A (Very) Brief History of Solar Energy
Antoine Lavoisier Solar Furnace - 1774
Melted Platinum at 3222°F
Augustin Mouchet, Paris Exposition, 1878
Solar steam engine pumped 500 gallon per hour.
The Modern Era
Phase 1 - The Beginning
1891 - 1950

Clarence Kemp’s
Batch Solar Water Heater
1891

... we should be using Nature's inexhaustible sources of energy - sun, wind and tide. ... I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that.

Thomas Edison - 1931

The first modern flat plate solar collector invented by William Bailey in 1909

- used separate storage tank
- company was called Day & Night

By 1900 there were 1600 solar water heaters in southern California.

By 1941 there were 60,000 Day & Night solar water heaters in Florida.
The end of Phase I

California - Cheap natural gas ended the solar era by 1920

Energy Prices declined steadily until the 1970s

Florida - Cheap electricity after WWII ended the solar era in Florida by 1950

And Then......
Two oil embargos occurred - in 1973 and 1979

US energy security was quickly destroyed
Energy Independence

“The moral equivalent of war”
Pres. Jimmy Carter

Goals
• Energy independence
• Reduce Pollution of fossil fuels
• Long term energy planning
• Created the Dept of Energy
• Started renewable energy incentives

“\textit{A generation from now this solar heater can either be a curiosity, a museum piece, an example of a road not taken or it can be just a small part of one of the greatest and most exciting adventures ever undertaken by the American people.}”

Pres. Jimmy Carter
Results: Residential - DHW Systems

Roanoke, VA

Durham, NC

Wrightsville Beach, NC
Residential - DHW, Space Heating

Raleigh, NC

Oak City, NC

Blacksburg VA

Nashville, NC
Residential - DHW, Space Heating (2), Pools

Williamsburg VA

Blacksburg VA
Residential Spec Housing Development

Chapel Hill, NC - 3 Home Project
DHW, Space Heating
Jacksonville, NC - 70 Home Project
DHW & Space Heating

Jacksonville, NC - 8 Home Project
DHW & Space Heating
Residential Spec Housing Development

Rome, GA - 10 Home Project
DHW & Space Heating
Commercial Projects

Fuquay-Varina, NC - 24 apts.
Low Income Housing
DHW & Space Heating

High Point, NC - Elm Towers Apts.- Elderly Public Housing
DHW & Space Heating

Smithfield, NC - Nursing home
DHW

Blacksburg, VA - Physical Therapy Clinic
DHW & Space Heating
Commercial Projects

Goldsboro, NC - Veterinary Clinic

Rocky Mount, NC - Dental Clinic (no picture)

High Point, NC - Public Health Center - DHW
Commercial Projects
Car Washes - VA & NC

Chapel Hill, NC - Restaurant - DHW
Murphy, NC - Dragon Palace Motel
DHW & Space Heating

Schools

Ft. Defiance, VA - Middle School
A/C & Space Heating

Marion, NC - Glenwood Elementary School
DHW Cafeteria

Wilkesboro, NC - Woodward Jr. High School
DHW Cafeteria/Gymnasium

Wilkesboro, NC - Boomer-Ferguson Elem. School
DHW Cafeteria

Raleigh, NC - East Millbrook Jr. High School
DHW Cafeteria

Raleigh, NC - West Millbrook Middle School
DHW Cafeteria
Schools

Apex, NC - Apex High School
DHW Cafeteria

Chapel Hill, NC - Carolina Friends School
DHW Cafeteria & Space Heating

Sampson County, NC - Lakewood High School
DHW Cafeteria

Randolf County, NC - Trinity High School
DHW Cafeteria

Hamlet, NC - Fairview Heights Elem. School
DHW Cafeteria
State & Local Government

NC Dept. of Transportation - 19 highway rest stops
DHW & Space Heating

Boone, NC - Watauga County Recreation Facility
Pool Heating

City of Rahway, NJ - Police Hdq. & Jail
DHW

Federal Government

Russell Lake, GA - U. S. COE Field Office
DHW & Space heating

Jordan Lake, NC - U. S. Corps of Engineers
DHW 9 Comfort Stations

Falls Lake, NC - U. S. Corps of Engineers
DHW 18 Comfort Stations

Honolulu, Hawaii - U.S. Army, Schofield Barracks
DHW
Federal Government

Aspen Colorado - US Post Office
DHW & Space Heating

Chatfield Colorado - Lake and Dam Park Visitor’s Center  DHW & Space Heating
Warner Robbins AFB, Georgia - Aircraft Wash Facility
874 collectors - 32,000 gallons storage

And Then......
By 1986, the oil scare subsided and federal energy policy was reversed

- Recommitted to fossil fuels and nuclear power
- DOE R&D budget for renewable energy cut by 80%
- Solar DHW system removed from the White House
- Tax breaks eliminated for all renewable technologies
  - left tax breaks for oil, gas, nuclear
Results:

• By 1988, 95% of US solar companies gone

• Surge in world energy consumption, especially India & China

• Increased pollution, global climate change

• Europe and asia are way ahead of US on conservation and solar adoption

• China produces about 80% of the solar water heaters used in the world

In the 1950s, the US imported 0% of its oil
In 1972, the US imported 28% of its oil
In 2005, the US imported 60.3% of its oil
In 2007, the US imported 57% of its oil = $700 B
In 2011, the US imported 44.8% of its oil

Sources: http://www.eia.doe.gov/emeu/25opec/sld002.htm
http://www.eia.gov/forecasts.ieo/
The Modern Era - Phase III - One More Time
(subtitle: Back to 1980)
2006 - ?

Energy Problems never went away, they only got worse.

"The Stone Age didn’t end for lack of stone, and the oil age will end long before the world runs out of oil."

- Saudi oil minister Sheik Ahmed Zaki Yamani, 2005

New Initiatives

Federal Tax Credits reinstated in 2005, Mod. in 2008
Runs from 2006 - 2016

25% of all energy from renewables by 2025

Many States have Solar Tax Credits
Utility incentives - Renewable Energy Credits (RECs)
**Results:** New Projects

- **Albany GA - Marine Corps Barracks,**
  **DHW - 50 collectors 1800 gallons storage**

- **Ft. Myer, VA  Army Base**
  **Adjoins Arlington National Cemetery**
  **DHW - 18 collectors**
  **800 gallons storage**
Bethesda Naval Base - Warrior Transition Unit

DHW - 50 collectors
2500 gallons storage
Duke University Student Center

DHW - 45 collectors
2000 gallons storage

Murphey School Apartments - Low Income Housing

DHW - 15 collectors
500 gallons storage
Durability

Rowan Helping Ministries - Homeless Shelter
Salisbury, NC

25 year old system
perfect working condition

New replacement system
Solar Hot Water System Design

Ben Gravely - Holocene Technologies

Blog <http://www.solarhotwater-systems.com/>

Solar Hot Water System Design

• Pressurized antifreeze
• Non pressurized drainback
System Design - How it works

Two main designs in use today
Pressurized Glycol System

Start with
- Collectors
- Pressurized tank
- Collector Side Exchanger
- Pump

Need a few more things
Add
• Air Vent
Add
• Air vent
• Expansion tank
Add
- Air vent
- Expansion tank
- PRV & drain
Add
• Air vent
• Expansion tank
• PRV & drain
• Check Valve

Critical Failure Modes
Overheating is a major problem with glycol systems.

Situation: Sunny day with low load

- Vacation
- Weekend
- Seasonal variation
- Shutdown for repairs, maintenance
- New construction

what happens?
Results:

- System overheats and blows PR valve(s)
- Cool down at night causes vacuum in line
- Air leaks in through air vents,
- Can vapor lock system
- Oxygen & high temp causes glycol degradation into acids, deposits
- Acid eats pipe, Gum plugs valves, vents, PRV

Downward spiral, no recovery, hard failure
Requires immediate maintenance
Replace vents, valves, flush system, recharge
Acid build up can eat pipes and components

The bigger the system, the greater the danger.
How to solve overheating problem

Overheating Solution #1

Add a Heat Dump
- fan coil
- pump
- three way valve
- controls

Also pool dump
Night time dump

Cons:
- more components to fail
- uses energy to waste energy
- no help in power failure

Still Not Fail Safe
Overheating Solution #2

**Steamback Method** (popular in Europe)

Let glycol boil. Vapor will push the glycol out, protecting it from high temperatures.

Have to move check valve & oversize the expansion tank.
Cons:

- Steamback starts working ~ 250°F and can go to 311°F.
- Collector pressure can go to 60 psi.
- Must limit steamback frequency.
  - Requires simulation software to limit number of temp peaks/yr.
  - Collector & piping geometry are critical or steamback doesn’t work.
- All standard glycol components still required.
Overheating Solution #3

High pressure system

“Raise system pressure high enough to keep the propylene glycol from boiling. ..... does not go through the stress of phase change and will last longer.”

Cons:

Stagnation Temperature can be 320F and higher, depending on the collector type.

The max. recommended temperature of Dowfrost propylene glycol is 250F.

Glycol begins to break down below 190°F.
Summary for pressurized glycol systems

http://timoelliott.com/blog/2009/02/data_governance_whats_that_and.html
Preferred Solar System Attributes

1. Eliminate freezing or boiling problems
2. Eliminate pressure vessels, no ASME codes
3. Eliminate glycol, use water for highest efficiency
4. Eliminate heat exchanger between collectors & tank
5. Eliminate air vents, check valves, PRV, expansion tank, isolation valves....
6. Eliminate heat dumps, night time dumps, pool dumps high pressure, and steamback
7. Make it Fail Safe for power failure

Got to be a better way! Start Over
Results:

• Fewer components, more reliable, lower cost
• Higher efficiency (water = 15% more efficient than glycol)
• Longer life (glycol decreases system life by ~ 30%)
• Low maintenance
• Non-pressurized is safer

How to do this?
Non-pressurized Drainback System

Start with
• Collectors
• Non-Pressurized tank
• Load Side Exchanger
• Pump

What to add?
Non-pressurized Drainback System

Nothing - That’s It!

- no air vent
- no expansion tank
- no PRV
- no check valve
- no ETC.

Water drains naturally whenever the pump stops

Summary:
- 15- 30% more efficient than glycol
- fewer parts
- lower cost
- less maintenance
- longer life
- no pressure = safety
Solar Thermal UFC Design Specification Update

• Specs are being revised by a tri-service committee, established by the Deputy Undersecretary of Defense Installation and Environment Office.

• The new specifications are being developed with input from the Eneref Institute and solar thermal industry advisors.

• The new specifications are expected to have a *stronger emphasis on drainback solar systems.*
Solar Hot Water Systems
Ben Gravely - Holocene Technologies

Blog <http://www.solarhotwater-systems.com/>
Applications  Typical Residential DHW System

Diagram showing a typical residential DHW (Domestic Hot Water) system with water inlet (CW INLET), water heater, and water outlet (HW OUTLET).
Applications  Typical Residential DHW System

Single Pass System
Applications  Residential SH - Forced Air

Any Furnace Type
- Gas
- Oil
- Heat Pump with Electric Backup
Applications  Residential SH - Forced Air

Three operational modes
- Solar Only (hot)
- Solar Assist (med)
- Furnace Only (cold)

Specify Coil for
Low Temp Delivery
Two operational modes
- Solar Only (hot)
- No heat (cold)
Applications  Residential SH - Radiant Slab

Boiler

Boiler Pump

Boiler Pump is Circulator
Applications Residential SH - Radiant Slab

Three operational modes
• Solar Only (hot)
• Solar Assist (med)
• Boiler Only (cold)

Design System for Low Temp Delivery

Boiler

Solar

Boiler Pump

Boiler Pump is Circulator

Solar Connection referred to as “Side Arm”
Applications  Residential SH - Radiant Slab

Three operational modes:
- Solar Only (hot)
- Solar Assist (med)
- Boiler Only (cold)

Design System for Low Temp Delivery

Solar & Boiler Connections are both Side Arm

Solar Pump

Boiler

Boiler Pump

Loop Pump is Circulator
Applications Commercial DHW
Applications  Commercial DHW

Single Pass System
Applications  Commercial Space Heating

Forced Air

Radiant Slab

T <= 100F return
T <= 120F supply
RETURN

SUPPLY

BOILER
Applications  Commercial Space Heating

Forced Air

Radiant Slab

Design for Low Temp Delivery
Applications  Pool Heating
Applications  Pool Heating
Other Applications - Process Hot Water

Car Washes

Breweries

Commercial Laundries

Heating / Cleaning Baths

Wash Down

Most Applications are a version of DHW
Solar Hot Water Systems
Ben Gravely - Holocene Technologies
Blog <http://www.solarhotwater-systems.com/>
SOLAR DOMESTIC HOT WATER SYSTEM (SDHWS)

Design and build each solar domestic hot water heating system meeting the requirements of UFC 3-440-04N Solar Heating of Buildings and Domestic Hot Water. Each system shall be fully integrated with the building DDC controls system. Provide a complete solar domestic hot water system including heating panels, roof supports, piping, pumps, hot water storage tanks, heat exchangers and controls as indicated in Bid Schedule. Provide a system designed to furnish a minimum of 30% of the daily demand for domestic hot water.

Provide complete solar domestic hot water system designed and built by a single contractor who specializes in solar heated water systems. System shall be designed, built, and tested by this contractor who shall be responsible for the provided system to operate as proposed. This design-build contractor must be endorsed in writing, prior to system design, by the manufacturer of the solar plate collectors provided for this solicitation.

If the solar domestic hot water system is located on the roof, provide a coordinated design of the roof elements including implementation of LEED requirements and sustainable systems roof mounted equipment. Organize the roof space necessary to accomplish the functions the roof has to provide, minimize roof penetrations, and plan the roof to facilitate future reroofing of the facility. The roof type selection and detailing of roof mounted equipment shall be made to compliment the implementation of the functions that have to take place on the roof and minimize the need for routine maintenance. Accomplish a Pre-Roof Design Conference prior to the design of the roof.

+ Drawings showing equipment locations
Typical method for sizing for DHW

Fixtures x GPM x dT\(_{\text{max}}\)

Calculate Btu/hr
Size Boiler x 1.25

Result is peak **Capacity** of Boiler in **Btu/hr**

**BUT**

Solar System Design **not based** on peak **Capacity** (Btu/hr)
Solar System Design is based on **total energy** (MBtu) needed

Example: Automobile
Specs give me engine HP
I need Gas consumption
Solar Analysis Methods - DHW Example

1. Load Estimation - Btu/month

- Occupants x GPM x dT\text{\,(actual)} x duration or ASHRAE tables

- Direct Measurement - put flow meter on CW makeup to hot water line - best

- Forensic Physics
  - take energy bill apart for DHW & SH
  - divide by boiler efficiency

- Find duty cycle - monthly variations
  Dorm, Seasonal Business, Hotel, 5/7 day week

Result is table of Monthly Energy Loads, not capacity.

Constant Load: Hospital, Jail, Apartment

Varying Load: Dormitory, Barracks, Hotel
2. **Energy Data** (the fuel) - Monthly Average Solar Radiation

- NASA Satellite data covers the whole earth.
- Solar Radiation - Monthly Btu/ft² on flat surface.
- Rotate radiation data to plane of collector - tilt angle & south azimuth
- Ground water temp is calculated from ambient temp.

3. **Choose Solar Collector** (the boiler)

- Performance specs come from certified tests listed with SRCC
- Only energy gain is from radiation. Choose number of collectors.
- Losses are radiation, convection, and conduction
- Performance is straight line equation. Downward slope indicates lower efficiency as dT increases.
3. **Choose Solar Storage** (the battery)
   - Based on collector area
   - Can fudge with daylight load

4. **Put all the inputs into computer program** (the brain)

Result is
- Monthly loads for SH & HW
- Monthly solar energy produced
- Monthly solar fraction
- Monthly output per collector
- Annual totals
**Holocene Technologies**  
**Solar Calculation Form**  
*Holocene #: 10/02/12  
Agent #:*  

<table>
<thead>
<tr>
<th>Prepared For</th>
<th>Project Name</th>
<th>Weather</th>
<th>Lat</th>
<th>Tilt</th>
<th>S. Azm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>College Dorm Example 250 occupants @ 20 GPD</td>
<td>Wilmington, NC</td>
<td>34.23</td>
<td>30</td>
<td>0</td>
</tr>
</tbody>
</table>

---

### Heating, Hot Water, & Aux Loads

#### DHW Loads
- **Well Temp:** 0
- **Gal/Day Use:** 5000
- **Output Temp:** 140

#### Space Ht Loads
- **Btu/DD:** 0
- **Btu/Hr:** 0
- **OR:**
- **Btu/DD**
- **Heated ft²:** 0
- **DD Base:** 65
- **Htg Design Temp:** 37.09
- **5/7 Day Wk:** 7

#### Auxiliary Heating Loads

<table>
<thead>
<tr>
<th>Month</th>
<th>DHW (MBtu)</th>
<th>Space Htg. (MBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.632</td>
<td>0</td>
</tr>
<tr>
<td>Feb</td>
<td>1.000</td>
<td>0</td>
</tr>
<tr>
<td>Mar</td>
<td>0.804</td>
<td>0</td>
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<tr>
<td>Apr</td>
<td>1.000</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>0.247</td>
<td>0</td>
</tr>
<tr>
<td>Jun</td>
<td>0.146</td>
<td>0</td>
</tr>
<tr>
<td>Jul</td>
<td>0.958</td>
<td>0</td>
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<tr>
<td>Aug</td>
<td>0.293</td>
<td>0</td>
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<tr>
<td>Sep</td>
<td>0.972</td>
<td>0</td>
</tr>
<tr>
<td>Oct</td>
<td>1.000</td>
<td>0</td>
</tr>
<tr>
<td>Nov</td>
<td>0.936</td>
<td>0</td>
</tr>
<tr>
<td>Dec</td>
<td>0.573</td>
<td>0</td>
</tr>
</tbody>
</table>

---

### Solar Equipment Selection

<table>
<thead>
<tr>
<th>Collector</th>
<th>Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collector #</strong></td>
<td><strong>Typical Tank Gal (x1.25)</strong></td>
</tr>
<tr>
<td>Collector Model</td>
<td>1874</td>
</tr>
<tr>
<td>No. Glass Panes</td>
<td>(x1.5) 2248</td>
</tr>
<tr>
<td>F(ta)</td>
<td>Selected Tank Gal 2000</td>
</tr>
<tr>
<td>FU(r)</td>
<td>Add % of GPD to tank 10</td>
</tr>
<tr>
<td>No. of Collectors</td>
<td>Add'l Storage 200 gal</td>
</tr>
<tr>
<td>Net Area / Coll. ft²</td>
<td>Total Storage 2200 gal</td>
</tr>
<tr>
<td>Total Coll. Area ft²</td>
<td>Solar Losses 3 %</td>
</tr>
</tbody>
</table>

---

### Results Summary

<table>
<thead>
<tr>
<th>F-Chart</th>
<th>DHW</th>
<th>Space Ht</th>
<th>Total</th>
<th>Solar</th>
<th>Solar</th>
<th>Energy</th>
</tr>
</thead>
</table>

---

**The F-Chart Program**  
**Retscreen is free version**
**Holocene Technologies**

**Solar Calculation Form**

<table>
<thead>
<tr>
<th>Prepared:</th>
<th>Project:</th>
</tr>
</thead>
<tbody>
<tr>
<td>For:</td>
<td>College Dorm Example</td>
</tr>
<tr>
<td></td>
<td>Name: 250 occupants @ 20 GPD</td>
</tr>
</tbody>
</table>

| Weather: Wilmington, NC | Lat: 34.23 | Tilt: 30 | S. Azm: 0 |

---

### Heating Loads and Solar Equipment

<table>
<thead>
<tr>
<th>Well Temp</th>
<th>Hot Water Gal/Day</th>
<th>Output Temp</th>
<th>Space Heating Btu/DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5000</td>
<td>140</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Collector</th>
<th>Number</th>
<th>Total Area</th>
<th>Storage Gals</th>
<th>Tank Gals</th>
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</thead>
<tbody>
<tr>
<td>AE40</td>
<td>40</td>
<td>1498.8</td>
<td>2200</td>
<td>2000</td>
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### Solar Contribution to Loads

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree Days</th>
<th>DHW Load MBtu</th>
<th>Space Htg. Load MBtu</th>
<th>Total Load MBtu</th>
<th>Solar Energy MBtu</th>
<th>Solar Fraction</th>
<th>Energy per Coll. MBtu</th>
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</thead>
<tbody>
<tr>
<td>Jan</td>
<td>481</td>
<td>64.89</td>
<td>0.00</td>
<td>64.89</td>
<td>21.20</td>
<td>0.34</td>
<td>0.53</td>
</tr>
<tr>
<td>Feb</td>
<td>364</td>
<td>93.84</td>
<td>0.00</td>
<td>93.84</td>
<td>24.40</td>
<td>0.27</td>
<td>0.61</td>
</tr>
<tr>
<td>Mar</td>
<td>252</td>
<td>82.55</td>
<td>0.00</td>
<td>82.55</td>
<td>32.67</td>
<td>0.41</td>
<td>0.82</td>
</tr>
<tr>
<td>Apr</td>
<td>85</td>
<td>97.08</td>
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<td>97.08</td>
<td>36.79</td>
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<tr>
<td>May</td>
<td>7</td>
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<td>22.90</td>
<td>0.98</td>
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<tr>
<td>Jun</td>
<td>0</td>
<td>13.27</td>
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<td>13.27</td>
<td>12.87</td>
<td>1.00</td>
<td>0.32</td>
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<tr>
<td>Jul</td>
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<tr>
<td>Aug</td>
<td>0</td>
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<td>0.00</td>
<td>26.41</td>
<td>22.97</td>
<td>0.90</td>
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<tr>
<td>Sep</td>
<td>0</td>
<td>85.26</td>
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<td>85.26</td>
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<td>56.74</td>
<td>20.91</td>
<td>0.38</td>
<td>0.52</td>
</tr>
</tbody>
</table>

**Totals:**

- DHW Load: 810.66 MBtu
- Space Htg. Load: 0 MBtu
- Total Load: 810.66 MBtu
- Solar Energy: 319.92 MBtu
- Energy per Coll.: 0.39 MBtu

---

**Annual Yield 39.46%**

**Solar Performance Graph**

- Total Load
- Solar Output
## Solar Contribution to Loads

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### Solar Performance Graph

- **Annual Yield**: 39.46%
- **Total Load**
- **Solar Output**
Q & A

Contact Info

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