Economic Comparison

Solar Domestic Water Heating & Grid-Tied Solar Electric Systems for Residences

by

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“Learning Objectives”

- To right an imbalance of perspective regarding Solar Domestic Water Heating & Solar Electric Systems:

  (Much attention has been given to solar electric systems and not enough to solar thermal systems, particularly Solar Water Heating. The latter have merit as well.)

- To Present Metered Data from 16 solar electric sys.: (Data has been compiled over the past 4 years. The effort began because of the scarcity of such data. Omit if Rob gets permission to present his LIPA data.)

1. House Hold Energy Uses: (It gives us some sense of the loads that we are trying to meet.)

2. Conventional Domestic Water Heating: (We are trying to provide some portion, or all, of the domestic hot water used in a household, thus we need to know how much is used; and we need to know about the equipment and fuels used to heat that water; and their costs.)

   Loads: Energy Required/Energy Consumed
   Conventional heaters;
   Fuels Used;
   Fuel Costs;

“Learning Objectives” (cont.)

3. Solar Domestic Water Heating Sys (SDHW); (our subject)
   - Performance:
   - Economic Analysis:

4. Household Electricity Use (We are trying to provide some portion, or nearly all, of the electricity used in a household, thus we need to know how much is used; and its cost.)
   - Electrical Loads:
   - Electricity Costs:

5. Solar Electric Systems (our other subject)
   - Performance;
   - Economic Analysis;

6. Comparison:
   - SDHW;
   - Solar Electric.

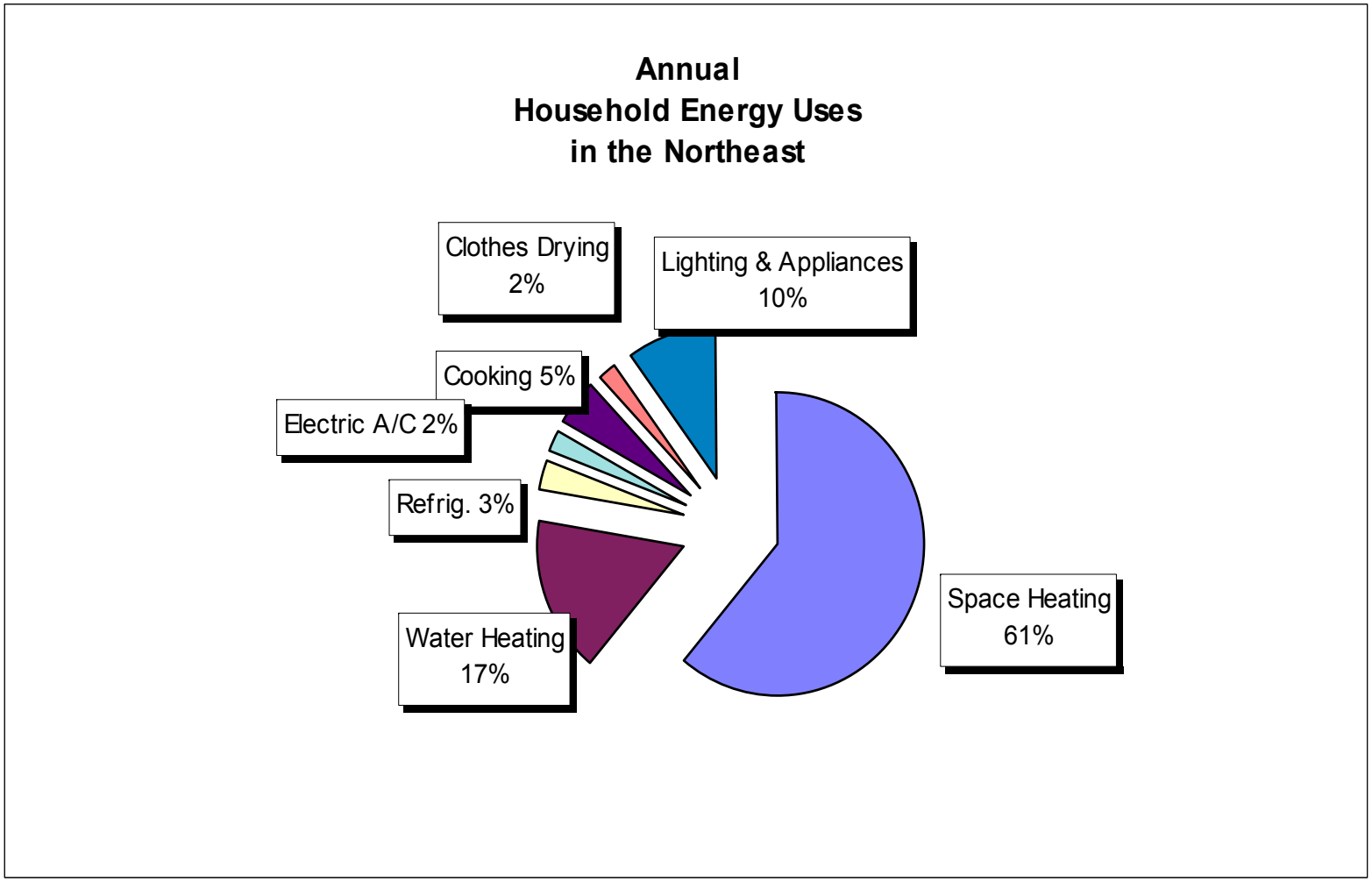
Dimensional Units

- "English" Units are used here:
  BTU/time (hour, month, year)
  BTU/sq.ft.
  kW-hr/sq.ft.
  kW dc (Standard Temperature Conditions)
  deg. F
- Conversions:
  1 kW-hr = 3413 BTU
  1 BTU = 1055 joules
  1 sq. meter = 10.76 sq.ft.

Part 1. Household Energy Uses

Household Energy Use

as % of total household consumption



1. EIA 2001 data

‘Typical’ Household Energy Use

as % of total household consumption

EIA 2001 data

- Summary of Annual Energy Uses in N.E.
  - Space heating: 61%
  - Electricity[1.]: 22%
  - Domestic Water Heating 17%

1. Site energy.

‘Typical’ Household Energy Use BTU

EIA 2001 data

- Summary of Annual Energy Uses in N.E.
  - Space heating: 71.4×10^6
  - Electricity[1]: 26.2×10^6
  - Domestic Water Heating 19.6×10^6
  - Total 117.2×10^6

1. Site energy.

Sizing the Equipment to Meet the Loads

- In order to size a solar system, solar water heating or solar electric, we first need to know the magnitude of loads that the equipment is to serve.

Different Loads

- The solar equipment we are discussing serves two different types of loads:

1. Solar Water Heating Sys.
   - Serves a thermal load, usually a single appliance, thus we look at just the water heating load;
2. Solar Electric Sys.
   - Serves an electric load. Since it is grid-tied, it serves the entire house, thus we treat the whole house as one load;

Determining Loads

- Domestic Water Heating Loads:
  - Since it is rare that a BTU meter is installed in a domestic water heating system, load determination is more involved:
    - Energy required is usually calculated;
    - Energy consumed can, at times, be measured.

- Electric Loads:
  - Load determination is easy. An accurate meter is provided by the utility Co. to measure kW-hr ac consumed.

Part I – Conventional Domestic Water Heating

Domestic Water Heating Loads

- Central to this presentation regarding solar water heating are two facts:
  1. There is a wide variability in energy consumed by appliances used to heat domestic water.

  2. For maximum benefit, the solar water heating system should be large enough to provide all, or nearly all, of the domestic water for the warmer ~ 6 months/year, thereby eliminating the energy consumption of those appliances.

Definition

- Domestic Hot Water is the water that is used in a household for bathing, washing hands, body, laundry. It is not the same as water used in a hydronic heating system for house heating or for pool heating.

Domestic Water Heating Load I

- Determinants:
  - Physical properties of water;
  - Volume of water to be heated;
  - Temperature rise:
    - water heater set point – entering water temp.
  - Efficiency of water heater.

Domestic Hot Water Load II

Volume to be heated:

- 20 gal/pers/day US avg.[1]
- 64.3 gal/household/day. US[2]

1. Russell Johnson's study & others;
2. GAMA directory (for Energy Guide Stickers) set bY DOE;

Domestic Hot Water Load III

- Incoming Water Temp:

  well water or city main temp. (~52 deg. F in CT; Boston, MA)

- Temperature to which water is heated:

  Water heater set point: 120 deg. F (most water heater mfg's)

- Temperature at which water is used:

  Typically 96 F to 100 F for hand/body washing;

  Max. ~104 deg. F; [1] water temp. hand/body

  Dishwashers: max. 140 deg. F; an integral booster heater; [2]

1. measurement/survey of numerous individuals;
2. Mfg. literature.

Energy for Heating Domestic Water

- Energy Required:
  - Output of the appliance;
  - Usually calculated.

- Energy Consumed:

  Input to the appliance, includes inefficiencies and standby losses of conventional heater;
  - Can be measured.

Energy Required for Heating Domestic Water

(output of heater)

# Users	Gal/user	Gal/day	BtuX10^6 /yr[1]	kW-hr/yr
2	20	40	8.27	2,422
3	20	60	12.4	3,634
* **3.2**	**20**	**64.3**	**13.3**	**3,894**
4	20	80	16.5	4,845

1. 52 F EWT; 120 F Tstat setting.

Energy Consumed in Heating Water

- Below we look at the different types of appliances used for domestic water heating and the energy they consume in the process.

Conventional Domestic Water Heaters in the Northeast I

- Types:
  - Storage
  - Instantaneous
- Function:
  - Single Function Appliances
  - Dual Function Appliances

Conventional Domestic Water Heaters in the Northeast II

- Single function appliances:

  heater heats domestic water only, year-round;

- Dual function appliances:

  heater provides space and domestic water heating during the winter season; domestic water heating during non-heating season.

Conventional Domestic Water Heaters in the Northeast III

- Why type of water heater is important:
  - There is a wide variation in the efficiency and standby losses among different types of water heaters…**that affects solar sys. perf.**

1. Single function water heaters:

   the efficiency and standby losses are nearly constant year round.

2. Dual function water heaters:

   the efficiency and standby losses vary widely between heating and non-heating seasons.

Water Heater Efficiency Info

- See the Gas Appliance Manufacturer's Assoc. Directory (GAMA) of measured efficiencies of practically all types of energy using appliances, including single function water heaters. They produce the Energy Guide stickers that appear on appliances.

- For dual function water heaters where the efficiency data is not published, must use field data, usually fuel bills, as the source.

A note about Efficiencies

- The efficiencies given in the GAMA directory are those of the latest, most efficient products.
- The majority of the water heating appliances in place are nowhere near as efficient.
- In general, the lower the efficiency of the conventional water heater, the more attractive is a solar water heating system.

Energy Consumed In DW Heating I

1. **Single Function Water Heaters**: (heat domestic water year-round; 3.2 pers)

Type	% Eff. Low GAMA '08	% Eff. hi GAMA '08	BTUx10^6/yr low eff.	BTUx10^6/yr hi eff.
Instantaneous elect. water htr (pou)	99%	99%	13.4	13.4
Storage type elect. water htr	81%	94%	16.4	14.1
Instantaneous gas fired, "wall hung", htr.	69%	84%	19.3	15.8
Storage type direct fired tank – gas	52%	65%	25.6	20.4
Storage type direct fired tank - #2 f.o.	51%	62%	26.1	21.4

Non-Heating Season Efficiencies of dual function water heaters
Boiler Hot

- 11 Systems observed (have all fuel delivery receipts for 1 or more years):

	Efficiency
Min.	14%
Max.	27%
Avg.	22%

Energy Consumed In DW Heating II

2. **Dual Function Appliances 1**: (heat house & water in winter, domestic water year-round)

Type	% Eff. low Fuel bills	% Eff. hi Fuel bills	BTUx10^6/yr low eff.	BTUx10^6/yr high eff.
Instantaneous: Tankless coil in fuel fired boiler (**summer**)	15%	27%	44.4	26.7
Instantaneous: Tankless coil in fuel fired boiler (**winter**)	70%	80%	9.5	8.3
Instantaneous: Tankless coil in fuel fired boiler (**year**)			53.9	32.9

Energy Consumed In DW Heating III

2. **Dual Function Appliances 2**: (heat house in winter, domestic water year-round)

Type	% Eff. low Fuel bills	% Eff. hi Fuel bills	BTUx10^6/yr low eff.	BTUx10^6/yr high eff.
Storage type: Indirect fired tank – fuel fired boiler (**summer**)	15%	27%	44.4	26.7
Storage type: Indirect fired tank – fuel fired boiler (**winter**)	70%	80%	9.5	8.3
Storage type: Indirect fired tank – fuel fired boiler (**year**)			53.9	32.9

“Back of Envelope” Check of Fuel Oil use in Residential Domestic Water Heaters:

- According to Fuel Oil Suppliers:

1. Tank-Type – year round:

– Very lowest: .4 gal #2 f.o./day

– Average Low: .6 “

2. Tankless & Indirect - summer

– Average 2 pers.: .88 “

– Average 4 pers.: 1.7 “

– Highest: 2.0+ “

“Back of Envelope” Check (continued) of Fuel Oil use in Residential Domestic Water Heaters:

non-space heating season (6 mos)

Fuel Oil Use	Lower use	Higher use
Tankless coil: gal/day	.88	1.7
Btu/gal #2 (hhv)	138,700	138,700
Btu/day	122,056	235,790
Btu/6 Mos.	22,275,220	43,031,675

Non-Heating Season Efficiencies of dual function water heaters

Boiler Cold

- 2 Systems Highest Observed (have all fuel delivery receipts for 1 or more years):

	Efficiency	
Min.	41%	Indirect: 'cold start' boiler
Max.	45%	Tankless: blr manually turned on when h.w. needed. (non-heating season)

Incidence of Existing Types of Domestic Water Heaters in the Northeast

- Single function appliances:

  The appliance heats domestic water year-round;

  <60% of total heaters in a survey of residential water heaters.[1]

- Dual function appliances:

  The appliance heats the house in the winter and domestic water year-round;

  >40% of total heaters in a survey of residential water heaters.[1]

1. Survey of 956 residential water heating systems in Sunsearch data base.

Fuels Used & Costs

Fuels Used for Domestic Water Heating – Residences – in N.E.

CT prices

2008 prices:

- #2 fuel oil: $3.00- 3.49/gal (138,700 Btu/gal)
- Elect: $.078- .225/kW-hr (3413 Btu/kW-hr)
- Nat. gas: $1.90/ccf (100,000 Btu/ccf)
- Propane: $1.85 - 3.25/gal (91,535 Btu/gal)

Fuel Cost Escalation Rates

	1970 – 2000 % per year	2000 – 2007 % per year
Elect.	5.1%[1]	7.3%[2]
Fuel Oil (#2)	7.0%[1]	14.6%[3]
Natural Gas	5.5%[1]	11.5%[3]
Propane	7.2%[1]	10.0%[2]

1. EIA
2. Residential Bills CT
3. CT – Office of Policy and Management

Part 3: Solar Domestic Water Heating

Important Concept

- Solar water heating systems can save more energy than they generate.

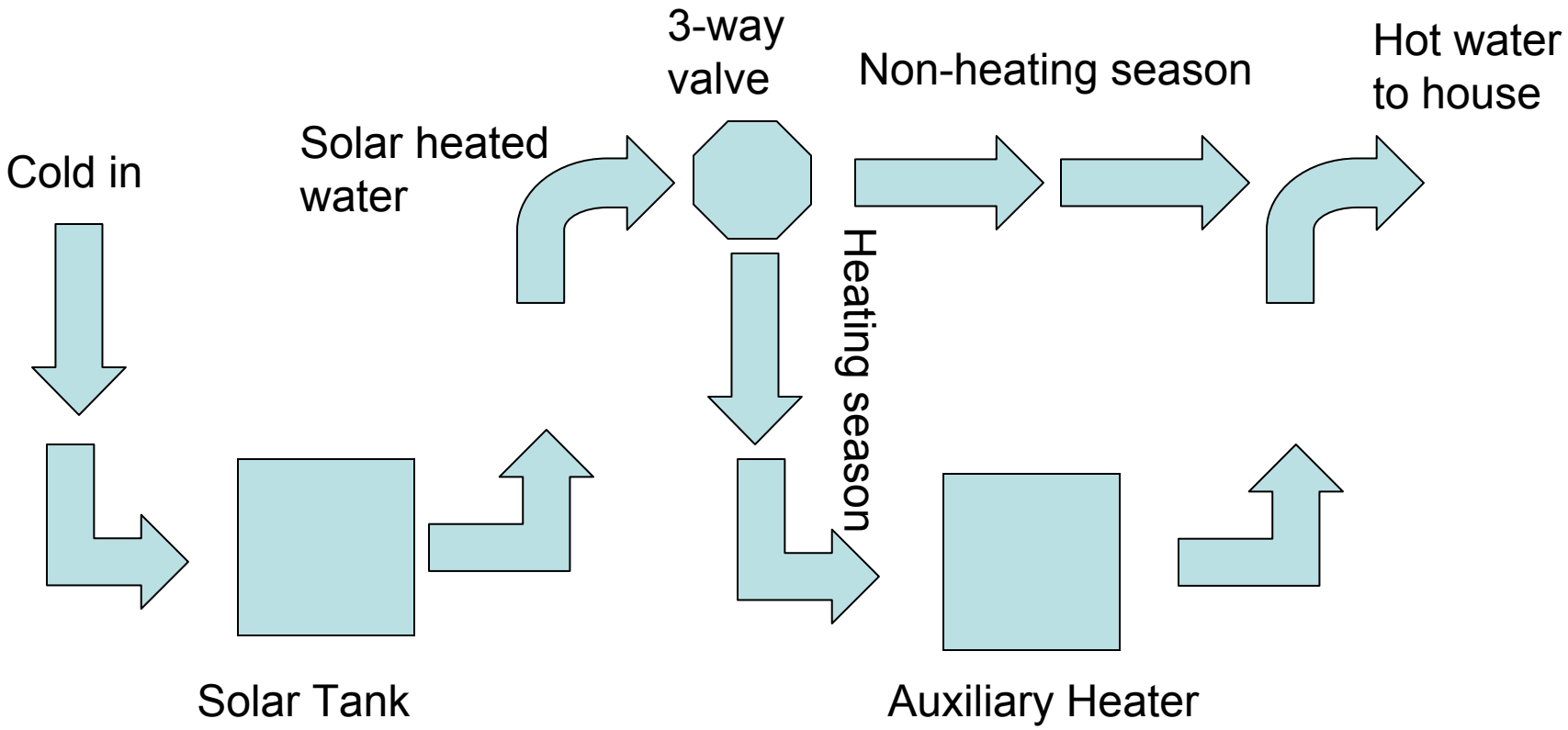
  not a conundrum.

Importance of Solar System Size

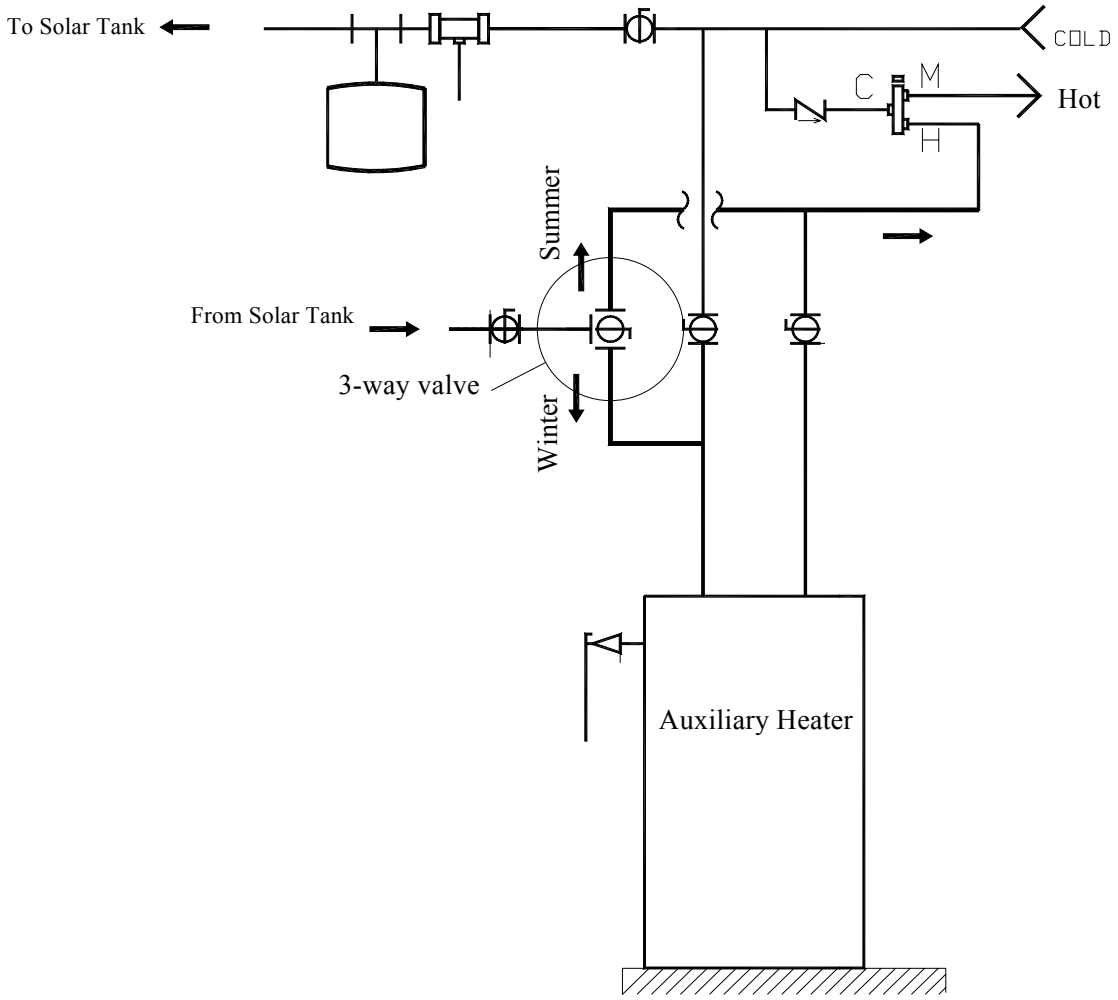
- The solar system should be large enough to permit bypassing and shutting off the supplemental heater for as many months as possible. In most cases, in the Northeast, 80 to 96 sq.ft. of collector will provide all domestic hot water for ~6 months (family of ‘3.2’ pers.)

- In so providing, the inefficiency and standby losses from the supplemental heater are eliminated for as long as the solar system carries the entire load. The more inefficient the heater the greater the savings from the solar system.

Solar Water Heating System Installed as Preheater



Summer/Winter bypass



Solar Water Heating System Savings I

(System sized to provide all hw during non-heating season.)

1. Single Function Water Heaters: (heat domestic water year-round; 3.2 pers)

Type	Low heater Eff. kW-hr/sq.ft./yr	Hi heater Eff. kW-hr/sq.ft./yr
Instantaneous elect. water htr	40	40
Storage type elect. water htr	49	42
Instantaneous gas fired, wall hung, htr.	57	47
Storage type direct fired tank – gas	73	58
Storage type direct fired tank - #2 f.o.	74	61

Solar Water Heating System Savings II

(System sized to provide all hw during non-heating season.)

2. Dual Function Appliances 1: (heat house & water in winter, domestic water year-round)

Type	Low Eff. kW-hr/sq.ft./yr	Hi Eff. kW-hr/sq.ft./yr
Instantaneous: Tankless coil in fuel fired boiler (year)	181	107

Solar Water Heating System Savings III

(System sized to provide all hw during non-heating season.)

2. Dual Function Appliances 2: (heat house & water in winter, domestic water year-round)

Type	Low Eff. kW-hr/sq.ft./yr	Hi Eff. kW-hr/sq.ft./yr
Storage type: Indirect fired tank – fuel fired boiler (year)	181	107

“Back of Envelope” Check of Solar System Savings for dual function heaters:

non-space heating season (6 mos)

Fuel Oil Use	Avg. use	High use
Tankless coil: gal/day	.88	1.7
Btu/day	122,056	235,790
Btu/6 Mos.	22,275,220	43,031,675
kW-hr/6 mos.	6,526.	12,608
kW-hr/sq.ft./6 mos. (80 sq.ft. coll.)	**81.5**	**148.3**

To Maximize Solar Sys. Savings

- Solar System must be large enough to heat all domestic water for non-space heating season, or ~6 months/year

- Supplemental heater must be off and bypassed for that time.

SDHW Performance

kW-hr/sq.ft./yr

- Two approaches:

1. Metered Systems:

   metered is better;

2. Computer Modeled Systems:

   model is your tool for designing new systems.

SDHW Observed Performance

• Metered	kW-hr/sq.ft./yr
– NU Report (top 5)[1.]	58.8
– TVA[2.]	56
– SRCC[3.]	53
– P. Fine[4.]	95
– R. Aldrich[5.]	36
"Average"	60

1. 40 metered, best 5; mostly 64/80; in CT
2. 'hundreds' metered, this based on 64/80; in TN
3. Hundreds metered, 64/80; MA (projected)
4. Savings averaged from 5 yrs of fuel records, 2 yrs of solar system operation; 72/120; boiler bypassed, off most of non-heating season; CT
5. 2 sys. 64/80: MA & WI; solar output passes thru a tempering valve, thus solar always preheats.

SDHW Simulated Performance

- Computer Modeled (Hartford CT data)

Basic System[1]:	kW-hr/sq.ft./yr
– F-Chart	40.5
– RETScreen.	43

1. 64/80; same collectors; 40/South; 64.3 gpd; 120 deg. F set point; Hartford, CT

SDHW Sys
Elect. Resist. BU
Years to Payback

- DHW Load: 64.3g/day (DOE)
- System: 80 sq.ft. w/s.blk/120gal/db type
- Elect. resist. BU: storage type heater
- Elect. cost: $.17/kW-hr
- Solar System Yield: 50 kW-hr/sq.ft./yr
- Fed. Tax Credit: $2000.
- Owning Costs: @2.5% installed cost/yr
- Pay cash for system.

SDHW Systems

- Owning Costs:
  - Removal and remounting of array for reshingling;
    - (avg. shingle life ~25 years)
  - Misc. Parts:
    - Circ/control/ext. insul./glycol: avg. life 15 years
  - Tank Replacement:
    - ‘ordinary’ glass lined tank: 8 to 15 years;
    - Stone line steel tank*: 8 to 14 years
    - Stainless steel tank: ? - Limited lifetime warranty

    * ~85% of solar tanks in so. New England are stone-lined.

Installed Costs

- Given in terms of $/sq.ft. of installed solar collector area. The cost figure includes all system components, installation, labor, overhead and profit.

- Example: a system with an 80 sq.ft. array of collectors might cost $9600, or $120/sq.ft. installed.

SDHW Sys
Elect. Resist. BU
Years to Payback

Fuel Cost Escalation Rates

Install. Cost	0%	5%	10%	15%
$100/sq.ft.	15	10	9	8
$120	19	12	10	9
$140	20+	14	11	9
$160	20+	16	12	10
svgs yr 1	$680	$680	$680	$680
svgs. yr 10	$680	$1054	$1603	$2392

SDHW Sys
Elect. Resist. BU
Internal Rate of Return % @ 20 yrs

Fuel Cost Escalation Rates

Install. Cost	0%	5%	10%	15%
$100/sq.ft.	3	11	17	23
$120/	1	8	14	20
$140/	-2	6	12	18
$160/	-3	4	10	16

Part 4 – Household Electricity Use

- The output of a grid-tied solar electric system is usually tied into the main electrical distribution panel, thus we are not looking at individual loads served by the system, as we were with domestic water heating, but rather at entire household loads.

Residential Electric Loads

- No Need to Estimate these Loads: they are metered for us:

1. Very Conserving (2 persons/household) (source: utility bills)

   240 – 300 kW-hr/mo

2. 'Average' residential use in CT (source: utility websites)

   700 – 750 kW-hr/mo

3. "Serious User" in CT (source: phone survey)

   2500 – 5000 kW-hr/mo.

Electricity Costs

- Residential Rates in CT:
  - Electric Co-ops[1]: $0.07 to $0.09/kW-hr
  - Connecticut Light & Power: ~$0.17/kW-hr
  - United Illuminating: ~ $.225/kW-hr

1. In CT elect. co-ops do not qualify for solar electric system rebate.

Elect. Cost Escalation Rates

	1970 – 2000 % per year	**2000 – 2007** % per year
Elect.	5.1%[1]	7.3%[2]

1. EIA
2. Residential Bills CT (CL&P)
3. CT – Office of Policy and Management

Dimensional Units

- kW-hr ac/yr per kW dc STC;
- kW-hr ac/yr per sq.ft. of solar electric module;
  - This is used to facilitate comparison with solar water heating systems.

n.b. 10.76 sq.ft. = l sq. meter

Part 5. Solar Electric Systems

Solar Electric System Performance

- Metered (Observed) Performance:
  - What a system actually produced;

- Simulated Performance:
  - Forecast production, modeled by computer;

Solar Electric Systems
Observed Performance I

- Observed Monthly Perf.[1.] 16 pV systems (1 – 4 years):

kW-hr ac/yr/kW dc STC

Min.	661
Max.	1410
Avg.	1127

1. 3 sys. Data from utility grade meters; 13 sys. Data from inverter displays. Compiled by EMB.

Solar Electric Systems
Observed Performance II

- Observed Monthly Perf.[1.] 16 pV systems (1 – 4 years):

	kW-hr ac/yr/sq.ft.
Min.	9.1
Max.	22.6
Avg.	15.4

1. 3 sys. Data from utility grade meters; 13 sys. Data from inverter displays. Data compiled by EMB.

Solar Electric System Simulated Performance

- Computer Modeled (Hartford CT)
  - PVWatts (.77 derate factor)

  Power Clerk* (proprietary)
    - *Clean Power Research

kW-hr ac/yr/kW dc STC

1162
1202

Residential Solar Electric Sys
Grid Tied
Basis for Payback/IRR Analysis

- Sys.: 5.4kW dc STC/5.0kW dc PTC (peak)
- Performance: 1200 kW-hr ac/yr/kW dc STC
- Net Metering: retail rate $0.17/kW-hr
- Rebate: $5./watt dc PTC (in CT)
- Fed. Tax Credit: $2000.
- Ren. Energy Credits: $0.03/kW-hr (in CT)
- Owning Cost @ 1% of installed cost
- Hartford CT weather data used;
- Pay Cash for system.

Solar Electric Systems
Grid-tied

- Owning Costs:
  - Removal and remounting for reshingling;
    - (avg. shingle life ~20-25 years)
  - Inverter replacement:
    - (avg. life of components used in inverters ~10 yrs)

Installed Costs

- Given in terms of $/watt STC dc installed solar collector. The cost figure includes all system components (BOS), installation, labor, overhead and profit.

- Example: a system with a 5 kW dc array, might cost $9/watt dc installed (before rebate, etc.)

Solar Electric Sys
Grid Tied
Years to Payback

Fuel Cost Escalation Rates

Install Cost	0%	5%	10.%	15%
$7.00/watt	14	10	9	8
$8.00/watt	26	15	11	10
$9.00/watt	>30	18	14	11
$10.00/watt	>30	22	16	13
svgs yr 1	$1249	$1249	$1249	$1249
svgs. yr 10	$1249	$1818	$2674	$3906

Solar Electric Sys
Grid Tied
Internal Rate of Return % @ 20 yrs

Fuel Cost Escalation Rates

Install Cost	0%	5%	10%	15%
$7.00/watt	4	11	17	22
$8.00/watt	-2	5	11	10
$9.00/watt	-6	2	8	13
$10.00/watt	-9	-1	5	11

Part 6 - Comparisons

Array Area Comparison I
SDHW vs. Solar Electric

- SDHW:
  - Year 1: 60 kW-hr/sq.ft./yr
  - Year 20: same
- Solar Electric:
  - Year 1: 16.4 kW-hr/sq.ft./yr.
  - Year 20: 13.6* kW-hr/sq.ft./yr.

    *based on PVWatts: 1%/yr degradation of output:

Array Area Comparison II
SDHW vs. Solar Electric

- SDHW: 70-80% annual dom. hot water energy consumpt.:
  - 80 - 96 sq.ft.

- Solar Electric system: 5.4 kW dc STC
  - 356 - 400 sq.ft.

Comparison

SDHW

Lowest	36	kW-hr/sq.ft./yr
Highest	181	kW-hr/sq.ft./yr
Avg	60	kW-hr/sq.ft./yr

Solar Electric

Lowest	9.1	kW-hr/sq.ft./yr
Highest	22.6	kW-hr/sq.ft./yr
Avg	15.4	kW-hr/sq.ft./yr

Some Conclusions

- As long as there is a rebate for solar electric systems, and not SDHW sys., solar water heating systems are a somewhat better investment than solar electric systems;
- Without a rebate for either, solar water heating systems are a much better investment than solar electric sys.;
- The efficiency of the conventional water heater that the solar system is connected to can greatly affect the annual savings of the solar system;
- The payback/IRR that is provided with a given system is greatly influenced by the fuel cost escalation rate one assumes.
- Don’t use dual function space/domestic water heaters…without a solar water heating system.

SDHW & Solar Electric Sys.

Questions?

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