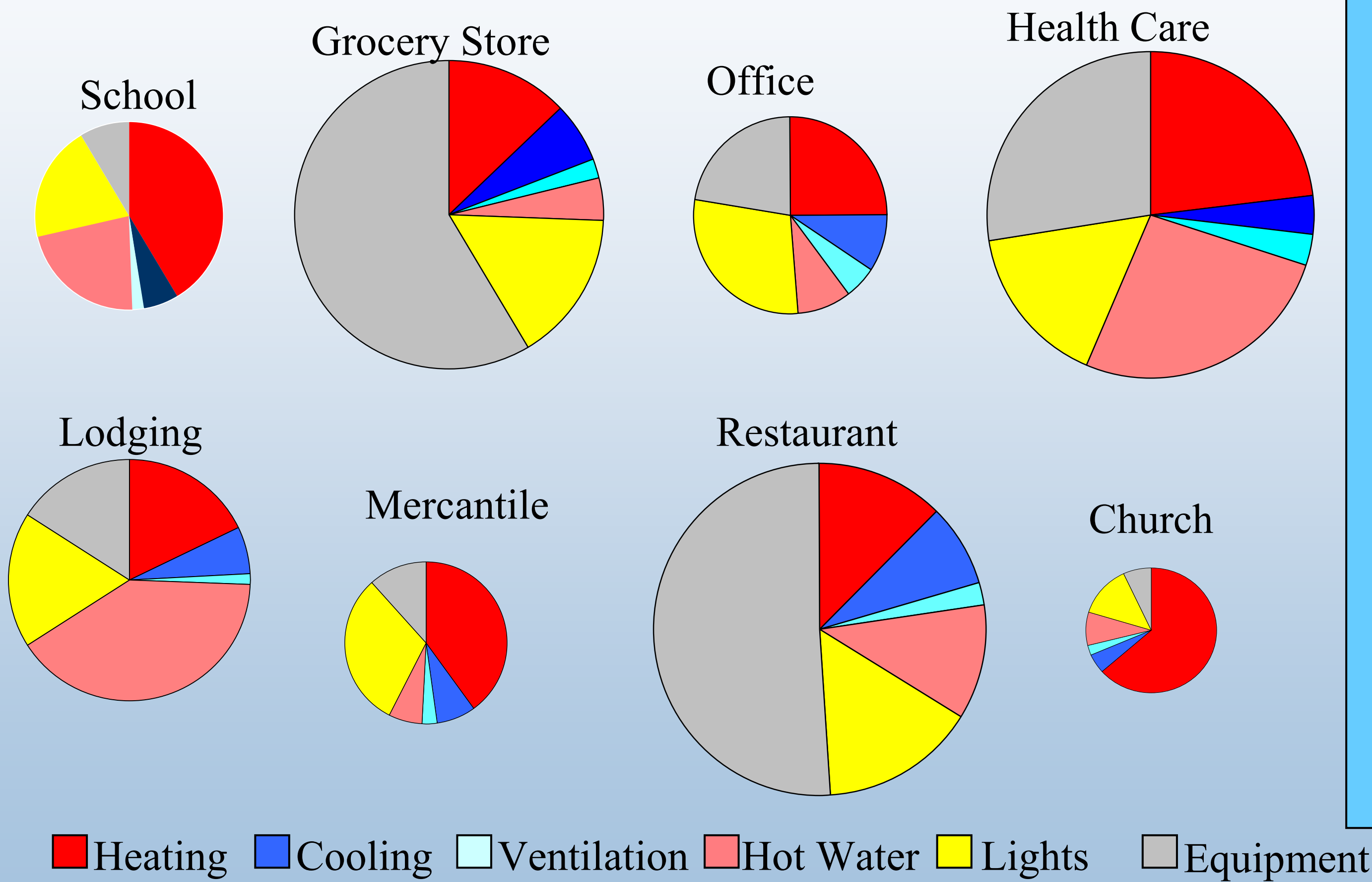
Solar Thermal Technology & Applications

Outline

Solar Water Heating

Solar Air Heating

Building Hot Water Energy Use
average 125 kbtu/sf/year



Energy for Water Heating

kBtu/sf/year

Office	8.7
Mercantile	5.1
Education	17.4
Health Care	63.0
Lodging	51.4
Pub Assembly	17.5
Food Service	27.5
Warehouse	2.0
Food sales	9.1
Public Safety	23.4
Other	15.3
All Buildings	13.8

Solar Water Heating Is Not New!

- Before the advent of gas pipelines and electric utilities, the technology gained footholds in Florida and California before the 1920's
- Over 1,000,000 systems are in use in American homes and business
- The technology is in widespread use in:

  - Caribbean basin
  - Israel
  - Japan
  - China
  - Greece
  - Australia

Technical And Economic Viability Of A Solar System Depends Upon:

- Amount of annual sunshine
- Capital cost of the solar system
- Prices of conventional fuels
- Solar system annual O&M cost
- Annual energy requirement and energy use profile
- Temperature and amount of hot water (kWh produced)
- Rate at which conventional fuels are escalating in price
- Other (e.g. legislative mandates, tax credits)

Solar Hot Water is
Worth Investigating When:

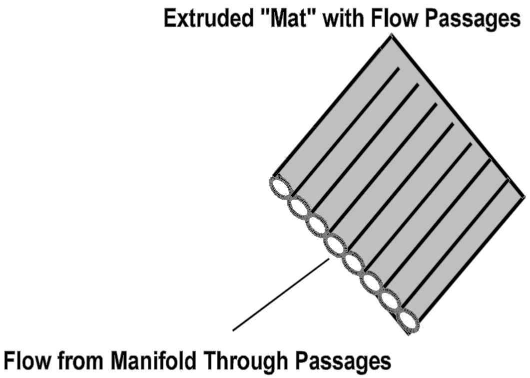
1. Hot water is used in large amounts, daily (absolutely or in terms of gallons per person per day) -- 365 days per year
2. Hot water is produced using electricity and it costs at least $0.055/kwh, or
   hot water is produced using gas or oil costing at least $8.00/million BTU
3. Tax credits or rebates are available
4. The building is properly oriented with respect to the sun
5. Space is available (on the roof?) for the solar panels
6. There is no need to worry about aesthetics
7. Good-to-excellent solar resource

Solar Thermal Applications

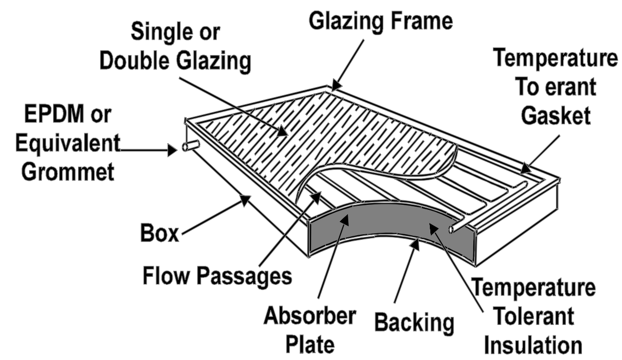
- **Low Temperature (> 30C)**
  - Swimming pool heating
  - Ventilation air preheating
- **Medium Temperature (30C – 100C)**
  - Domestic water and space heating
  - Commercial cafeterias, laundries, hotels
  - Industrial process heating
- **High Temperature (> 100C)**
  - Industrial process heating
  - Electricity generation
- **Solar thermal and photovoltaics working together**

Collector Types

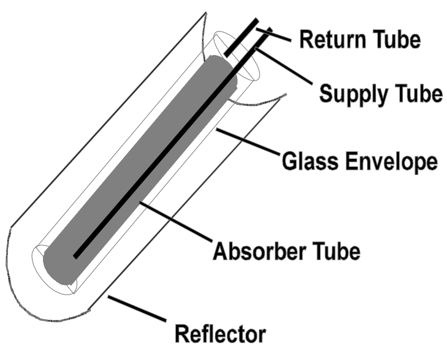
Unglazed EPDM Collector



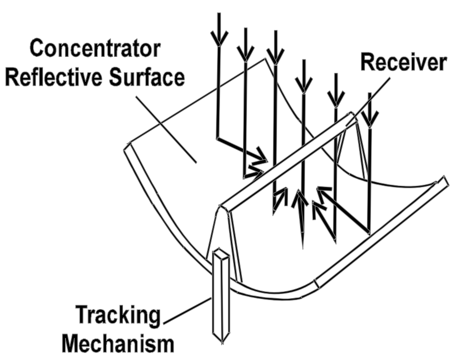
Flat Plate



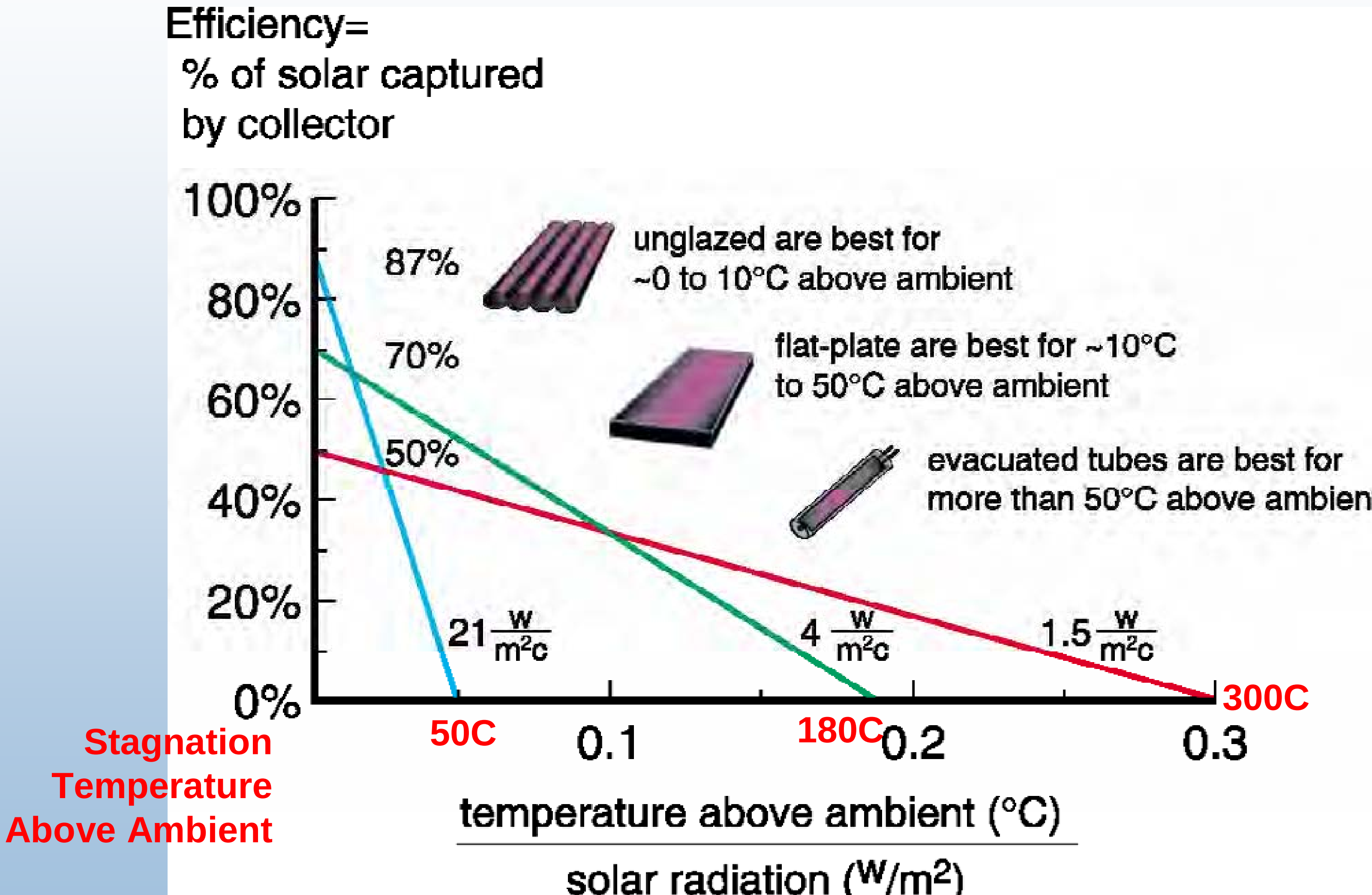
Evacuated Tubes



Parabolic Trough



Which collector is best depends on the temperature...



Solar Rating and Certification Corp.

Contact information

Solar Rating and Certification Corporation
c/o FSEC, 1679 Clearlake Road
Cocoa, FL 32922-5703
Voice (321)638-1537
Fax (321)638-1010
E-mail: srcc@fsec.ucf.edu

- An independent nonprofit organization that tests performance and certifies almost every solar heater on the market today.
- Reports efficiency and annual performance for different climates and temperature uses.

Typical Low Temperature Application

Low Temperture Example:

Barnes Field House, Fort Huachuca, AZ

- 2,000 square feet of unglazed collectors
- 3,500 square feet indoor pool
- Installed cost of $35,000
- Meets 49% of pool heating load
- Saves 835 million Btu/ year of natural gas
- Annual savings of $5,400
- Installed by the Army in June, 1980.

Mid-Temperature Example:
Chickasaw National Recreation Area, OK

Small Comfort Stations
- 195 square feet of flat plate collectors
- 500 gallon strorage volume
- Cost $7,804
- Delivers 9,394 kWh/year
- Saves $867 / year

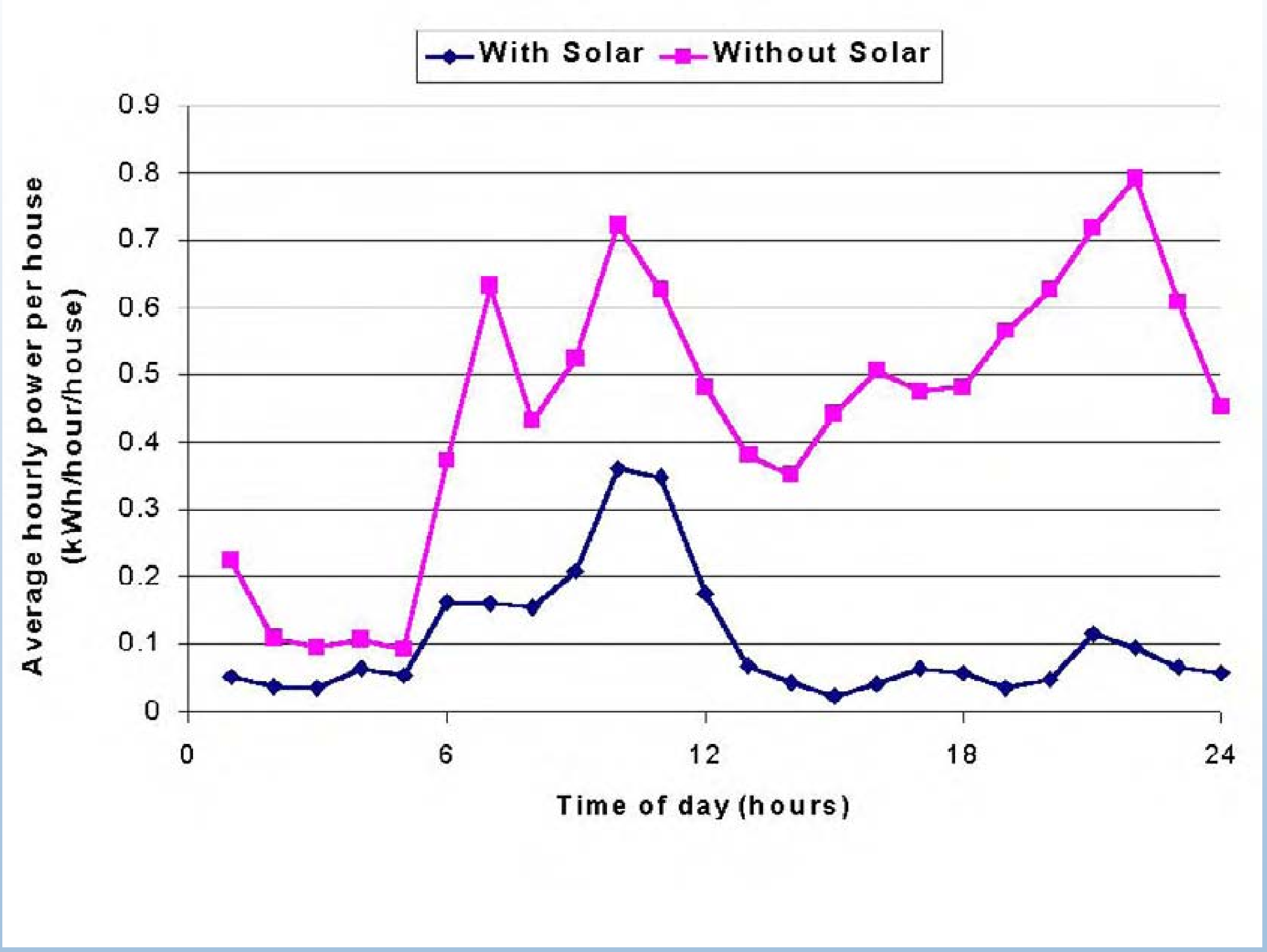
Large Comfort Stations
- 484 square feet of flat plate collectors
- 1000 gallon strorage volume
- Cost $16,100
- Delivers 18,194 kWh/year
- Saves $1,789 / year

Mid Temperature Example:

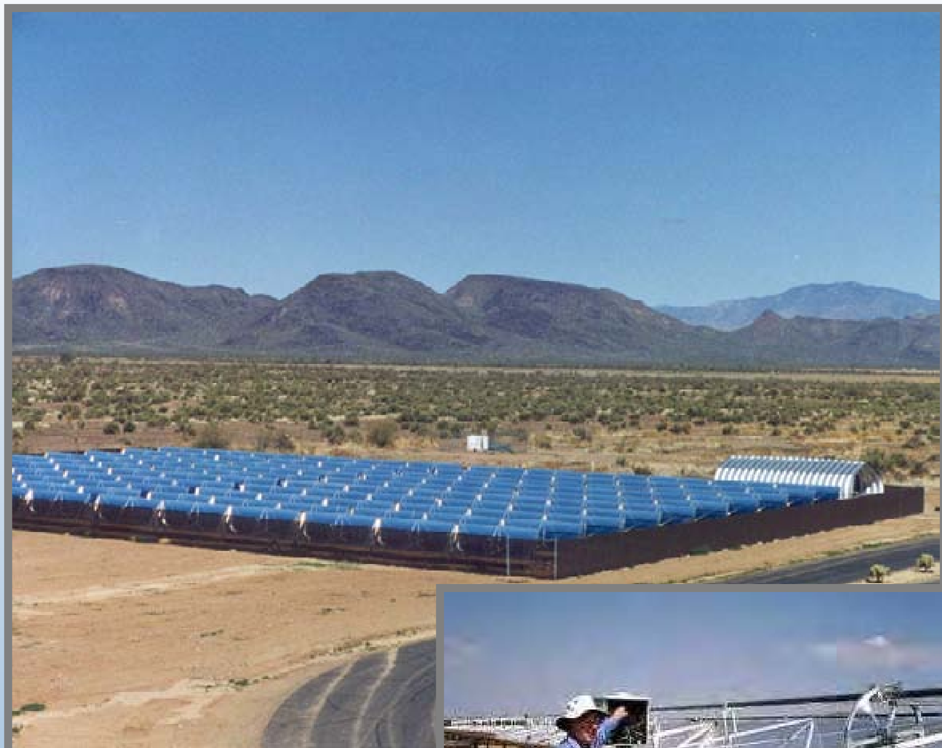
USCG Kiai Kai Hale Housing Area, Honolulu HI

- 62 units installed 1998
- Active (pumped), Direct systems
- Average cost $4,000 per system
- 80 sf per system
- $800 per system HECO rebate
- Savings of 9,700 kWh/year and $822/year per system
- Simple Payback 4 years (with rebate)

USCG Housing, Honolulu HI

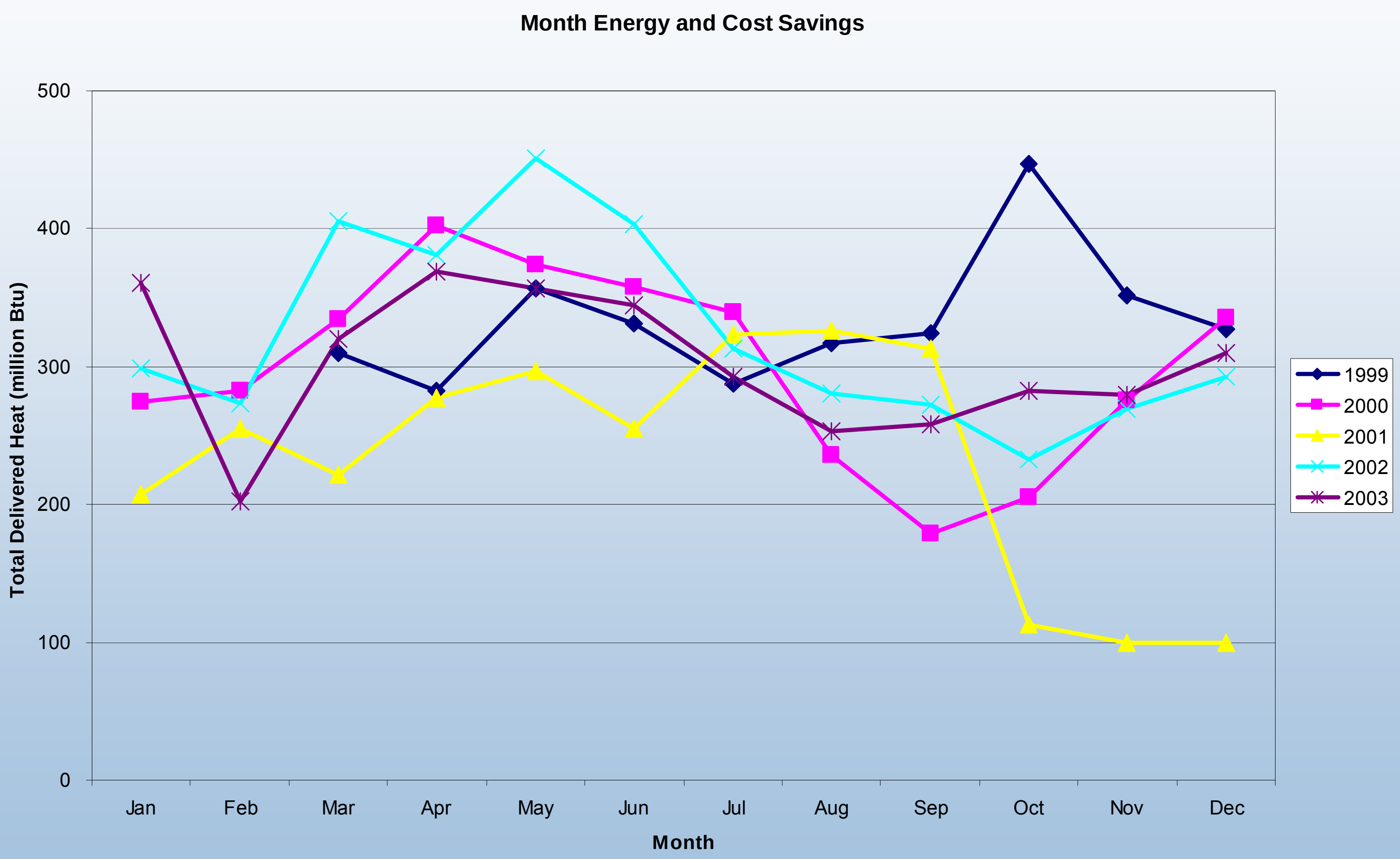


High Temperature Example:
Phoenix Federal Correctional Institution



- 17,040 square feet of parabolic trough collectors
- 23,000 gallon storage tank
- Installed cost of $650,000
- Delivered 87.1% of the water heating load in 1999.
- Saved $77,805 in 1999 Utility Costs.
- Financed, Installed (1998) and Operated under Energy Savings Performance Contract with Industrial Solar Technology, Inc.
- The prison pays IST for energy delivered by the solar system at a rate equal to 90% of the utility rate (10% guaranteed savings), over 20 years.

High Temperature Example: Phoenix Federal Correctional Institution



Simple Evaluation Procedure

- Estimate Daily Water Heating Load
- Determine Solar Resource
- Calculate Solar System Size
  - meet load on sunniest day
  - undersize rather than oversize
- Calculate Annual Energy Savings
- Calculate Annual Cost Savings
- Estimate System Cost
- Calculate Savings-to-Investment Ratio and Simple Payback Period

Daily Water Heating Energy Load

$$L = MC\,(T_{hot} - T_{cold})$$

L = Daily Hot Water Energy Load (kWh/day)

M= mass of water per day (kg/day),
3.785 kg/gallon

C = specific heat of water =
0.001167 kWh/kg°C

T_{hot}= hot water delivery temperature (°C),
often 50 ° C = 120 ° F

T_{cold} = cold water temperature (° C),
often 13 ° C = 55 ° F

Typical Hot Water Usage:

Dormitory	13 gal/day/person
Motel	15 gal/day/unit
Hospital	18 gal/day/bed
Office	1 gal/day/person
Food Service	2.4 gal/meal
Residence	40 gal/day/person
School	1.8 gal/day/student

Solar Energy Resource

- Collectors should face south (in northern hemisphere)
- Tilt Angle=latitude maximizes annual gain (lat+15°for winter, lat-15° for summer)

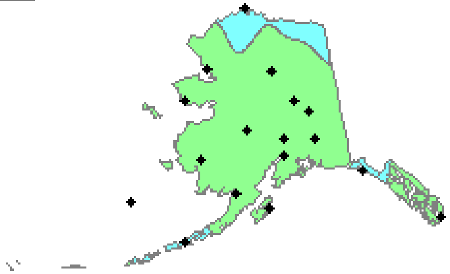
Location	I Max	I Ave (kWh/m2/day)
Anchorage, AK	4.6	3.0
Austin, TX	6.3	5.3
Boston, MA	5.6	4.6
Chicago, IL	5.7	4.4
Denver, CO	6.1	5.5
Fargo, ND	6.5	4.6
Honolulu, HI	6.5	5.5
Jacksonville, FL	6.1	4.9
Sacramento, CA	7.2	5.5
San Diego, CA	6.5	5.7
Seattle, WA	5.7	3.7

For COMPLETE data on hundreds of sites, check out www.nrel.gov

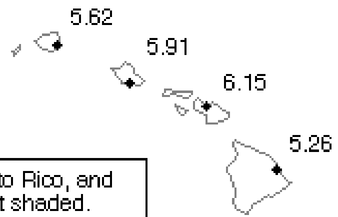
Maximum Daily Solar Radiation Per Month

ANNUAL

Alaska

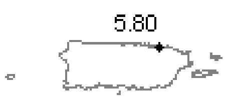


Hawaii

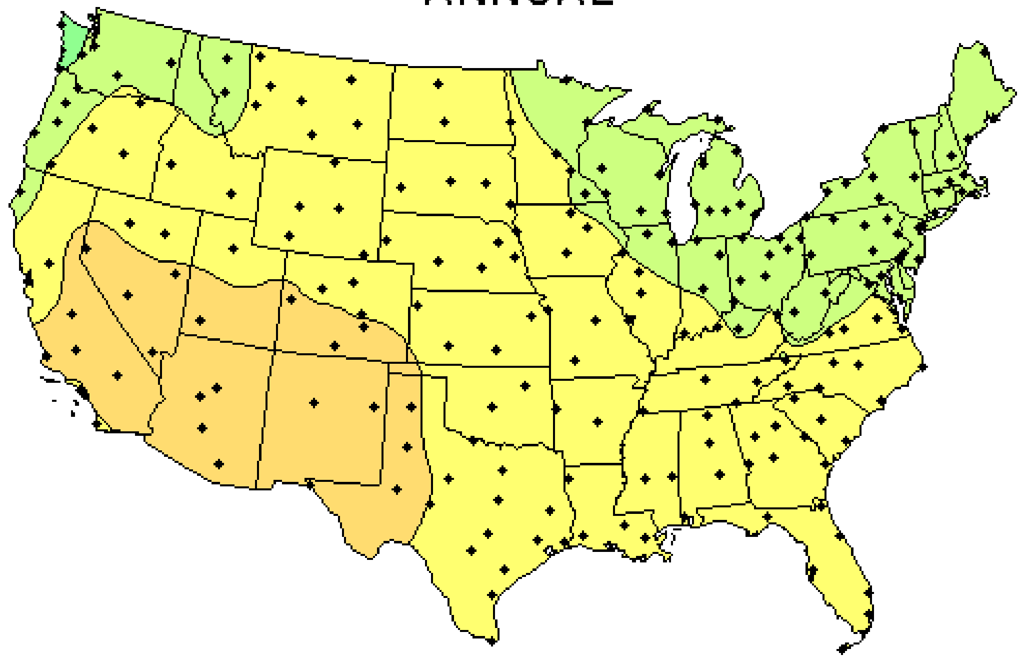


Hawaii, Puerto Rico, and Guam are not shaded.

San Juan, PR



Guam, PI



Flat Plate Tilted South at Latitude

Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site: Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

FEMP
FEDERAL ENERGY MANAGEMENT PROGRAM

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

NREL

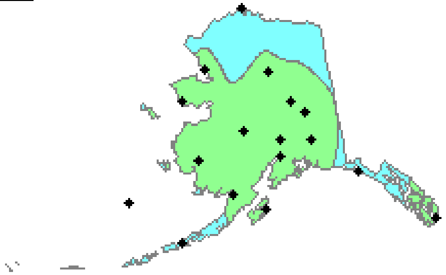
National Renewable Energy Laboratory
Resource Assessment Program

$kWh/m^2/day$

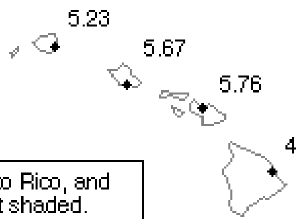
- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

FLATU13-23

Alaska



Hawaii



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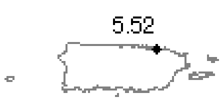
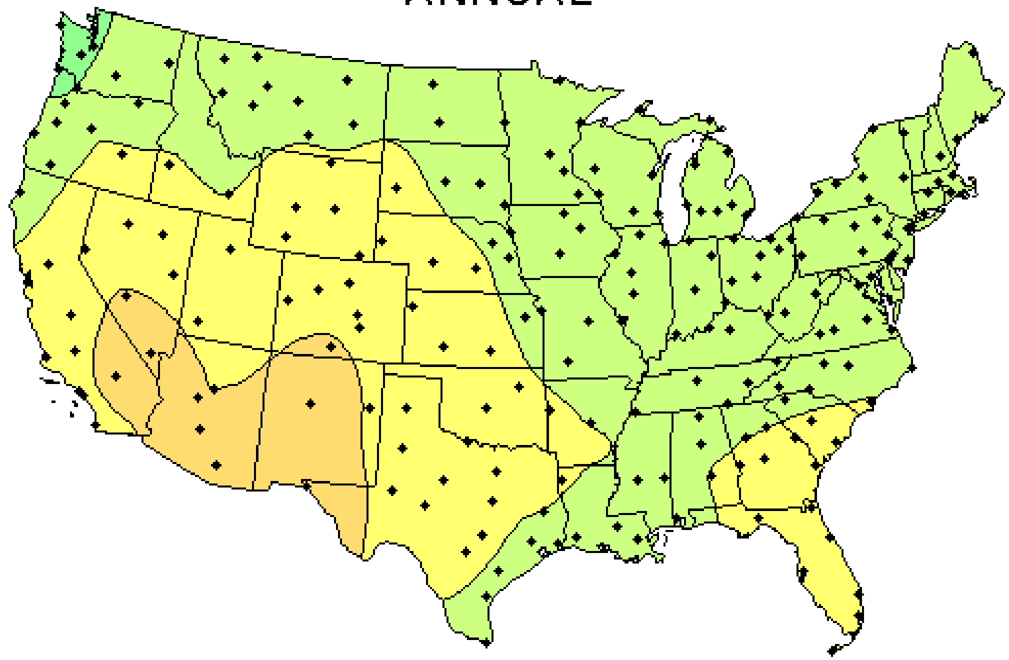


Guam, PI

Average Daily Solar Radiation Per Month

ANNUAL



Flat Plate Tilted South at Latitude

Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site: Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

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National Renewable Energy Laboratory
Resource Assessment Program

$kWh/m^2/day$

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

FLATA13-208

Solar Water Heating System Size and Delivery

Solar Water System Size

$$A_c = \frac{L}{(\eta_{solar} I_{max})}$$

A_c = collector area (m^2)

L = Daily Load (kWh/day)

η_{solar}= efficiency of solar system (typically 0.40)

I_{max} = maximum daily solar radiation ($kWh/m^2/day$)

Annual Energy Saving

$$E_s = \frac{A_c I_{ave} \eta_{solar} 365}{\eta_{boiler}}$$

I_{ave} = average solar radiation (kWh/m2/day)

η_{boiler} = auxiliary heater efficiency

- gas = 0.43 to 0.86, assume 0.57
- electric = 0.77 to 0.97, assume 0.88
- heat pump assume 3.0
- propane= 0.42 to 0.86, assume 0.57
- oil = 0.51 to 0.66, assume 0.52

Source: GAMA

Solar Water Heating System Cost and Savings

Solar System Cost

$$C = c_{solar} A_c$$

C = Installed Cost of Solar System ($)

c_{solar} = per-unit-area cost of installed solar system ($/$m^2$), typically

$400/ m^2 for large system

$1000/$m^2$ for small systems

$750/ m^2 might be average

Annual Cost Savings

$$S = E_s C_e$$

S = annual cost savings ($/year)

Ce = cost of auxiliary energy typically:

Electricity $0.084/kWh

Solar Water Heating System Cost Effectiveness

Savings-to-Investment Ratio

SIR = S*pwf / C

project is cost effective if SIR>1.

pwf = present worth factor for future savings stream, = 17.4 years for 25 year lifetime and 3% real discount rate (specified by NIST for 2003).

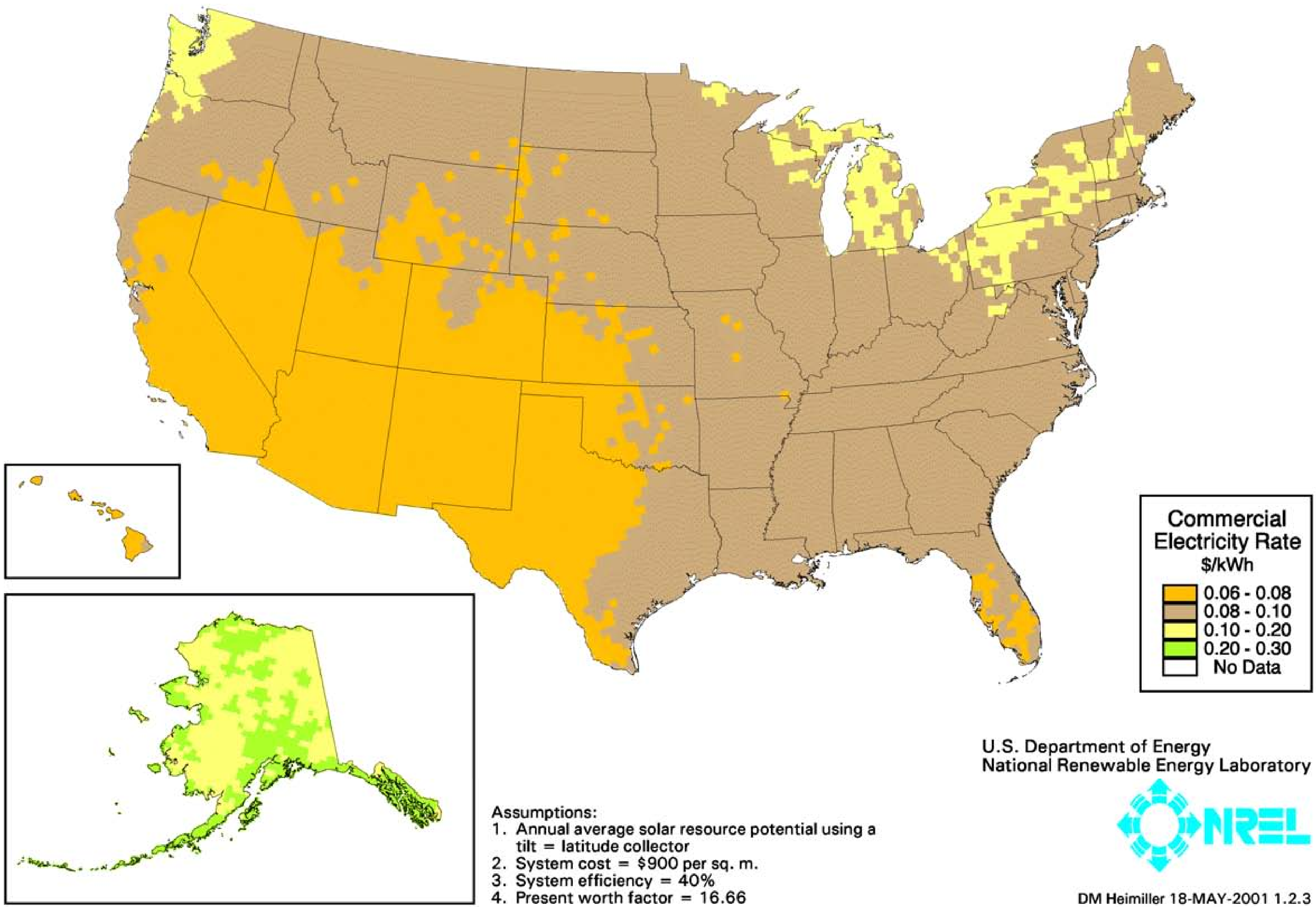
Simple Payback Period

SPB = C / S

Example: 4 person residence in Chicago against electricity

- M=4person*40gal/person/day*3.785 kg/gal=**606 kg/day**
- L=MC(T_{hot}-T_{cold}) =606 kg/day*0.001167kWh/kgC*(50C-18C) =**22.6 kWh/day**
- For Chicago IL, Imax = 5.7 and I ave = 4.4 kWh/m2/day
- **A_c = L / (η_{solar} I_{max})** = 22.6 kWh/day / (0.4 * 5.7 kWh/m2/day) =9.9 **m2**
- **E_s = A_c I_{ave} η_{solar} 365/ η_{boiler}** = 9.9 m2 * 4.4 kWh/m2.day * 0.4 * 365days/year / 0.88 = **6,556 kWh/year**
- **C = c_{solar} A_c** = $1000/m2 * 9.9 m2 = **$9,900**
- **S = E_s C_e** = 7,227 kWh/year * $0.084/kWh = **$607/year**
- **SIR = S*pwf / C** = $607/year * 17 years / $9,900 = **1.04**
- ***SO IT IS COST EFFECTIVE!***

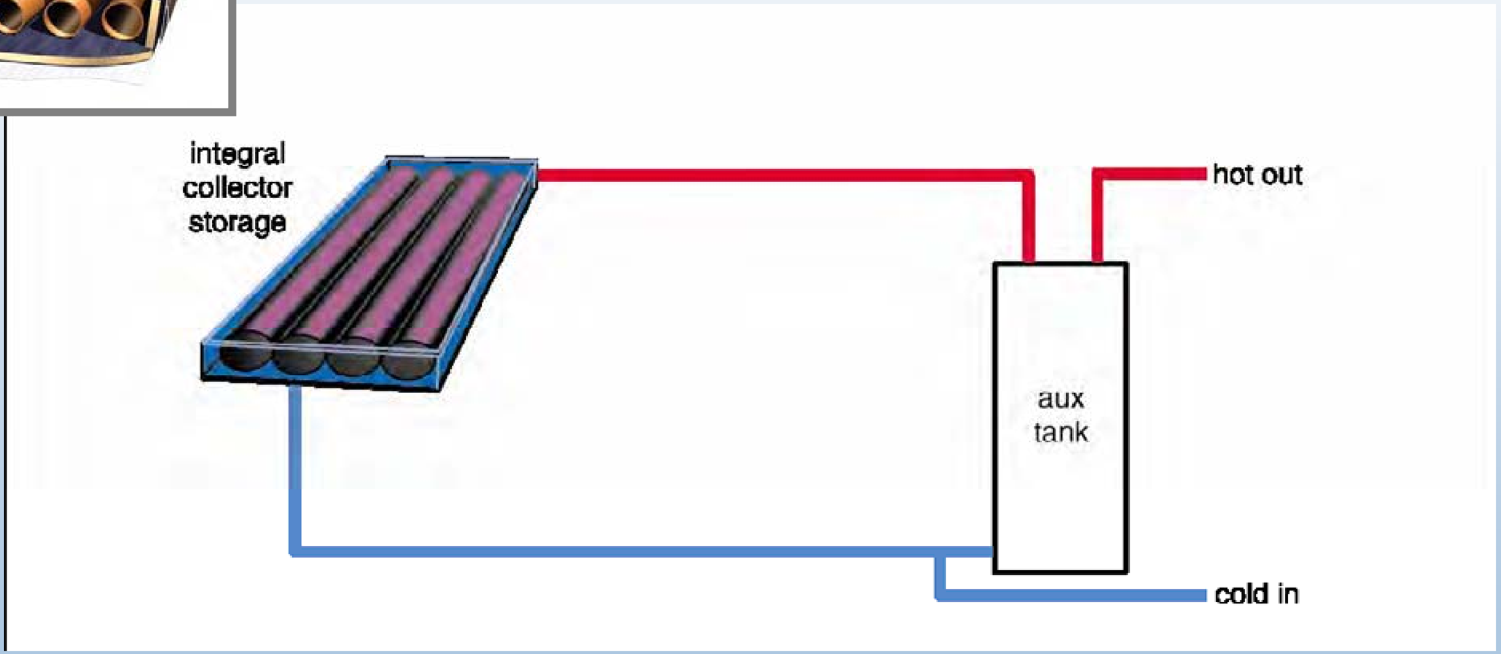
Solar Hot Water: Electricity Rate Corresponding to Savings to Investment Ratio = 1



System Types

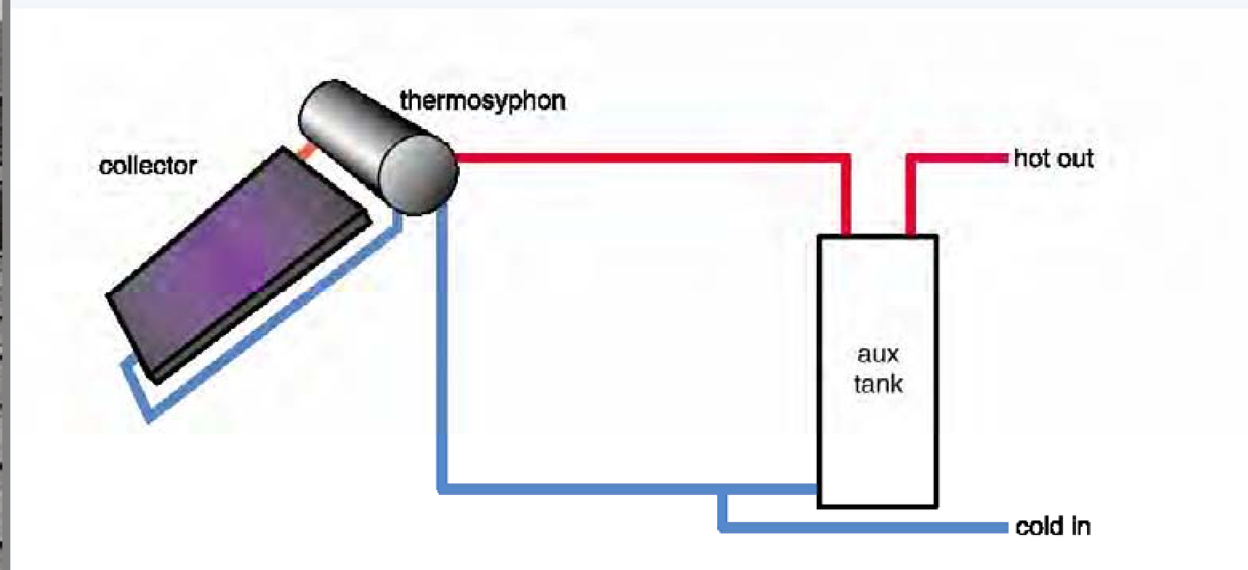
- Passive Systems (no pumps)
  - Integral Collector Storage
  - Thermosyphon
- Active Systems (pumps & controls)
  - Open Loop:
    - Direct
    - Drain Down
  - Closed Loop:
    - Drain Back
    - Antifreeze

Passive, Integral Collector Storage (ICS) Direct System



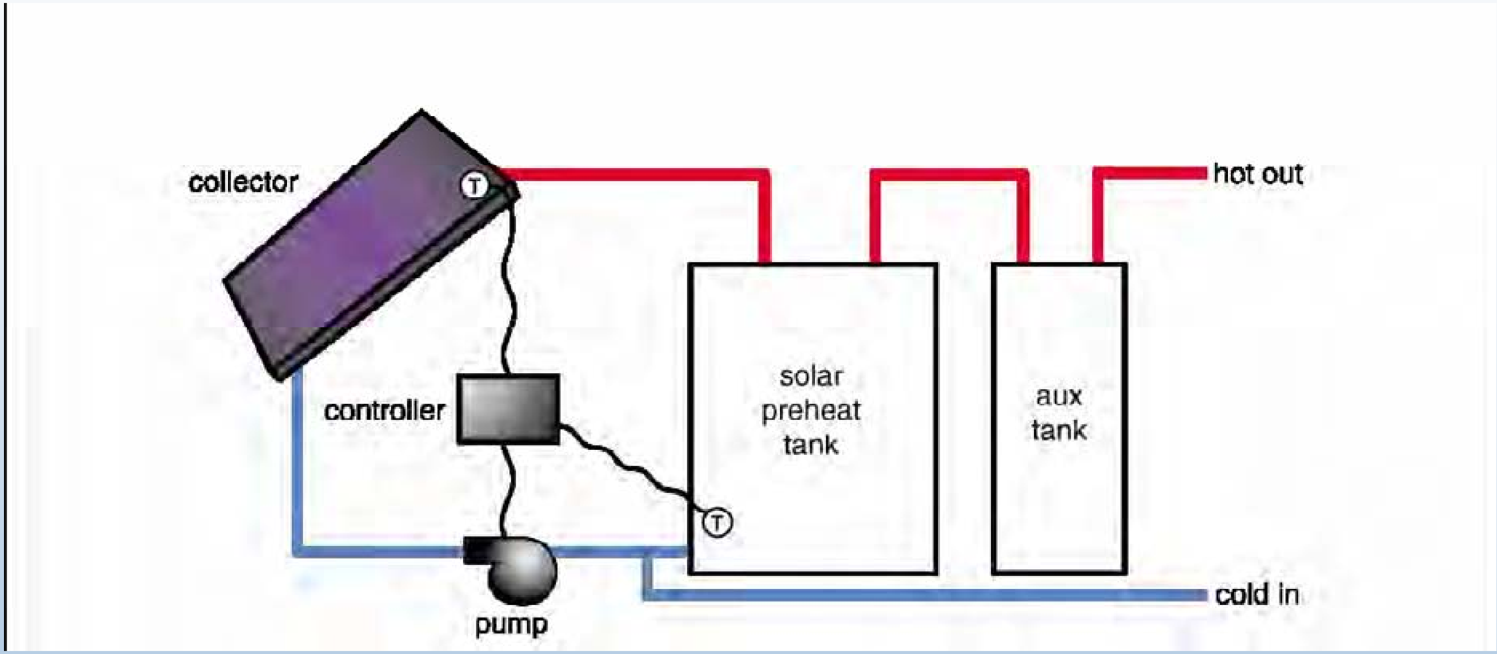
- Moderate freeze protection (pipes at risk)
- Minimal hard water tolerance
- Very low maintenance requirements

Passive, Thermosyphon, Direct System



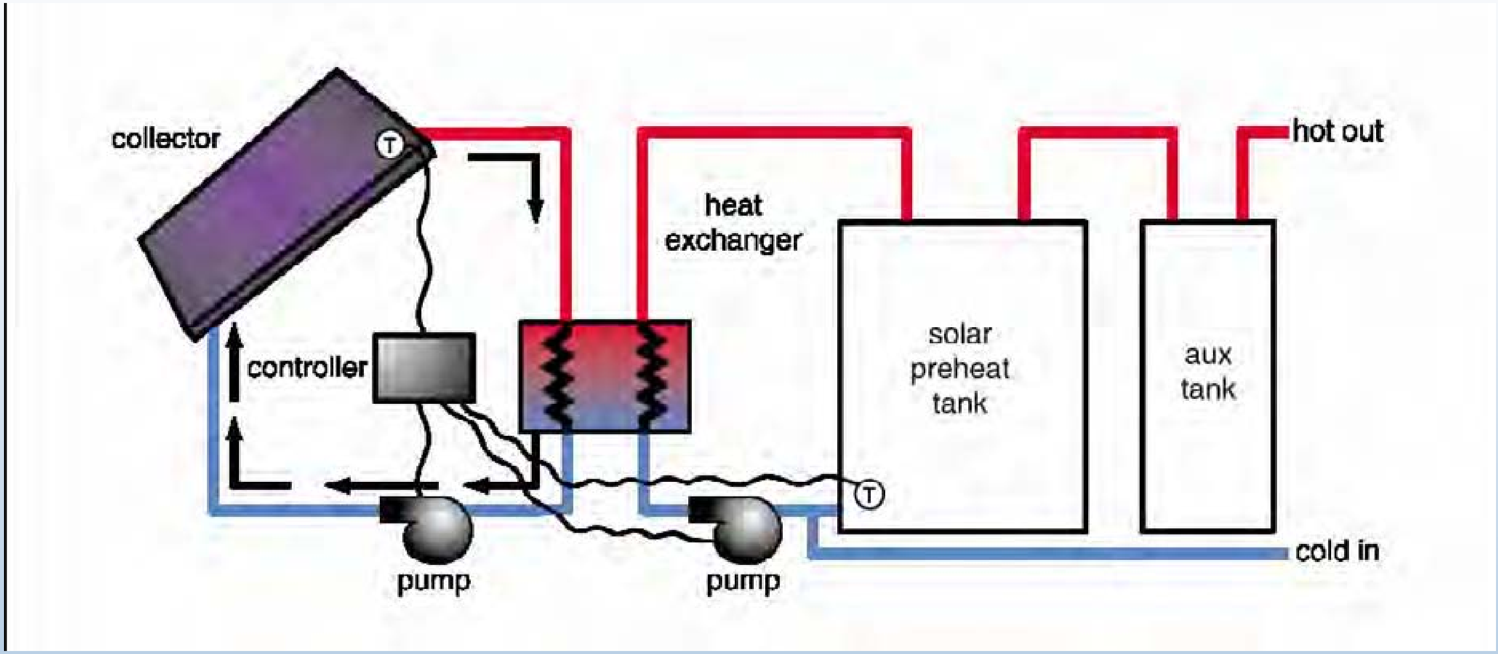
- Auxiliary element can also be in tank above collector, eliminating the auxiliary tank altogether.
- No freeze protection
- Minimal hard water tolerance
- Low maintenance requirements

Active, Open-loop, Pumped Direct System



- No freeze protection
- Minimal hard water tolerance
- High maintenance requirements

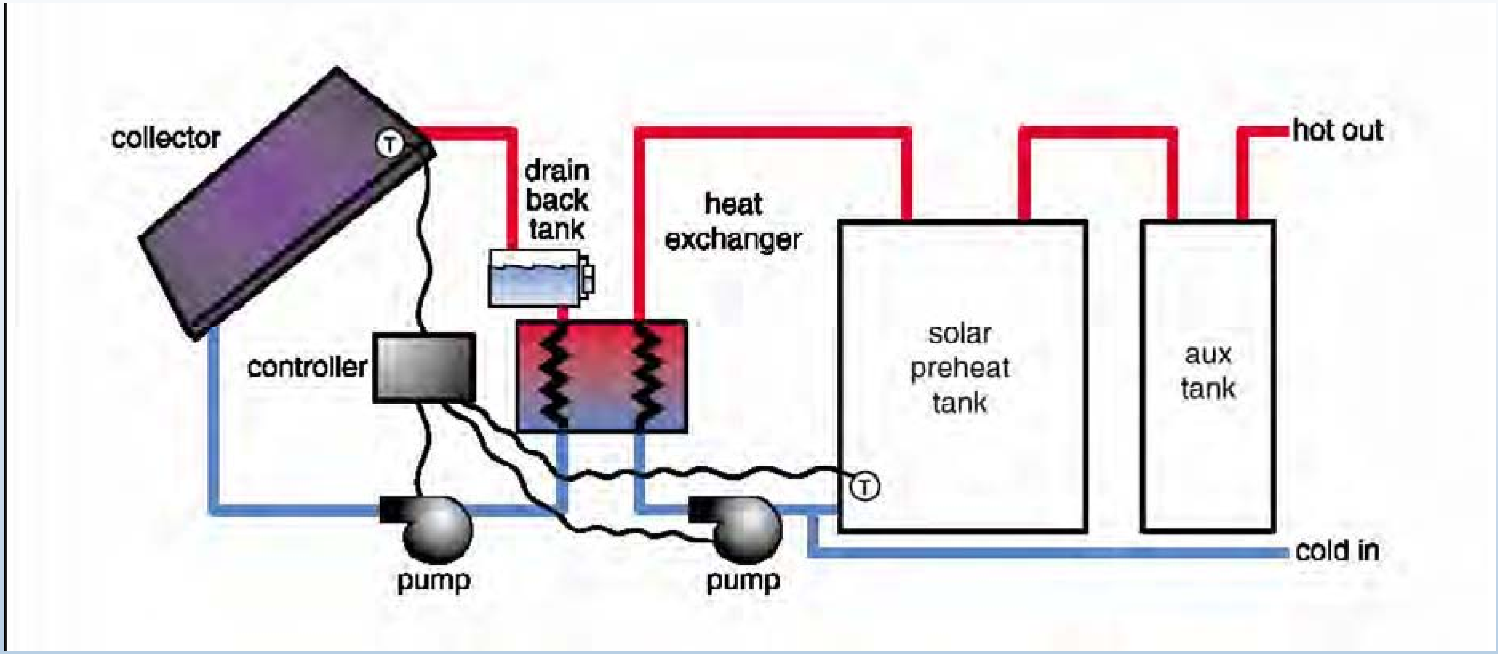
Active, Closed-loop (antifreeze), Indirect System



- Excellent freeze protection
- Good hard water tolerance
- High maintenance requirements

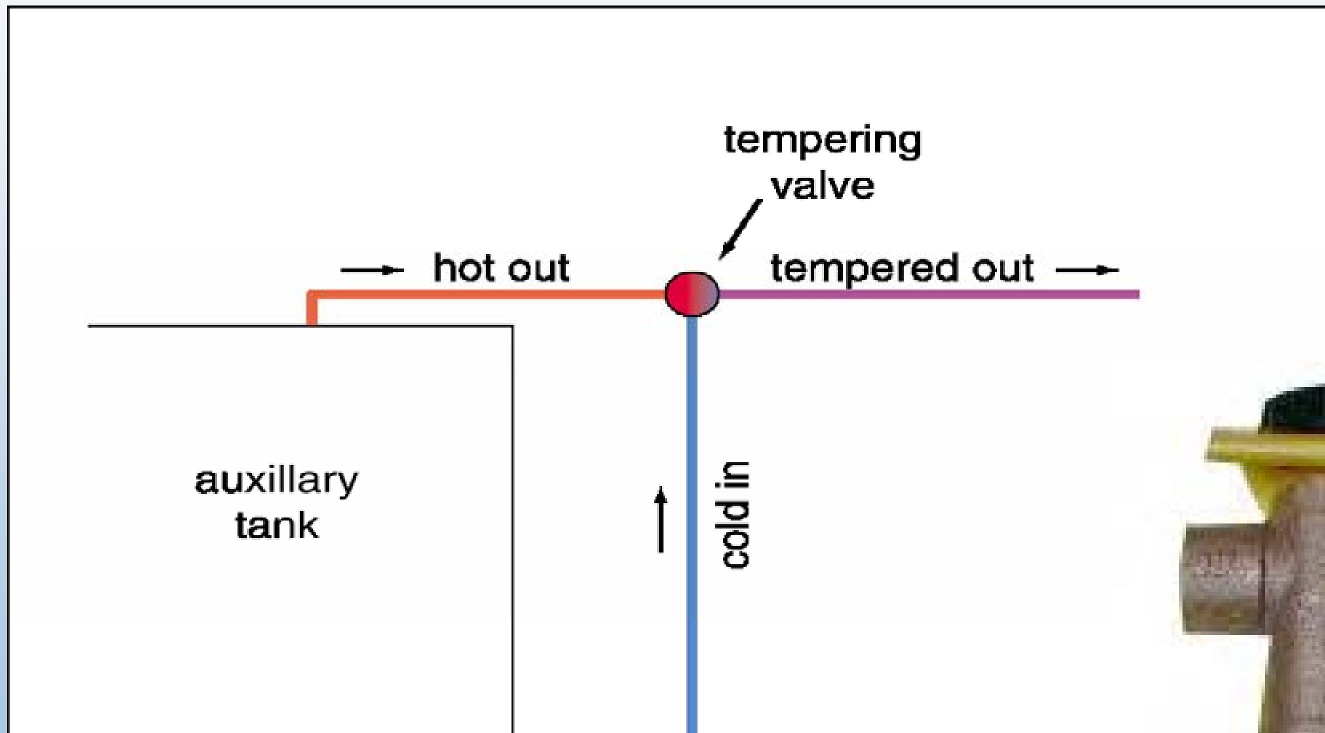
Mazatlan, Mexico; El Cid Mega Resort

Active, Closed-loop, Drainback, Indirect System



- Good freeze protection
- Good hard water tolerance
- High maintenance requirements

Tempering Valve to Prevent Scalding: Extremely Important for Safety!



Promising Potential Candidates For Solar Water Heating Systems

1. Residential
   - Single family homes
   - Low-income or subsidized homes and housing developments
   - Apartment buildings with central boilers
2. Commercial
   - Casinos, Hotels and motels
   - Health care facilities
   - Restaurants
   - Spas, pools and health clubs
3. Government
   - Single family housing units
   - Food service facilities
   - Correctional facilities
   - Hospitals and clinics
   - Dormitories
   - Recreational facilities/swimming pools

Procuring Solar Water Heating Systems

- Look for the best opportunities within your Tribe:
  - Large water heating loads.
  - High cost of backup energy.
  - Constant loads throughout week and year.
  - Area for collectors.
  - Facility “champions.”

Requirements for Success

- Appropriate Application (Provide a Reasonable Payback)
- Proven Design
- Freeze Protection
- Properly Sized (undersized, not oversized)
- Require No Manual Intervention
- Operational Indicators or Monitoring
- Conservation First
- Verify Load
- Performance Guarantee
- Require Operations and Maintenance Manual and Training
- Acceptance Test

A Tribal Energy Service Organization (TESO) could bring the following to the table:

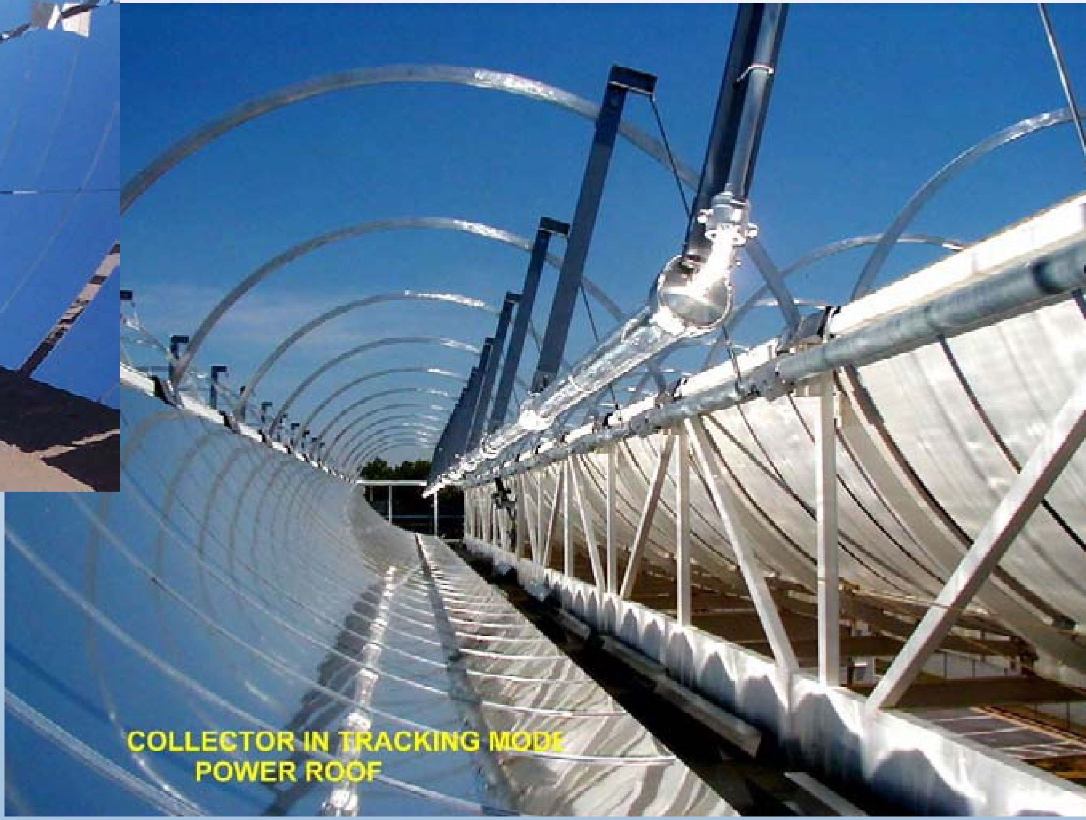
- Establish a basis for local economic development
- Save homeowners, renters, and housing departments money
- Help reestablish pride of ownership (personal sovereignty) through energy independence
- Aggregate community for lower-cost financing
- Provide steady employment that goes hand-in-hand with home efficiency and weatherization improvements.

Help in implementing your solar water heating project:

- Solar Energy Industries Association and local chapters.
- Experienced private-sector suppliers & installers.
- National Laboratories.
- State energy offices.

Resources and References

- **American Society of Heating, Air Conditioning and Refrigeration Engineers, Inc.**
  - ASHRAE 90003 -- Active Solar Heating Design Manual
  - ASHRAE 90336 -- Guidance for Preparing Active Solar Heating Systems Operation and Maintenance Manuals
  - ASHRAE 90346 -- Active Solar Heating Systems Installation Manual
- **Solar Rating and Certification Corporation**
  - SRCC-OG-300-91 -- Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems


COLLECTOR IN TRACKING MODE
POWER ROOF

Outline

Solar Water Heating

Solar Air Heating

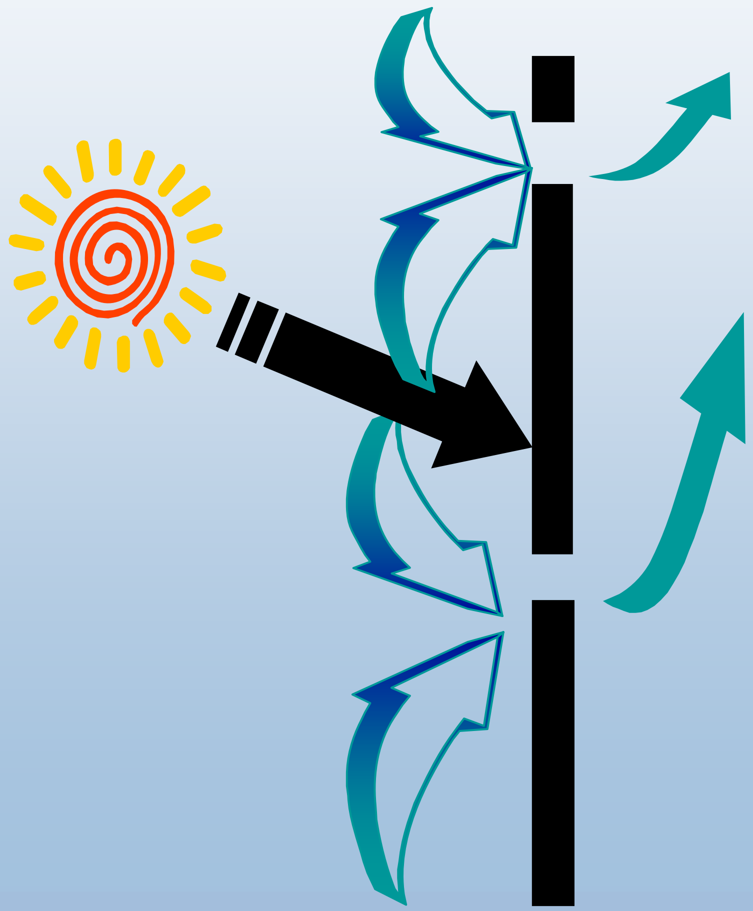
Objectives

- Explain the operating principle of a transpired solar collector.
- Explain solar ventilation air preheating systems and their appropriate applications.
- Discuss how to assess the viability (cost and performance) of a solar ventilation preheating system at a specific site.

Topical Outline

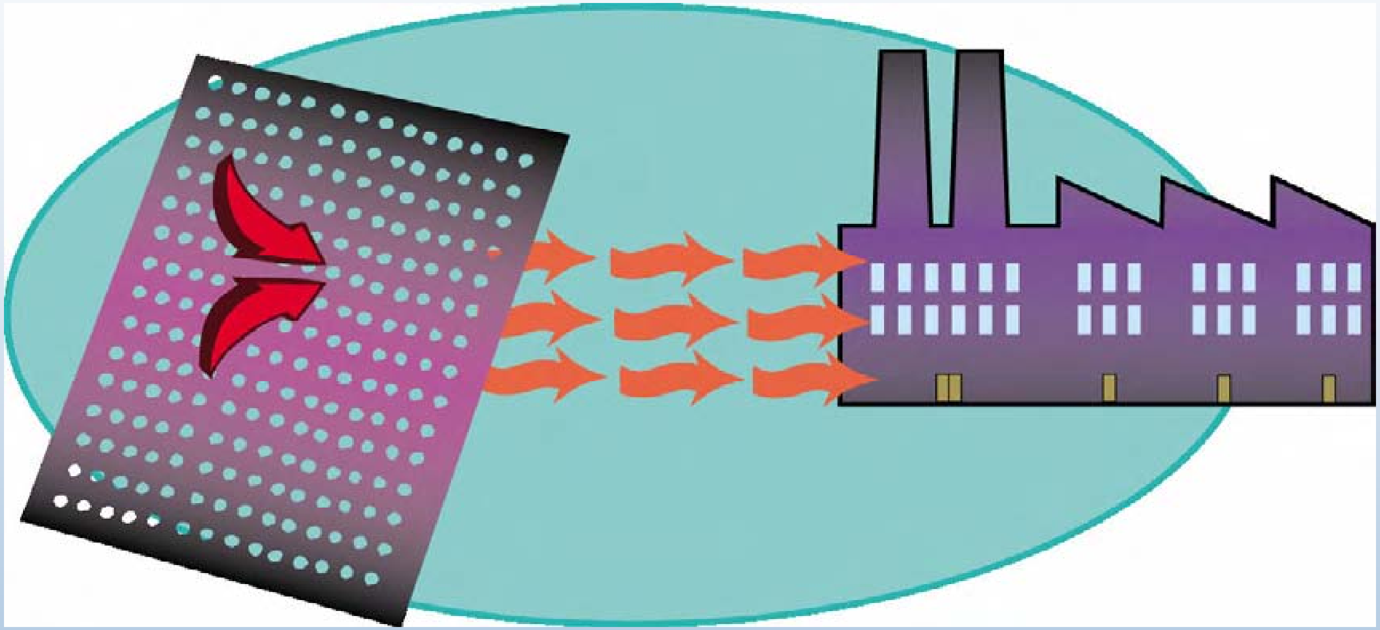
- Technology Overview
- Cost and Performance
- Examples of Successful Systems
- Requirements for Successful Systems
- Design Considerations

Transpired Collector Principle



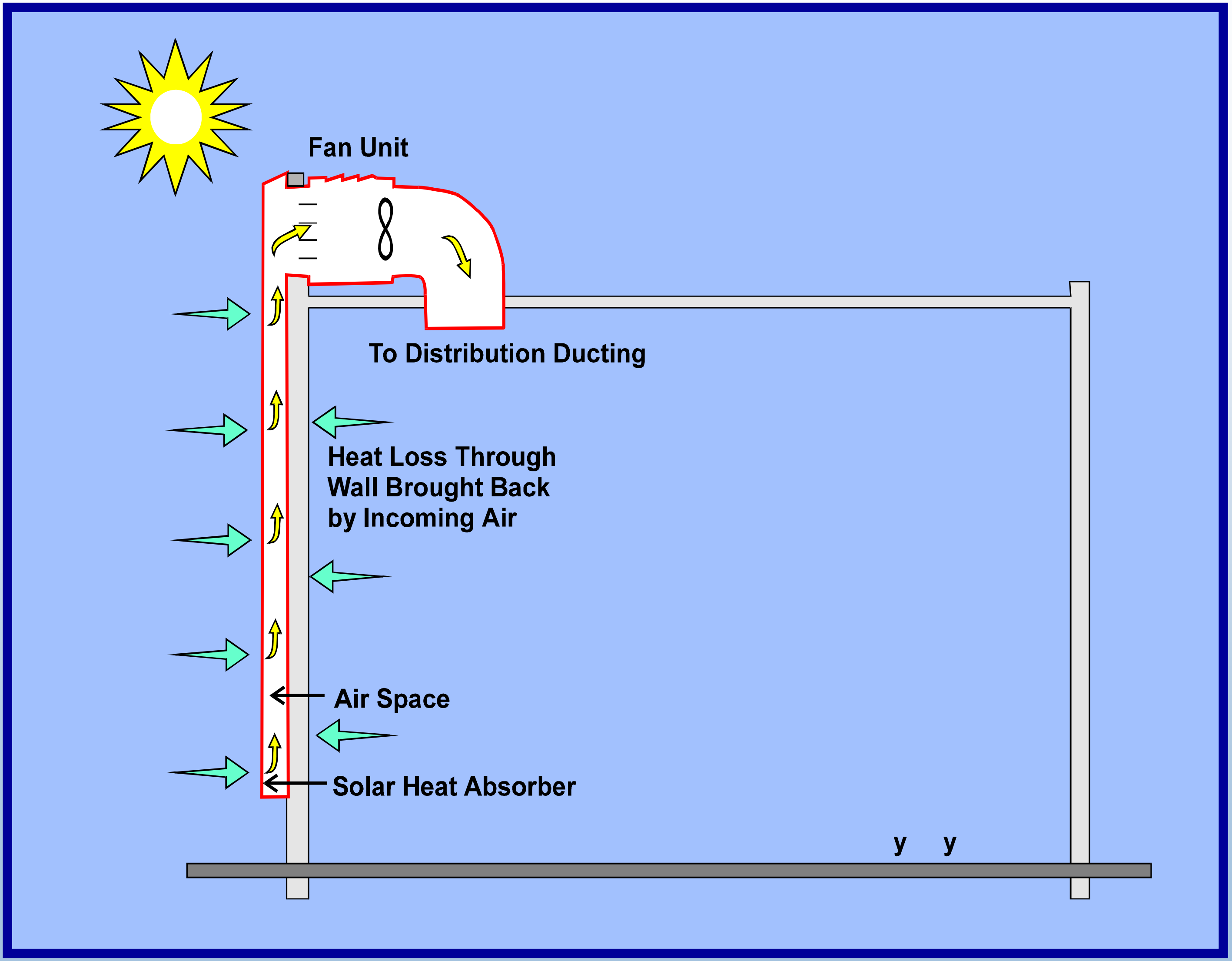
- Sun warms the surface
- Heat conducts from surface to thermal boundary layer of air 1 to 3 mm thick
- Velocity boundary layer of air is drawn into hole before heat can escape by convection

Transpired Collector Principle



- Efficient radiant-to-air heat exchanger
- Once-through process, no recirculation to collector inlet.

Solar Ventilation Preheating System



Summer Operation

- Bypass damper brings outside air directly in, bypassing solar wall.
- The stack effect causes outside air to enter the solar cladding along the bottom and rise to the top where it exits through holes in the outer skin.
- The net result is that any unwanted solar gain will be transferred to the air and not to the interior of the wall. (collector shades the south wall)
- Sun is higher in the sky in summer, shines primarily on the roof, not on the south wall.

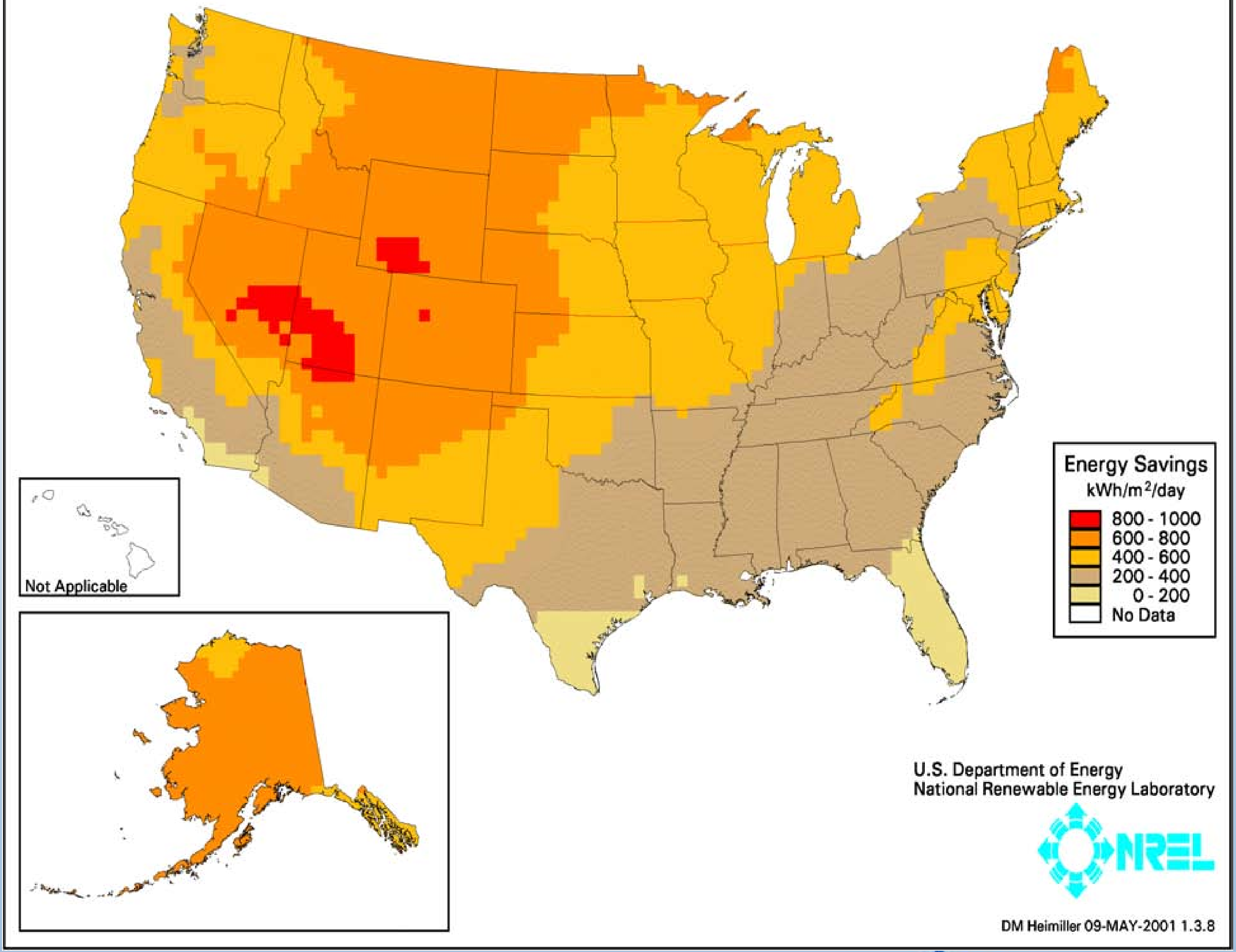
Typical Applications

- Preheating ventilation air for:
  - Industrial and maintenance buildings.
  - School and institutional buildings.
  - Apartment buildings.
  - Commercial and penthouse fans.
  - Aircraft hangers.
- Crop drying
- Process air heating

When to Consider

- New construction.
- Requirements for outside air and fan intake near south wall (includes penthouse walls--retrofit and new) exist.
- For retrofit, south wall is uninsulated and requires new cladding.
- Available south wall area.
- High ventilation requirements.
- High air quality needed.

Energy Savings Utilitizing Solar Vent Preheating Technology



…other benefits

- Ventilation air introduced high in high-bay space destratifies air, resulting in lower ceiling and exhaust air heat loss.
- Positive pressure on building reduces incoming drafts, increasing comfort.
- Looks better than an old, dilapidated facade

Advantages of Transpired Collectors

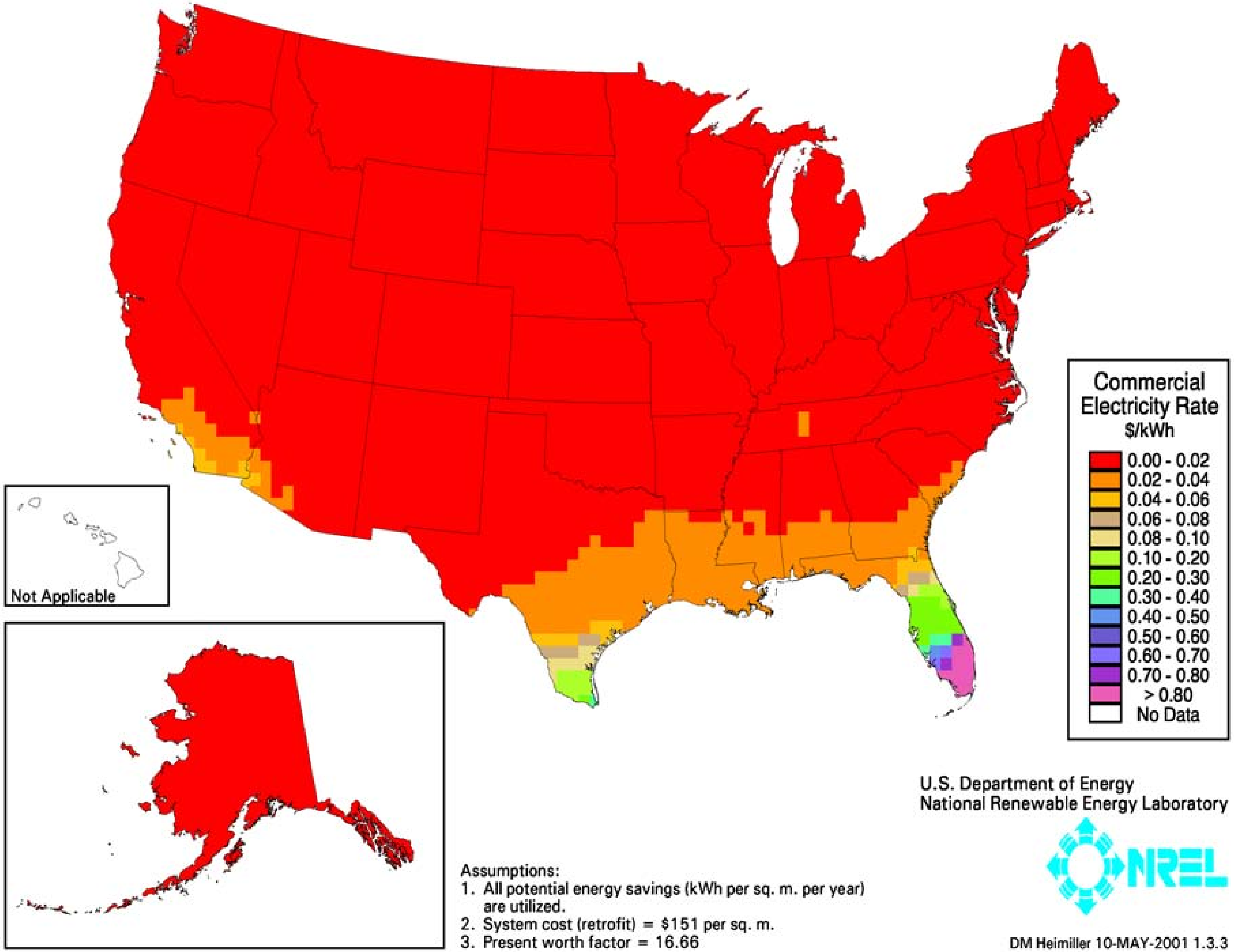
- Very low cost.
- Extremely reliable (no moving parts but fan).
- No maintenance.
- High Efficiency (up to 80%).
- Operates near ambient temperature.
- No problems with freezing or fluid leaks.
- No storage required.

Solar Ventilation Preheat System Costs

- Installation Costs in Retrofit Applications
  - Absorber $3.50/ft^2
  - Supports, Flashing, Etc. $2.50/ft^2
  - Installation $4.00/ft^2
  - Other Costs $4.00/ft^2
  - Total **$14.00/ft^2**

- In new construction, subtracting $4 to $7 for displaced facade gives net installed cost of $7 to $10 per ft^2

Solar Vent Preheat: Electricity Rate Corresponding to Savings to Investment Ratio = 1



Example: NREL Chemical Storage

- 300 ft^2
- Saves 14,310 kWh/year
- 3,000 CFM
- Saves $360/year of electric heat (no flames allowed in building)
- Payback = 4.7 years

Example: Ford Engine Assembly, Canada

- 20,000 ft^2
- Saves $30,000/year
  - 17% of plant's air heating costs
- 5 year payback period

Example: GM Battery Plant, Canada

- 4,520 ft^2
- 40,000 CFM
- Saves 940 Mbtu/year
  - Q solar = 678 Mbtu/yr
  - Q htrec = 262 Mbtu/yr
- Saves $10,200/year
- Cost $66,530 ($14.72/ft2), including duct modifications
- Payback period = 6 years

Example: Federal Express Denver, CO

Federal Express in Denver

- 5,000 ft^2 (465 m^2) system
- 45,000 cfm
- Saves 2,300 million BTU/year
- Saves $12,000 per year
- Lease payments $4,800/ year
- FEDEX saves $7,200 /year for the 10 year term of the lease.

Summary

- More than 1,000,000 square feet of solar ventilation preheat systems installed.
- Multiple systems monitored, including Ford, General Motors, and NREL (63% efficiency over 3 years).
- Computer design program available.
- Winner of multiple awards; featured in *Popular Science, Popular Mechanics, R&D Magazine*, and *Energy Users News.*