bill savings for a common tank and fuel type. While the larger 1020 system produces less value per square foot, it also costs less to install per square foot. There is, of course, a balancing point at which it no longer makes sense to install an additional collector: for New York State the optimal size appears to be two collectors. This can be seen by comparing the payback of systems 820, 920, and 1020 in Table 35 – the payback is shortened by adding a second collector (920), but then lengthened by adding a third collector (1020). This reversal is due to the diminishing returns of adding additional collectors to solar thermal systems – as described in the energy section, each additional collector added to a system produces less energy than the previous one.

It is interesting to note that while larger systems cost more to install, they also recoup the initial investment more quickly. This is because the marginal cost of installing the additional capacity is smaller than the fixed cost of completing a smaller installation.

Table 35. Simple Payback of selected SDHW systems for two tank arrangement co-fired with natural gas[33]

Sys ID	100	200	300	520	600	700	820	920	1020
Albany	31	35	39	54	44	87	48	38	41
Binghamton	36	39	45	64	54	106	57	46	50
Buffalo	29	32	36	49	40	81	44	35	38
Elmira	25	27	31	43	37	74	39	31	34
Islip	25	28	31	45	35	74	38	31	33
Jamestown	29	33	37	50	42	83	45	36	39
Massena	29	33	37	51	42	83	46	37	40
New York City	22	25	28	39	31	65	34	27	29
Plattsburgh	25	28	31	42	35	73	39	31	34
Rochester	33	37	42	55	46	91	49	40	43

[33] The Systems 600, 820, and 1020 are not offered by the manufacturers. For purposes of levelized comparison in this table, Payback of these systems was estimated by the following equations:

$Payback_{600} = Payback_{300} * Payback_{610} / Payback_{310}$

$Payback_{820} = Payback_{920} * Payback_{821} / Payback_{921}$

$Payback_{1020} = Payback_{920} * Payback_{1021} / Payback_{921}$

Syracuse	32	36	40	54	45	87	49	39	42
Utica	32	37	41	56	47	89	50	41	43
Watertown	31	35	39	53	44	85	47	39	42
NYS Average	29	33	37	50	42	83	45	36	39

ECONOMIC BENEFITS - CONCLUSIONS

According to this analysis, "flat plate" technology is the most cost-effective collector technology. This is true across all fuel types. A flat plate collector system (System ID 101) installed in New York City with electric resistance backup heating, yielded a simple payback net of tax credits of 8- to- 21 years and Net Present Value (NPV) of $2,600 to $6,800 over the course of system life. Shortly behind that in terms of cost effectiveness was Evacuated Tube Model A (System 2xx), followed by Evacuated Tube Model B (System 3xx), two collector Flat Plate Model C (System 9xx), three collector Flat Plate Model C (System 10xx), Evacuated Tube Model C (System 6xx), one collector Flat Plate Model C (System 8xx), Flat Plate Model B (System 5xx), and the Building Integrated System (7xx). It is important to remember that the building integrated system has an estimated system life that is over twice as long as the other systems, allowing the system more time to recoup the initial investment. Perhaps, as important as choosing the right collector model, is making sure that it is sized correctly. Generally speaking, the most cost effective systems were those that maximized net aperture area with the constraint of peak summer production that did not exceed the coincident summer domestic hot water load.

The above tables indicate that energy cost is at least as important as system type in determining the economic performance of SDHW systems. In terms of payback, the best-in-class systems range from eight years to 23 years[34]. Similarly, the payback of natural gas systems at the "best" location of New York City ranges from 22 years to 39 years.

The payback times displayed above are exclusive of maintenance costs and inclusive of tax credits – in other words they are as "optimistic" as possible[35]. Yet, only in the case of SDHW systems backed up with electricity does payback drop below 10 years, and even then only in locations with ample natural gas supply unlikely to have expensive electric backup heat. This indicates that the payback time for almost all systems is longer than the manufacturer's collector warranty.

SDHW systems with natural gas as a backup fuel display a negative Net Present Value, regardless of technology type. This indicates that current government incentives are insufficient to bring the cost of SDHW technology to a level that most consumers would consider cost effective. Consumers using

[34] displayed in the "shortest" row of Table 30
[35] Note that payback net of maintenance costs was calculated for each system. See APPENDIX 5.

electricity or propane for water heating, who have a tolerance for long term investments, may find some systems to be attractive investments. Most homeowners, however, use natural gas to heat water in New York State.

There is significant variability in system performance within a technology type. Payback time ranged by about 20 years between the best-in-class and worst-in-class performers for both flat plate and evacuated tube technologies. This indicates that consumers should shop around to obtain a system that is well designed for their homes. The best performing systems used cost-effective collectors, thermally optimal tank configurations (with stratification), and were designed to meet 100% of the average summer load. The worst performing systems analyzed in this assessment were either undersized or had sub-optimal tank configurations. Such non-optimal tank configurations include those in which an external heat exchanger is directly attached to a conventional natural gas or propane hot water heater.

System sizing is also an important consideration from an economic standpoint as seen by the analysis of Flat C systems 820, 920, and 1020. From this assessment's results, it would be more cost effective to install the 2 collector (920) system than the 1 -collector (820) or 3 collector (1020) system. The reason for this has to do with the balance of two factors:

- The decreasing marginal cost of installation for each additional collector
- The decreasing energy savings associated with each additional collector

When the marginal savings become less than the marginal cost, that additional collector does not make economic sense, i.e. each additional panel costs less, but produces less energy; at some point, adding additional panels is not cost effective.

New York City appears to be the most favorable market in New York State for SDHW on single family homes, due to relatively high energy costs and levels of solar irradiation. For systems with natural gas providing backup heat, the simple payback against a conventional natural gas tank baseline is 22-39 years for flat plate systems, 25-38 years for evacuated tube systems, and 65 years for building integrated systems. The low natural gas costs and lack of solar resource make Binghamton the least favorable market in the State with a simple payback of 36-64 years for flat plate, 39-63 years for evacuated tube, and 106 years for building integrated systems with natural gas fired backup.

SECTION 8

BARRIERS TO THE SDHW INDUSTRY AND STRATEGIES FOR FUTURE SUCCESS

METHODOLOGY

Manufacturers, distributors, and installers were interviewed over the phone and asked to identify major barriers to SDHW proliferation in New York. The purpose of the interview was to identify the major barriers to SDHW proliferation, and the results are qualitative, rather than quantitative. The primary question posed was: "In your experience, what are three major barriers to the proliferation of SDHW in New York State?"

Follow up questions were used to clarify interviewee responses. Still, the interviewer was careful not to influence the opinions of the interviewee. While participant comments varied greatly, those with similar underlying themes have been grouped and summarized in the paragraphs below. A separate section contains the author's opinions regarding the major barriers to SDHW proliferation, based on their experiences installing SDHW systems in the New York Metropolitan area.

The responses presented in this section represent the opinions of manufacturers/distributors and installers and are based on experience and personal opinions. Survey participant involvement in the SDHW marketplace varies greatly, from 2 - 3 installations total to 60 – 120 installations per year. For the purposes of this qualitative survey, responses from more active participants were weighted equally with responses from less active participants.

MARKET OVERVIEW

Before interview responses are summarized, a brief market overview is presented. There were 499,000 sq. ft. of solar collectors delivered to New York State in 2005, corresponding to 3% of the U.S. market[36]. Nationally, the solar collector market was 94% for Pool Heating and 4% Hot Water heating. The hot water heating market is further segmented to 75% Flat Plate, 21% ICS/Thermosiphon, and 3% Evacuated Tube[37]. While similar information could not be located for New York State, if the New York State solar thermal market corresponded to the national market, then 4% of solar thermal installations would have been for hot water. This would be the equivalent of roughly 20,000 square feet of solar collectors, corresponding to 289

[36] "Shipments of Solar Thermal Collectors Ranked by Origin and Destination," US Department of Energy, Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_5.html

[37] "Shipments of Solar Thermal Collectors by Market Sector, End Use, and Type," US Department of Energy, Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_10.html

three panel Flat Plate A systems or 404 two panel Flat Plate B systems. This analysis indicates that there were probably roughly 300-400 installations completed in 2005 for SDHW in New York State[38].

SDHW BARRIERS

System Costs

The costs associated with the purchase and installation of a SDHW system far exceed those associated with the purchase and installation of a conventional hot water heater, often leaving interested customers with "sticker shock." The installed cost of a SDHW system can often be orders of magnitude greater than a conventional hot water heater, making a SDHW system sale very difficult, even with the reduced annual operating expenses. The low initial cost of a conventional hot water heater relative to the high initial cost of a SDHW system creates a significant obstacle to the cost-conscious homeowner.

Energy Costs

The cost of energy has a direct impact on SDHW proliferation. Although energy costs have been rapidly escalating, they have yet to reach the level necessary to drive the SDHW market. Cost-conscious customers interested in purchasing a SDHW system have a difficult time justifying the purchase of a SDHW system relative to their annual hot water energy costs. This is compounded by the continued costs associated with operating a conventional backup water heater and the limited solar fraction attainable during winter months in even the warmest parts of the state. As energy prices continue to escalate, installing a SDHW system will become a more cost-effective solution to reducing a customer's energy bill. Nevertheless, present day sales of SDHW systems in New York State remain low due to high SDHW system costs relative to statewide energy costs. A long payback period for the installation of a SDHW system is a major deterrent to the proliferation of SDHW in New York State.

Financial Incentives

In New York State today, federal and state tax credits are the only financial incentives available to customers interested in purchasing a SDHW system. For residential customers, there is a federal tax credit for 30% of the installed system cost, with no maximum, and a New York State tax credit of 25%, up to a maximum of $5,000. For commercial customers, there is a federal tax credit for 30% of the installed system cost, with no maximum, and no New York State tax credit. There is no cash incentive available for SDHW systems through New York State. Conversely, the State offers an incentive of up to $4.00 per watt of installed capacity, or approximately 50% of the installed system cost, for solar PV systems.

---

[38] If the NYS Solar thermal market was 40% hot water instead of 4%, that number would be 3,000-4,000 installations in 2005. On the other hand, if large-scale commercial installations were more common, the total number of installations completed would be fewer. Without more information regarding the end uses of collectors, a definitive number is not attainable.

While helpful, tax credits are "credits" that are deducted from a customer's tax liability at the end of the fiscal calendar year and are a less effective sales tool than the NYSERDA incentives available to New York State solar PV customers. Additionally, for residential customers, the tax credit maximums limit the amount of tax credits that can be claimed.

Of the manufacturer/distributors and installers who participated in the interview, there is no consensus regarding SDHW financial incentives. A majority believe that without an incentive for SDHW systems, customers are more apprehensive about SDHW as a viable solar technology. Others feel that the lack of financial endorsement is undermining the legitimacy of a proven solar technology. Customers interested in a SDHW system may be tempted to change to a solar PV system because of the lucrative financial incentives; consumers like receiving discounts. If New York State is willing to offer financial incentives for solar PV, why not offer financial incentives for SDHW? This opinion, however, is not shared by all manufacturers/distributors and installers. A minority think that the SDHW industry is better off without financial incentives. Financial incentives can increase the administrative costs involved with the installation of SDHW systems. There is concern that a New York State funded SDHW incentive program will create bureaucratic obstacles and red tape, making it difficult for SDHW installers to keep their costs low.

Customer Education and Awareness

Because SDHW technology has limited market penetration, it is a technology that is often misunderstood by the average homeowner. As solar power begins to take center stage in the public eye, there is confusion surrounding the difference between solar photovoltaic technology and solar hot water technology. Many customers are unaware of the differentiating factors that make these two technologies distinct. Misinformed customers with high expectations are sometimes disappointed after learning of the limitations of a SDHW system. Some common misconceptions include:

- A SDHW system entirely replaces a conventional hot water heater
- A SDHW system generates electricity
- A SDHW system can be used to heat conditioned spaces

Furthermore, SDHW technologies have garnered a poor reputation from installations that resulted from the 1979 energy crisis. The previous nascent industry shrank considerably after financial incentives for the technology were repealed. Existing installations were often not maintained, and very few repairmen possessed the necessary skills, resulting in SDHW systems in disrepair. While the reputation of SDHW has improved significantly since that time, the lingering sentiment is a barrier to the proliferation of SDHW technology.

Installer Competency

Due to the limited number of experienced SDHW installers and the recent increase in homeowner demand for this technology, there are unqualified installers entering the SDHW marketplace. In general, skilled installers make a concerted effort to ensure a well trained field crew, comfortable with the technology and the equipment. Conversely, unproven installers have little to no experience with SDHW systems and rely upon on-the-job training and trial and error. Installations such as these can produce mixed results, and in the worst instances, a poorly installed SDHW system. While some training exists through manufacturers and distributors, it is insufficient for the growing demand for SDHW installations.

The Author's Experience

Based on the installations undertaken in the New York Metropolitan area, the authors of this report noticed a number of obstacles. Local codes and ordinances vary widely throughout the State of New York. In certain areas, the construction code requires a licensed plumber to install a SDHW system. Since plumbers are expensive, this results in increased labor costs. In New York City, plumbers are almost always busy, especially the more experienced and well qualified plumbers; they have little financial motivation to learn the intricacies involved with SDHW technology installations.

In addition to requiring a licensed plumber, planned SDHW installations on landmark buildings are subject to review by The New York City Landmarks Preservation Commission. The Landmarks Preservation Commission is the New York City agency that is responsible for regulating changes to the city's landmarks and the buildings in the city's historic districts. A similar commission exists for many municipalities across New York State. A proposed SDHW system installation on a landmark building is generally viewed as incongruent with the visual character of a historic district, and many proposed installations are denied.

SDHW STRATEGIES FOR FUTURE SUCCESS

System Costs, Energy Costs, and Financial Incentives

Survey responses identified three factors that drive the economics of SDHW throughout New York State: SDHW installation costs, energy costs, and SDHW financial incentives. A combination of lower SDHW customer costs, higher energy prices, and better financial incentives would help jumpstart the SDHW industry in New York State.

Of the three economic components addressed, financial incentives are the most pivotal to the success of SDHW. While energy costs are projected to increase in the coming years, higher energy costs alone will not drive the SDHW industry. Furthermore, energy costs are determined by the free market and cannot be readily controlled. Because SDHW technology has yet to obtain a solid foothold in New York State, SDHW installation costs remain high. Manufacturers/distributors and installers are limited in their ability to lower costs due to volume constraints. Increased sales volume can drive down the cost of a SDHW system, thereby leveraging incentive dollars to create additional value.

Financial incentives would help to bolster the New York State SDHW industry by bringing SDHW technology within reach of cost-conscious homeowners and businesses. A financial incentive would improve the economics of a SDHW system by reducing the payback period and easing the financial burden for interested customers. The NYSERDA-funded solar PV incentive program has been successful at bolstering the solar PV market throughout New York State. A similar incentive program could grow the market for SDHW technology in the State.

The results of this assessment could be used to craft a policy on incentives that would at least create a positive NPV for SDHW systems backed up with natural gas water heating. According to this analysis, an additional incentive of $1,900 per system would accomplish this. A second issue is reducing the payback time – the best-in-class flat plate system has a simple payback of 29 years for an average location in New York State. Each $150 - $200 in incentive would reduce the payback by one year; therefore to achieve a payback within the typical warantee period of 10 years an incentive of roughly $3,300 per system would be required. This incentive would be in addition to the federal and State tax credits available in 2008.

Many renewable energy incentive programs are moving toward performance-based incentives. These incentives are particularly well suited when the value of the commodity produced fluctuates throughout the day, as in the case of electricity. This strategy seems less viable for SDHW technology due to the relatively low system cost and the absence of electricity grid interaction for most SDHW systems. Additionally, performance- based incentives are expensive to implement due to the high cost of monitoring. As an alternative, incentives proportional to capacity reported by Solar Rating and Certification Corporation (SRCC) ratings[39] could be implemented. Reductions in efficiency due to shading and non-optimal orientation could also be accounted for in calculating any incentive by requiring an on-site shading study. A capacity based incentive for SDHW could effectively add value to an SDHW system, while keeping administrative costs to a minimum.

In addition to the monetary benefits, financial incentives can also have a positive psychological impact on interested customers. A financial incentive funded by the State of New York works to legitimize SDHW technology. With the backing of the State of New York, customers will likely be reassured of the benefits of SDHW.

Customer Education and Awareness

Responses recorded from survey participants pinpointed education and awareness as a key component to the success of the SDHW industry. An educated public will better understand the strengths and weaknesses of SDHW systems, curbing unrealistic expectations and the spread of misinformation. Effective public campaigns funded by NYSERDA, such as "ENERGY STAR® Products and Marketing (ESPM) Program, and the Stay Cool!® Program, were designed to influence decisions regarding electricity use and reduce households' energy bills. Successful programs such as these can be used as a model for effectively promoting SDHW technology.

Installer Competency

SDHW technology requires competent installers who can specify, install, and maintain SDHW hot water systems. While typical system installations draw upon basic plumbing skills, field installers need to be familiarized with the technology-specific installation procedures. Some manufacturers and/or distributors are already offering limited installation training for their installers. By offering additional training seminars, installers can get hands-on training in a controlled setting, rather than at a customer's facility. Experienced installers with adequate training will help to build consumer confidence in SDHW technology by ensuring a properly installed system.

The North American Board of Certified Energy Practitioners (NABCEP) is an organization that could help certify qualified installers. NABCEP is a volunteer board of renewable energy stakeholder representatives. Its mission is to support and work with the renewable energy and energy-efficiency industries, professionals, and stakeholders to develop and implement quality credentialing and certification programs

[39] SRCC is an organization that publishes performance ratings for solar collectors and systems.

for practitioners. While certification is not a guarantee of quality, it does indicate that the installer has met established standards and requirements. Since it is voluntary, an installer awarded the NABCEP credential demonstrates a high level of dedication and commitment to the profession.

If financial incentives for SDHW systems become available in New York State, one way to increase quality would be to allow only a short list of eligible installers to have access to the available funds. As with NYSERDA PON 1050, The Solar Electric Incentive Program, eligibility could be determined by adequate experience and insurance policies. Creating a short list of eligible installers keeps the quality of the installation high and limits the possible abuse of funding. Augmenting this list by indicating which installers are NABCEP certified would further help in differentiating between the experienced and the inexperienced.

SECTION 9

BENEFITS OF A SDHW MARKET TO NEW YORK STATE

The benefits of a robust SDHW market to New York State include an increase in jobs, a reduction in non-renewable energy use, and the potential for reduced energy costs. Assuming that 1.2 million households[40] in New York State will be able to reduce their fossil fuel consumption for DHW by 50% by using SDHW systems, this would yield energy savings of 171 million kWh of electricity, 6.5 billion cubic feet of natural gas, and 25 million gallons of fuel oil annually[41]. Furthermore, a blossoming SDHW industry would create jobs. Estimates of hours per system are provided in Table 36 below. Contracting and back office work is excluded from job growth figures, although such job growth may be substantial.

Table 36. Estimated time to install & maintain a typical SDHW system

Labor Type	hours
Plumbing	30
SDHW Tech – install collectors on roof	90
SDHW Tech – maintain over life of system	25

Given the estimates in Table 36, estimated jobs created at different SDHW market penetration levels are shown in Table 37 below.

Table 37. Job years created in New York State at various levels of market penetration[6, 42]

Market Penetration Level:	0.1%	0.5%	2.5%
Systems Installed	**1167**	**5833**	**29167**
Plumbing	18	88	438
SDHW Tech - install	53	263	1313
SDHW Tech - maintain	15	73	365
TOTAL	**92**	**458**	**2290**

Even at relatively low levels of market penetration, a significant number of new jobs would be created by the proliferation of SDHW systems across the state. This would involve a combination of a new "green collar" workforce of SDHW Techs as well as an expansion of the existing trades of plumbing and contracting.

[40] Due to shading, inadequate load, or other reasons, only 1.2 million of the 7 million households in New York State are assumed to be eligible homes.
[41] Based on 2001 water heating data referenced earlier, assuming the proportional distribution of electricity, gas and oil fired water heating as in the 2001 EIA data
[42] Percentages given are of homes eligible to receive installations in New York State.

Consumers are apt to choose the lowest cost option for water heating, which is presently conventional natural gas water heating. An appropriately sized incentive could change this picture, by making the effective cost to heat water with an SDHW system less than that of natural gas. Then, this would grow demand for the technology, which should allow economies of scale to reduce prices. This idea is presented graphically in Figure 3.

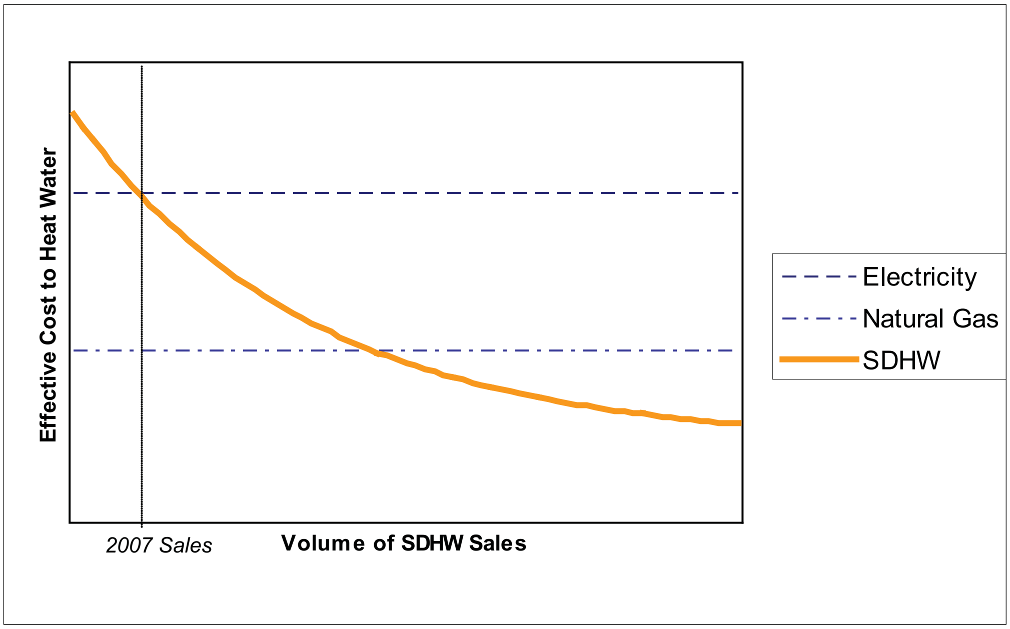

Figure 22. Effective Cost to Heat Water with Solar, Electricity, and Natural Gas (hypothetical)

Incentive levels could be tapered as the price of SDHW systems decreases. Depending upon the scale of the SDHW market, a robust SDHW market in New York State could reduce the cost for heating water to all New Yorkers. A robust SDHW market is also a hedge against the rising prices of electricity, natural gas, propane, and oil – SDHW systems represent energy independence which corresponds to energy security.

BIBLIOGRAPHY

ASHRAE. "Service Water Heating." In *HVAC Applications Handbook of 2003*, Chapter 49. Atlanta: ASHRAE Publications, 2003.

Biaou, A., Bernier, M. *Domestic Hot Water Heating in Zero Net Energy Homes.* Montreal: Department de Genie Mecanique, Ecole Polytechnique de Montreal, 2005.

Builders Websource. "Tankless Water Heaters," Builders Websource. http://www.builderswebsource.com/techbriefs/tankless.htm (accessed 2007).

Burch, Jay, Jim Salasovich, and Tim Hillman. "An Assessment of Unglazed Solar Domestic Water Heaters." Presented at the annual conference for the American Solar Energy Society 2005, Orlando, Florida, August 6-12, 2005.

de Winter, Francis. "Solar Water Heating With Backup Heating: A Review". Presented at the annual conference for the American Solar Energy Society 2005, Orlando, Florida, August 6-12, 2005.

Energy Information Administration. "Shipments of Solar Thermal Collectors by Market Sector, End Use, and Type." US Department of Energy, Energy Information Administration. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_10.html (accessed 2007).

Energy Information Administration. "Shipments of Solar Thermal Collectors Ranked by Top 5 Origins and Destinations." US Department of Energy, Energy Information Administration. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_4.html (accessed 2007).

Energy Information Administration. "Table CE1-7c. Total Energy Consumption in U.S. Households by Four Most Populated States, 2001." U.S. Department of Energy. http://www.eia.doe.gov/emeu/recs/recs2001/ce_pdf/enduse/ce1-7c_4popstates2001.pdf (accessed 2007).

Energy Information Administration. "Table CE4-7c. Water-Heating Energy Consumption in U.S. Households by Four Most Populated States, 2001." U.S. Department of Energy. http://www.eia.doe.gov/emeu/recs/recs2001/ce_pdf/waterheat/ce4-7c_4popstates2001.pdf (accessed 2007)

FAFCO. "How FAFCO Solar Hot Water Systems Work." Chico, CA: FAFCO. http://fafco.com/SolarHotWater/How-FAFCO-Solar-Products-Work.html (accessed 2007).

National Renewable Energy Laboratory (NREL) *Solar Radiation Data Manual for Flat Plate and Concentrating Collectors*. Report NREL/TP-463-5607, 1994, http://rredc.nrel.gov/solar/pubs/redbook/HTML/ (accessed 2007).

Natural Resources Canada. "RETScreen International Overview." Natural Resources Canada. http://www.retscreen.net/ang/centre.php (accessed 2007).

New York State Department of Labor. “Captial District Workforce and Industry Data.” New York State Department of Labor. http://www.labor.state.ny.us/workforceindustrydata/index.asp?reg=cap (accessed 2007).

New York State Department or Labor. “Prevailing Wage Rates for 07/01/2007 – 06/30/2008.” New York State Department of Labor, 2008. http://wpp.labor.state.ny.us/wpp/viewPrevailingWageSchedule.do?county=87 (accessed 2008).

Perez, R. “A Time Series Generator. Technical Status Report No.3.” National Renewable Energy Laboratory (NREL) subcontract AXE-0-30070-01. Golden: NREL, 2000.

Schuco. "Solar Tank 80 HE-2 / 105 HE-2 Operation and Installation Manual." Newington, CT: Schuco, 2006.

Solar Rating and Certification Corporation (SRCC). “Directory of SRCC Certified Solar Collector Ratings.” Cocoa, Florida: 2007.

Thermal Energy System Specialists (TESS). http://www.tess-inc.com (accessed 2007).

The Weather Channel. Data for Old Forge, NY & Massena, NY. The Weather Channel. http://www.weather.com (accessed 2007).

US Department of Energy. “EERE Consumer’s Guide: Heat Exchangers for Solar Water Heating Systems.” US Department Of Energy, Energy Efficiency and Renewable Energy. http://www.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12930 (accessed 2007).

U.S Department of Labor. “Quarterly Census of Employment and Wages.” U.S. Department of Labor, Bureau of Labor Statistics, http://data.bls.gov/PDQ/outside.jsp?survey=en (accessed 2007).

Wilcox, S., M. Anderberg, R. George, W. Marion, D.l Myers, D. Renné, N. Lott, T. Whitehurst., C. Gueymard, R. Perez, P. Stackhouse and F. Vignola. *Completing Production Of The Updated National Solar Radiation Database For The United States*. Boulder, CO: American Solar Energy Society, 2007.

APPENDIX 1 – ADDITIONAL INFORMATION ON DESIGN FACTORS

Collector Type

In addition to the flat plate and evacuated tube collectors mentioned in the solicitation, we recommend one more:

Building-integrated SDHW (Bi-SDHW)

Building integration of solar photovoltaics (PV) has been popular for some time. Solar thermal building-integrated solutions are somewhat less common. Bi-SDHW systems can use a specially-constructed metal or slate roof as an unglazed solar thermal collector. Bi-SDHW systems should be represented in the assessment because they are commercialized, achieve longer lifetimes through installation behind the envelope with durable cross-linked polyethylene tubing, and overcome the aesthetic concerns that could otherwise hinder the implementation of SDHW in New York State.

Tank Type/Arrangement

We recommend adding two variations to the modeled tank types to more accurately reflect the diversity of water heating appliances and configurations in use in New York State. Since tank arrangements are specific to certain manufacturer design, the only tank types analyzed for a given manufacturer will be those they offer on the market.

- Single Tank – Electric or Boiler-fed; internal or external heat exchanger
- Two Tank – with conventional tank or instantaneous (tankless) hot water heater; internal or external heat exchanger, drainback, or closed-loop system.

There are a number of nuances to the way in which hot water heating is typically performed in New York State homes. While the majority of homes, both existing and constructed, heat their water with a stand-alone gas-fired hot water tank, the other water heating types are also worth modeling because they either:

- are achieving greater market share than in the past
- are uniquely compatible with SDHW systems
- significantly alter the economics of installation and running costs

The tank types recommended for inclusion are further explained below:

A. Fossil Fuel-Fired Hot Water Tanks
Common in much of New York State, these conventional tanks are usually fired with natural gas, and, less often, with propane or oil. They can be integrated into an SDHW system in a two-tank arrangement only, with the solar tank acting as a preheat for the conventional tank.

B. Electric Hot Water Tanks
These tanks contain an electric element to heat hot water. They can be integrated into a SDHW system either in a two-tank arrangement, or, the existing electric tank can be replaced by a special SDHW storage tank with an electric element that contains both a heat exchanger for the solar loop and an electric element for auxiliary heating.

C. Instantaneous Hot Water Heaters
This is a newer, more fuel efficient water heating option that replaces the tank entirely. They are typically fired by natural gas but are also available in electric versions. Specific instantaneous hot water heaters are designed to work with SDHW systems, in place of the second (conventional) tank.

D. Indirect-Fired Hot Water Tanks
Primarily in urban areas, many homes use boilers instead of furnaces to supply their heat. The same boilers are often used to supply hot water, either via a tankless coil in the boiler or via a tank that uses the boiler's hot water, pumped through a heat exchanger in the tank, to supply DHW (called an indirect-fired hot water tank). Special solar two heat-exchanger (2HX) tanks allow for a single indirect-fired tank that supplies all the DHW needs for a home by using the lower heat-exchanger to capture the solar energy and the upper heat exchanger to capture the boiler heat when the solar irradiance is insufficient, as seen below in Figure 23.

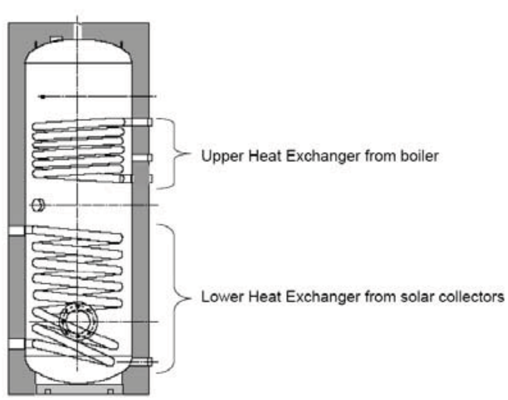

Figure 23. A two heat exchanger solar tank for installation with a heating boiler (Schüco)[43]

[43] Schüco. *Solar Tank 80 HE-2 / 105 HE-2 Operation and Installation Manual*, May 2006

E. External Heat Exchanger Tanks[44]

Shell-and-tube: The heat exchanger is separate from (external to) the storage tank. It has two separate fluid loops inside a case or shell. The fluids flow in opposite directions to each other through the heat exchanger, maximizing heat transfer. In one loop, the fluid to be heated (such as potable water) circulates through the inner tubes. In the second loop, the heat-transfer fluid flows between the shell and the tubes of water. The tubes and shell should be made of the same material. When the collector or heat-transfer fluid is toxic, double-wall tubes are used, and a non-toxic intermediary transfer fluid is placed between the outer and inner walls of the tubes.

[44] "EERE Consumer's Guide: Heat Exchangers for Solar Water Heating Systems," US Department Of Energy, Energy Efficiency and Renewable Energy, http://www.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12930

F. Drainback System Design

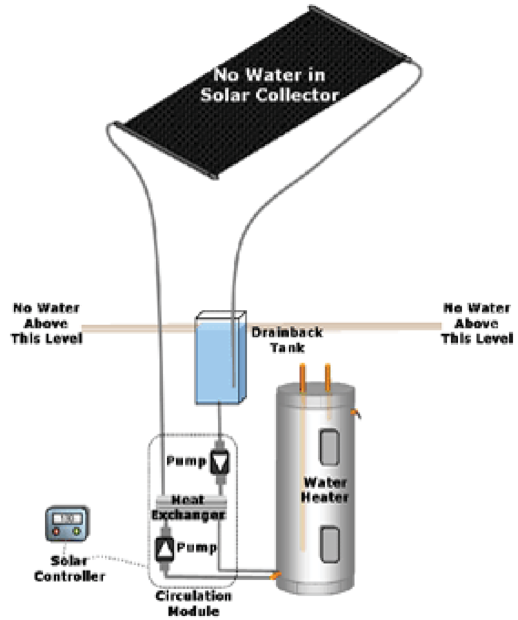

Figure 24. Drainback system "off"

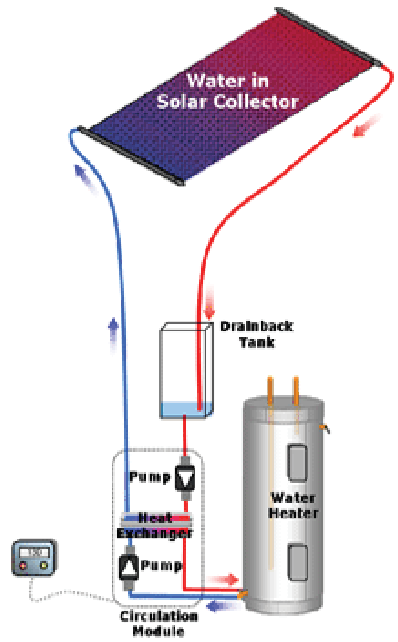

Figure 25: Drainback system "on"

Drainback systems are those systems designed to be drained of fluid. The two potential states of the drainback system can be seen in the above diagrams: charged when there is sufficient solar resource and drained when there is insufficient solar resource.[45] This design feature also offers some measure of freeze protection as cold temperatures cause the system to drain of fluid. In order to prevent freezing care must be taken to ensure the pipes are negatively pitched at all points running from the collectors to the tank so that fluid is not trapped in the pipes. Drainback systems usually consist of two pumps, one for charging the system and one for moving the fluid once the system is charged – additional pumping energy will be included in the energy model. The systems also consist of two tanks – a small tank for the working fluid and heat exchange, and a larger conventional water heater.

Any drainback system included in this assessment must meet the following criteria:

- Suitable for all of New York State, defined as those systems having a Freeze Tolerance Limit below the record low temperature for New York State of -48 F[46]
- Only systems that offer off-the-shelf components will be considered. Custom fabrication is difficult to model, difficult to price, and difficult to fabricate at scale.
- Only panels with well-established durability will be considered. This is defined as greater than five years in the marketplace.

[45] "How FAFCO Solar Hot Water Systems Work," FAFCO, http://fafco.com/SolarHotWater/How-FAFCO-Solar-Products-Work.html.
[46] Data for Old Forge, NY & Massena, NY, The Weather Channel, http://www.weather.com

Even though drainback systems are not well-established in the New York market, or the national market, OG-300 systems suitable for New York State do exist, and therefore if one of the below designs meet the above criteria and the manufacturer is willing to participate, their system will be included. Eight drainback systems have obtained an OG-300 rating from the Solar Rating and Certification Corporation (SRCC) as seen in Table 38 below.

Manufacturer	System Model	Freeze Tolerance Limit (ºF)
Bobcat & Sun Inc	Sun-Pak	-60
Morley Manufacturing	High Sierra Drainback	-60
Radco Products, Inc	Drainback Heat Exchanger	-60
Synergy Solar	Drainback Stainless HX	-50
Alternate Energy Technologies	EagleSun	-20
Fafco	Polymer Drainback	-20
Solar Energy, Inc	Duro-Drainback	-20
Solene	Solene/Chromagen Drain Back	-10

Table 38. SRCC OG-300 certified Drainback systems

Roof Type & Orientation

A. Flat Roof

Installing on a flat roof instead of a roof that is sloped to the south should not impact system performance as much as installation cost. Flat roof installations must still be angled towards the south, and thus incur additional material and labor costs. We do not recommend performing additional energy models based on roof type, but we will investigate the effect of flat-roof installation cost in the economic analysis.

B. Roofs Sloped Other than Towards Due South

Orientation of roof affects orientation of solar collectors, which, in turn, affects SDHW system output at different times of the day (e.g. collectors oriented to the West will generate more hot water towards the end of the day than collectors oriented due South). Rigorous analysis of every SDHW system at multiple orientations and multiple locations is outside the scope of this project, however at least three representative systems will be simulated at different orientations at a single location (e.g. Albany).

Explored but Not Recommended

Below are design factors considered, but excluded from the assessment.

A. Glazed vs. Unglazed collector panels

Unglazed collectors are the most commonly used collectors in the United States, due to their success in the pool heating market. An analysis by Jay Burch, Jim Salasovich, and Tim Hillman indicates that when collector costs comprise a large portion of system installation, usually through reduced labor costs, and roof area is available to house the less efficient unglazed collectors, unglazed collectors can be more cost-effective than glazed collectors[47]. The scenarios under which unglazed collectors are more cost-effective are well documented in this report. Bright Power's report will expand upon this analysis by analyzing an unglazed, building-integrated system from Bldg. Int. Solar.

B. Alternative two-tank configuration

Francis de Winter advocates for the following tank design based on: "a modified, heavily insulated 'two-tank' design, in which the backup tank is mounted above the solar tank, and the tanks are coupled with a natural convection thermal diode. The solar tank is about 30% larger than the average daily hot water usage, and an efficient backup heater is used; if the temperatures are controlled properly, it can get solar fractions of above 90% (25-27), as shown by lab tests, a field test, and computer runs. This design does not require costly features; it just requires useful design and control ideas."[48] After reviewing commercially available technology, Bright Power was unable to find manufacturers implementing this technique in a product. Bright Power will consult with our manufacturers to see if it is a system design they could provide.

C. Direct vs. Indirect systems

We considered including direct SDHW systems (e.g. thermosiphon and direct-pumped systems) – those that pump water directly to the collectors to be heated instead of using a heat-transfer fluid such as a glycol/water mixture. Nevertheless, our research leads us to believe that this will not be a viable system worth modeling due to New York's winter freezing climate.

D. Solar Fraction

We considered including solar fraction, the percent of domestic hot water generated from solar, as a design factor. In order for the studied systems to most accurately reflect the types of systems customers will likely purchase, we will allow manufacturers to design systems as they would in the marketplace, to the solar fraction they think most cost-effective.

---

[47] Jay Burch, Jim Salasovich, and Tim Hillman. "An Assessment of Unglazed Solar Domestic Water Heaters" (paper presented at the annual conference of the American Solar Energy Society, Orlando, Florida, August 6-12, 2005).

[48] de Winter, Francis. "Solar Water Heating With Backup Heating: A Review." (paper presented at the annual conference of the American Solar Energy Society, Orlando, Florida, August 6-12, 2005).

APPENDIX 2 – DEFINITION OF EACH SYSTEM TYPE AND ASSOCIATED PARAMETERS

Table 39. Solar Domestic Hot Water Systems for the Assessment

	System ID	Delta T (ºF)	System Pumping Rate (GPM)	Collector Low Limit (ºF)	Tank High Limit (ºF)	Description
Flat A - Flat Plate	100	12/8	1.5	N/A	170	This configuration will have a single heat exchanger solar-fed tank acting as the pre-heat for a natural gas, and three collectors with HE-1 105 gallon single heat exchanger tank.
	101	12/8	1.5	N/A	170	As above with electric resistance backup
	102	12/8	1.5	N/A	170	As above with propane backup
	110	12/8	1.5	N/A	170	As above with tankless water heater Takagi FLASH Model T-K1[49] in place of the conventional tank
	143	12/8	1.5	N/A	170	This configuration will have a double heat exchanger tank with the lower heat exchanger fed by the solar loop and the upper heat exchanger fed by a boiler with an 80% combustion efficiency, and three collectors with HE-2 105 gallon double heat exchanger tank.
Evac A&B - Evac. Tube	200	13.5/5.5	1.5	N/A	175	Twenty four tube Seido 1/80 gallon single heat exchanger pre-heat tank with conventional natural gas fired hot water heater
	201	13.5/5.5	1.5	N/A	175	As above with electric resistance backup
	202	13.5/5.5	1.5	N/A	175	As above with propane backup
	243	13.5/5.5	1.5	N/A	175	Twenty four tube Seido 1/80 gallon double heat exchanger tank
	330	13.5/5.5	1.5	N/A	175	Twenty four tube Seido 5/80 gallon conventional natural gas fired tank with external heat exchanger
	331	13.5/5.5	1.5	N/A	175	As above with electric resistance backup
	332	13.5/5.5	1.5	N/A	175	As above with propane backup
	310	13.5/5.5	1.5	N/A	175	Twenty four tube Seido 5/80 gallon single heat exchanger tank with instantaneous hot water heater
	300	13.5/5.5	1.5	N/A	175	Twenty four tube Seido 5/80 gallon single heat exchanger pre-heat tank with natural gas fired conventional hot water heater
	301	13.5/5.5	1.5	N/A	175	As above with electric resistance backup
	302	13.5/5.5	1.5	N/A	175	As above with propane backup
	343	13.5/5.5	1.5	N/A	175	Twenty four tube Seido 5/80 gallon double heat exchanger tank

[49] "Tankless Water Heaters," Builders Websource, http://www.builderswebsource.com/techbriefs/tankless.htm

	System ID	Delta T (ºF)	System Pumping Rate (GPM)	Collector Low Limit (ºF)	Tank High Limit (ºF)	Description
Flat B - Flat Plate	520	18/5	1.5	80	160	Two Gobi 3366 Flat Plate/ two- tank configuration: 80 gallon solar preheat (external heat exchanger), natural gas fired conventional
	521	18/5	1.5	80	160	As above with electric resistance backup
	522	18/5	1.5	80	160	As above with propane backup
	530	18/5	1.5	80	160	Two Gobi 3366 Flat Plate/ one tank configuration: 80 gallon conventional natural gas fired with external heat exchanger attached
	531	18/5	1.5	80	160	As above with electric resistance backup
	532	18/5	1.5	80	160	As above with propane backup
Evac C	641	13.5/5.5	1.5	N/A	175	Thirty tubes/ 120 gallon Sepco storage tank with electric element
	610	13.5/5.6	2.5	N/A	175	Thirty tubes/ 120 gallon storage tank coupled with instantaneous gas hot water heater.
Bldg. Int.	700	12	2.5	N/A	N/A	Six hundred sf building integrated collector under metal roof/ 120 gallon single heat exchanger tank & 40 gallon conventional tank
	701	12	2.5	N/A	N/A	As above with electric resistance backup
	702	12	2.5	N/A	N/A	As above with propane backup

Notes on Table 39*: The Delta T is defined as the difference between the collector and solar tank temperatures. It is comprised of two numbers, the first indicates the Delta T at which the system pump turns on, and the second is the Delta T at which the system pump turns off. For example the Flat A Delta T setting is 12/8 – when the difference between collector and tank temperature is 12°F, the pump turns on and will continue to run until the Delta T drops to 8 °F. When the system is on, it runs at the "system pumping rate". Additionally, the system pump will not turn on when the collector temperature is below the "collector low-limit" or when the tank temperature is above the "tank high limit". Several systems do not have a collector low limit specified – however it is important to remember that there is an effective "collector low-limit" of minimum tank temperature plus Delta T. For example, since the tanks rarely fall below 60 °F, and Delta T is rarely set below 10 °, there is an effective collector low-limit of 70 °. Numbers in red indicate assumptions to be confirmed by the manufacturer. It is worth noting that Evac A&B does not have SRCC ratings for its flat plate collector and is not releasing system designs at this time. Therefore, Evac A&B flat plate collectors (Systems would be labeled with 4 as the first digit, e.g., 4XX) are not shown in* Table 39.

APPENDIX 3 – DATA MATRICES OF ESTIMATED ENERGY PERFORMANCE

Matrices located on following pages

APPENDIX 4 – RESIDENTIAL ENERGY COSTS

Table 40. Residential Cost of Energy

Location	Electricity** (cents/kWh)	Oil* (cents/gallon)	Natural Gas** (cents/therm)	Propane* (cents/gallon)	Utility (Electric)	Utility (Gas)
Albany	13.5	257.2	117.5	246.4	National Grid (Capital Region)	National Grid
Binghamton	12.9	257.2	96.2	216.5	NYSEG	NYSEG (Binghamton)
Buffalo	12.1	243.9	132.7	217.1	National Grid (Frontier Region)	National Fuel Gas
Elmira	12.9	243.9	130.5	217.1	NYSEG	NYSEG (Elmira Area)
Islip	19.9	271.9	145.3	251.4	LIPA	Keyspan
Jamestown	12.1	243.9	132.7	217.1	National Grid (Frontier Region)***	National Fuel Gas
Massena	13.1	258.4	120.3	233.1	National Grid (Utica Region)	St. Lawrence Gas
New York City	21.1	275.8	172.4	-	Con Edison	Con Edison
Plattsburgh	12.9	258.4	135.1	233.1	NYSEG	NYSEG (Combined Area)
Rochester	9.4	243.9	114.5	217.1	Rochester Gas & Electric	Rochester Gas & Electric
Syracuse	13.1	257.2	117.5	216.5	National Grid (Central Region)	National Grid
Utica	13.1	257.2	117.5	216.5	National Grid (Utica Region)	National Grid
Watertown	13.1	258.4	117.5	233.1	National Grid (Utica Region)	National Grid

APPENDIX 5 – ECONOMIC MATRICES

Matrices are included in the following pages.

For information on other
NYSERDA reports, contact:

New York State Energy Research
and Development Authority
17 Columbia Circle
Albany, New York 12203-6399

toll free: 1 (866) NYSERDA
local: (518) 862-1090
fax: (518) 862-1091

info@nyserda.org
www.nyserda.org

Solar Domestic Hot Water Technologies Assessment

Final Report 08-09

State of New York
David A Paterson, Governor

New York State Energy Research and Development Authority
Vincent A. DeIorio, Esq., Chairman
Paul D. Tonko, President, and Chief Executive Officer