U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON 2011

Renewable Energy for the Homeowner: How to Prepare for Renewable Energy Options

Michael J Brandemuehl, PhD, PE, FASHRAE
University of Colorado **Boulder**
michael.brandemuehl@colorado.edu

Overview

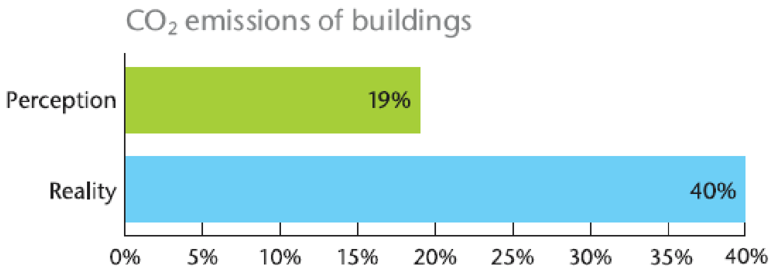
- Residential energy use
  - Role in US energy use
  - End use by location, age, size, etc.
  - Typical costs
- Opportunities for energy efficiency improvements in existing homes
  - Envelope
  - HVAC system
  - Behavior
- Renewables for homeowners
  - Water Heating
  - PV

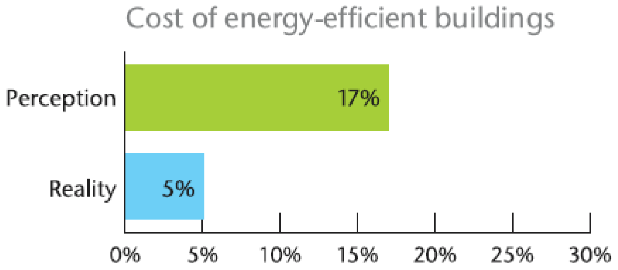
Recognizing the Opportunity

- What percentage of CO_2 emissions in the developed world come from buildings (materials as well as annual operations)?
- How much more would it cost to build more energy efficient buildings, say, 30% better than today's average?

Recognizing the Opportunity

- Survey of building professionals in US, Europe, Japan, Brazil, India, China in 2007
- Most people don't understand





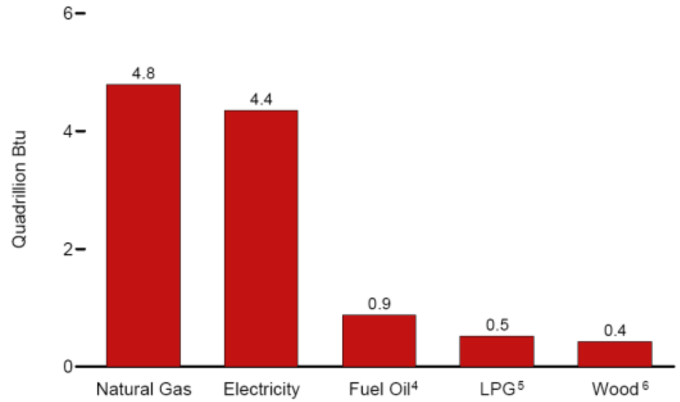
Source: WBCSD 2008

Impact of Buildings in U.S.

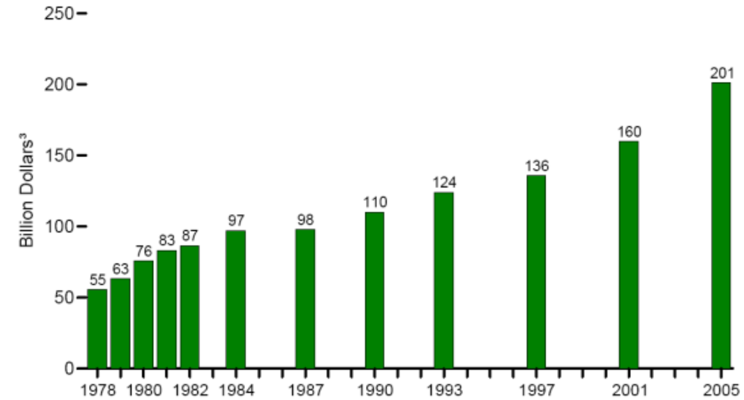
- 41% of energy use
  - Residential: 22%
  - Commercial: 19%
- 72% of electricity use
- 40% of greenhouse gas emissions
  - US: 20% of global GHG with 4.6% of population

Residential Energy Consumption

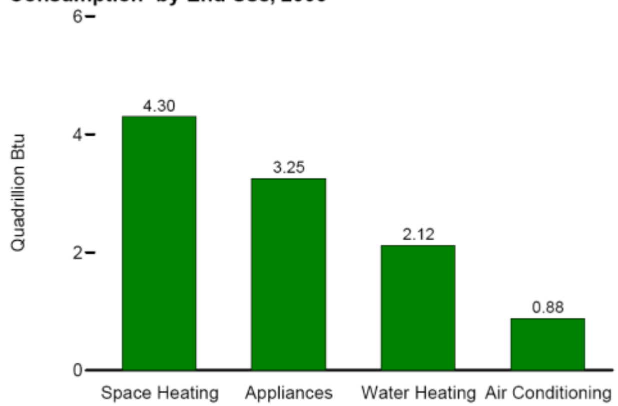
Consumption by Energy Source, 2005



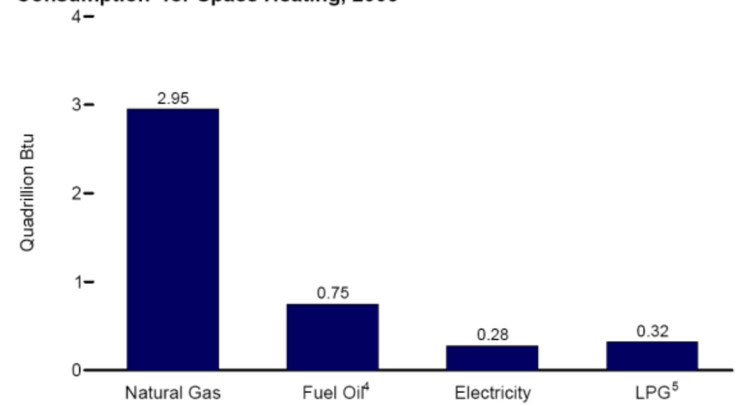
Expenditures[1], Selected Years, 1978-2005[2]



Consumption[1] by End Use, 2005

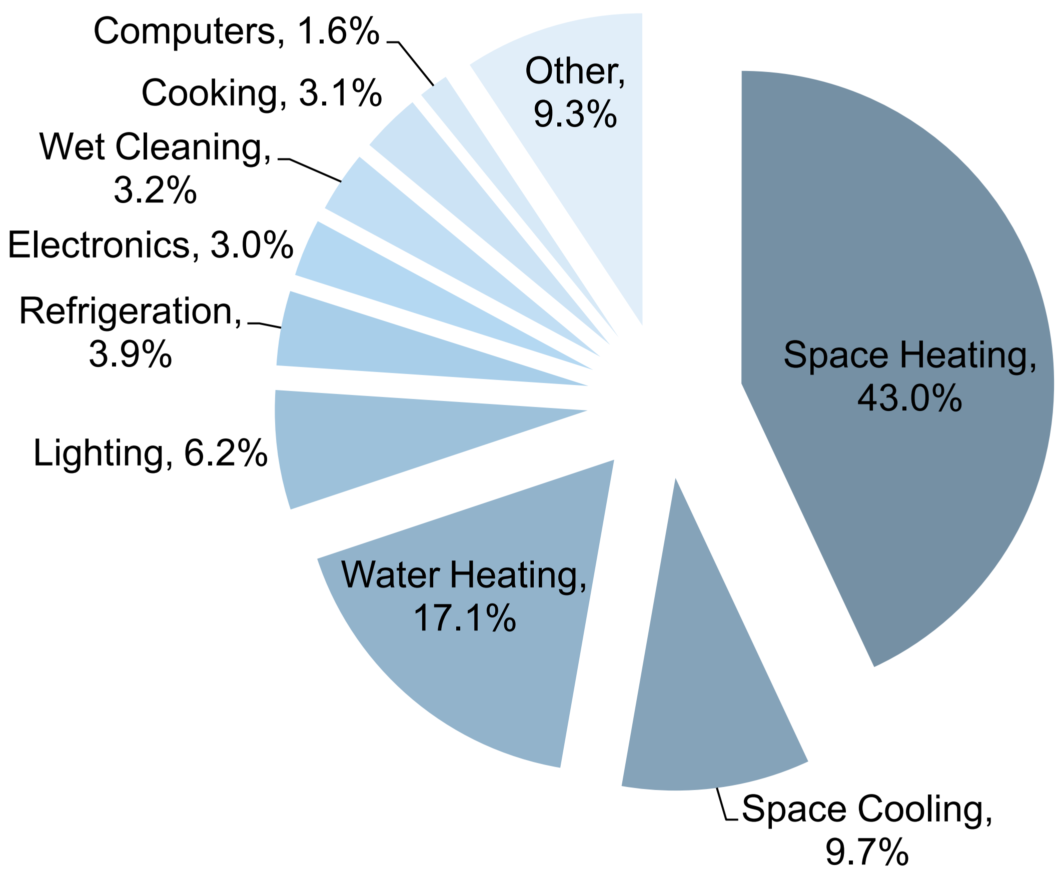


Consumption[1] for Space Heating, 2005

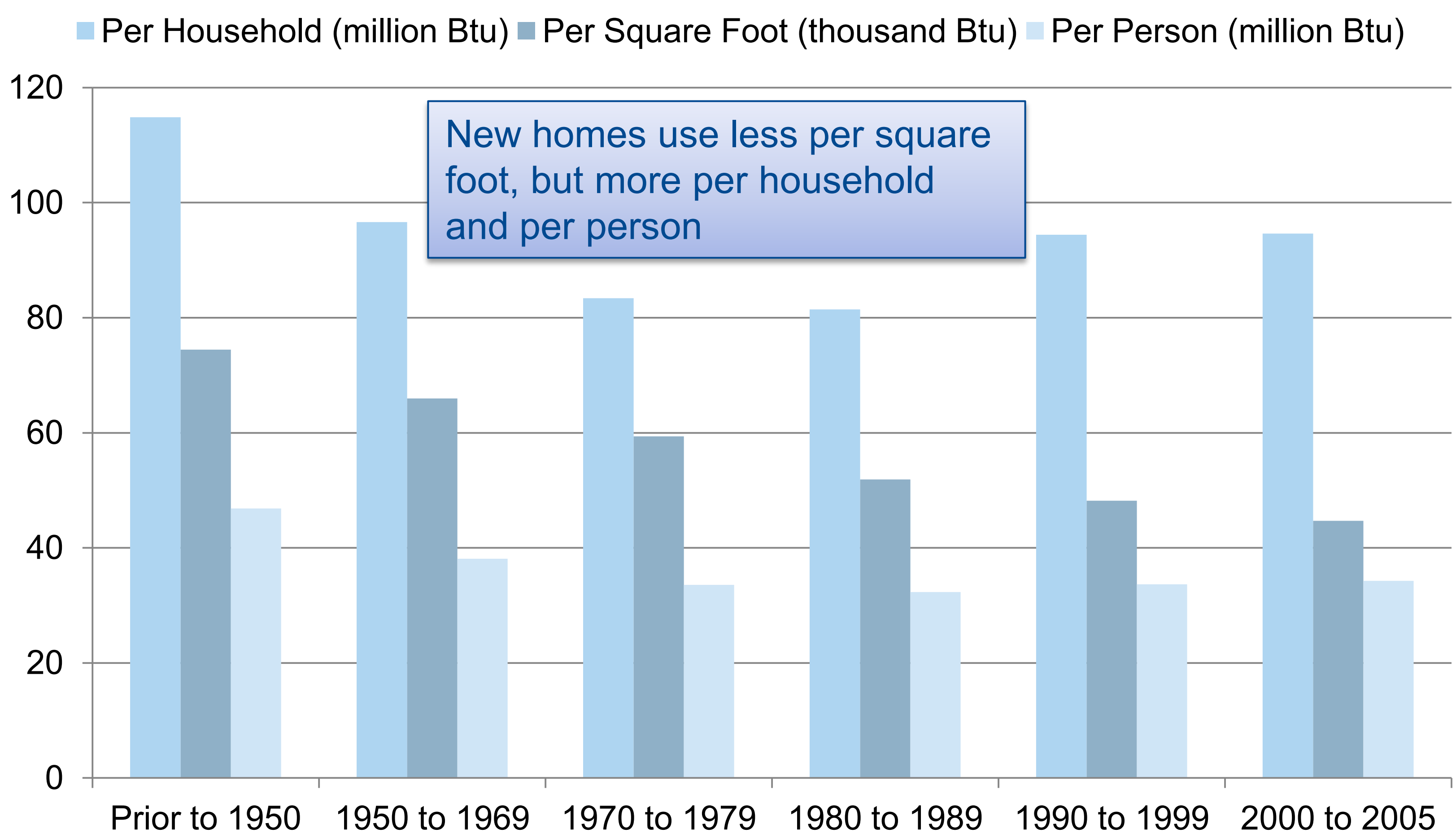


[1] Does not include wood, which is used for both space heating and ambiance.
[2] For years not shown, there are no data available.
[3] Prices are not adjusted for inflation. See "Nominal Dollars" in Glossary.
[4] Distillate fuel oil and kerosene.
[5] Liquefied petroleum gases.
[6] Used for both space heating and ambiance.
Source: Table 2.5.

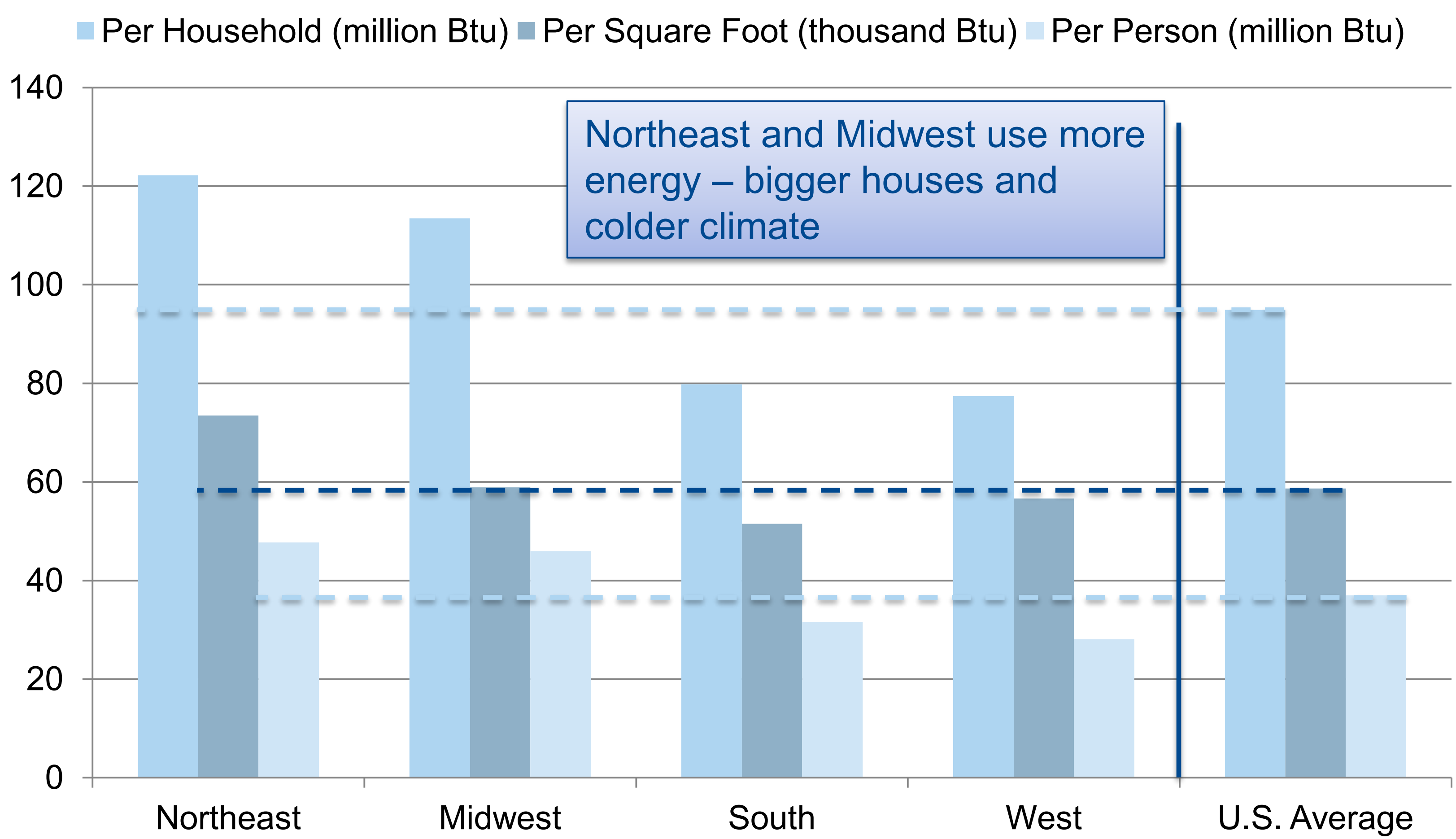
Site Energy Consumption by End-Use



Energy Consumption by Vintage

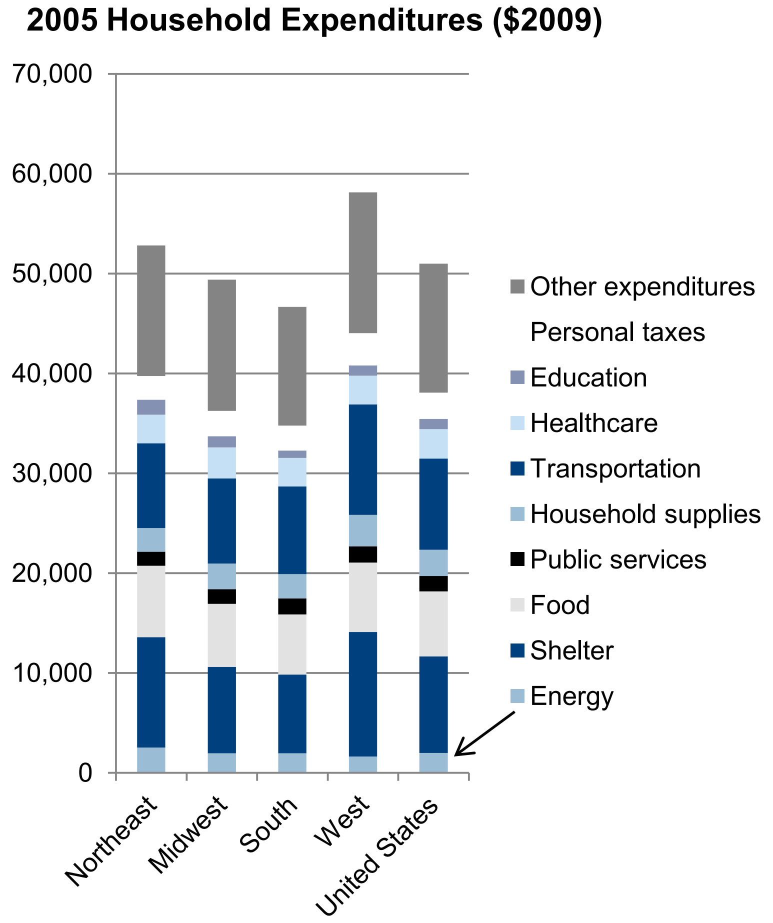


Energy Consumption by Region



Energy Expenditures

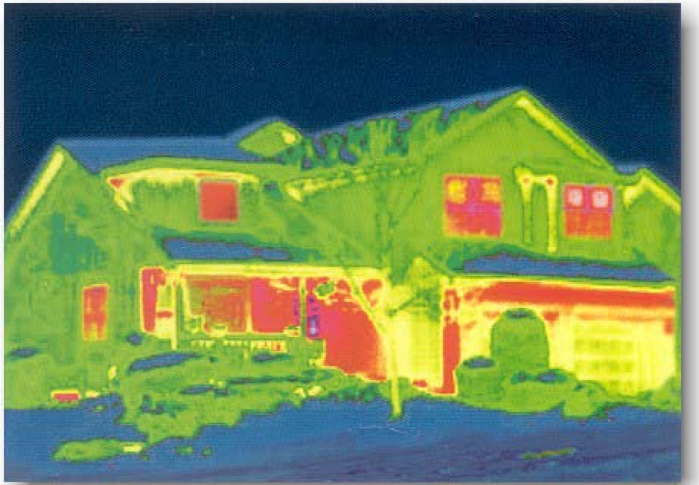
- The typical US household spends 3% of its income on energy costs
- Nationally, energy expenditures are 8% of gross domestic product

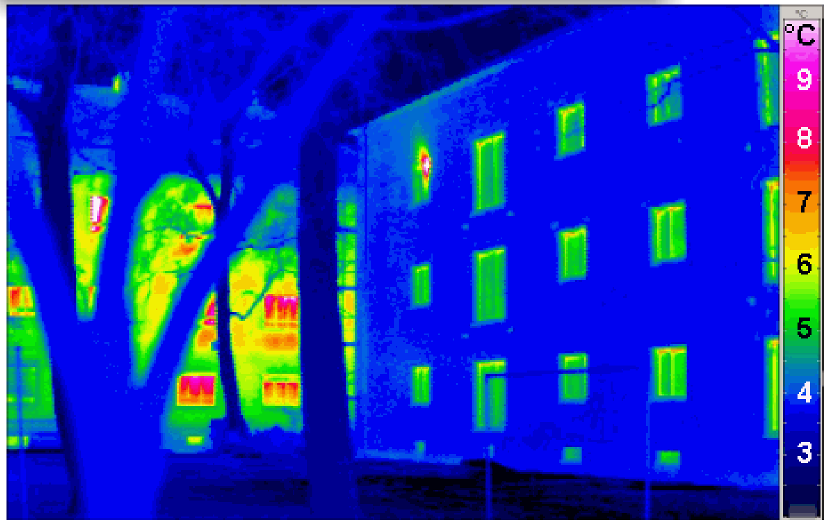


Source: DOE 2010 Building Energy Data Book

Residential Energy Challenge

- 22% of US energy use
- 40% of US electricity use
- 115 million housing units
- 60% are more than 25 years old
- Energy is small part of any one house



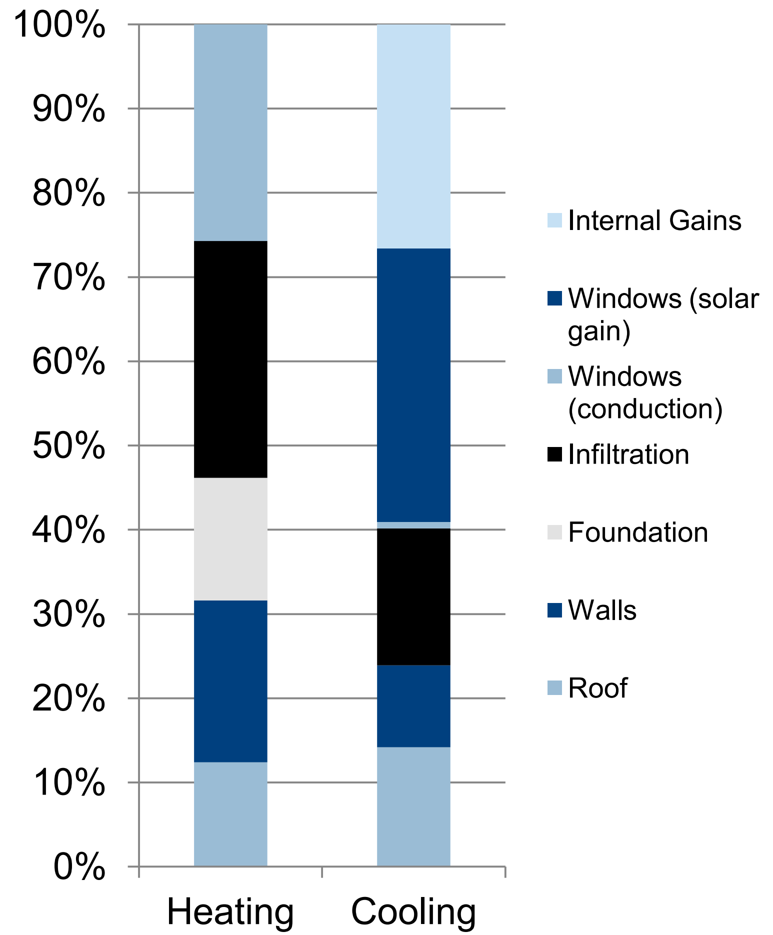


Home Improvements

- In 2007, we spent $234 billion on 56 million home improvement projects
- While you're at it, upgrade energy efficiency and save some money
- 1.2 million siding projects – improve wall insulation!
- 7 million appliance/major equipment projects – EnergyStar!
- 4.5 million window/door projects – low-e glass!

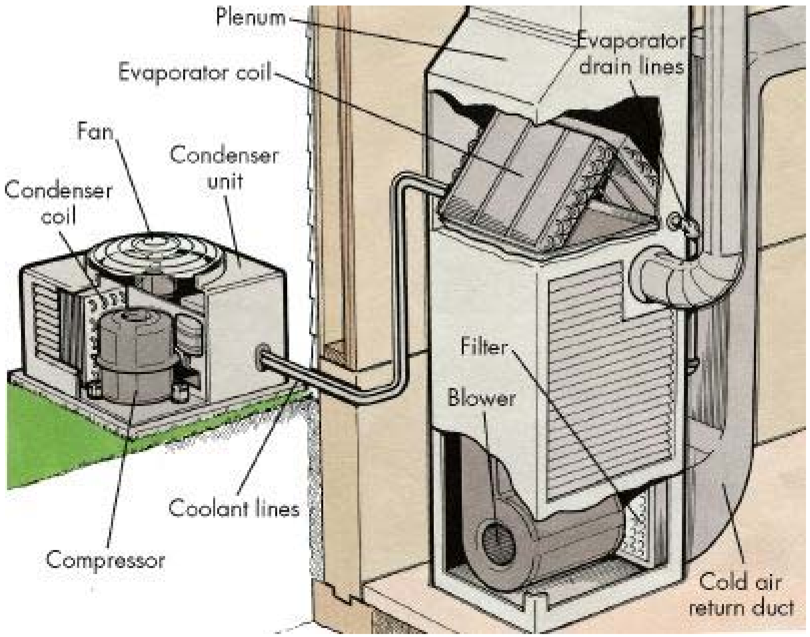
Opportunities: Reduce Loads

- Seal the leaks to reduce infiltration – easy DIY project
- Add ceiling insulation
- Upgrade windows during replacement/repair
- Shade windows



Opportunities: Efficient HVAC Systems

- Reduce heating and cooling energy use by 15-20%
  - Condensing furnace
  - High SEER air conditioning
- Seal ductwork, especially in unconditioned spaces
  - Leaks typically 10-20% of airflow
  - Unconditioned attics and crawlspaces can be 20°F hotter or colder than indoors



Opportunity: Hot Water

- Second only to space heating
- Insulate tank or go tankless
  - As much as 20% lost in stand-by
  - Condensing gas tankless water heater can reduce hot water energy by over 40%
- Improve hot water efficiency of clothes washer and dishwasher
- Reduce hot water consumption

Opportunities: Lighting and Appliances

- CFLs really do make a big difference, but …
  - Better color rendering with incandescent/halogen
  - Difficult (expensive) to dim fluorescent lighting
- Refrigerators
  - Upgrade to EnergyStar® when replacing
  - Get rid of that 20-year-old second refrigerator in the basement. Cost effective to buy new low-end EnergyStar®

Opportunities: Behavior

- Use your programmable thermostat
  - Study: 80% of programmable thermostats not programmed
- Manage your windows and fans
  - Air movement can improve cooling comfort, but only if the room is occupied!
  - Night ventilation can often reduce air conditioning (careful with humidity)

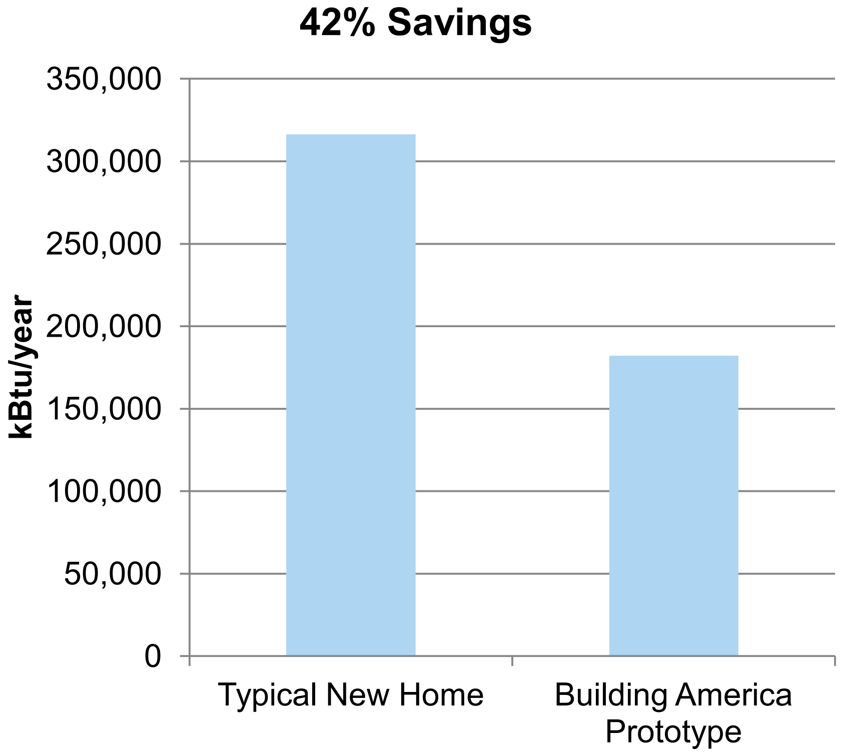
New Home Case Study

Stockton, CA

One Example of Building America Cost Trade-offs in a Hot-Dry Climate

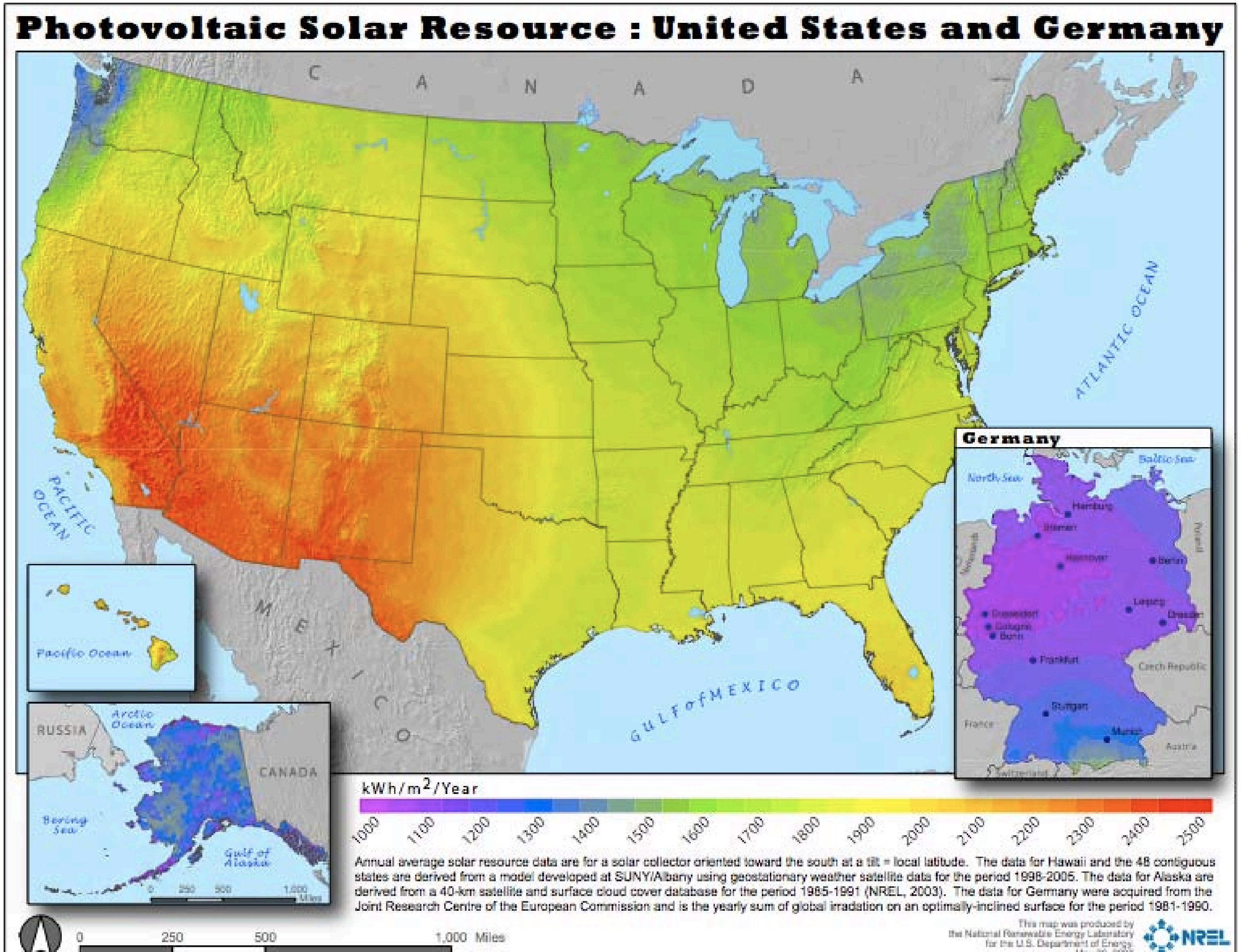
Standard Practice	Building America	Cost Impact*
Roof vents	Unvented roof	- $250
Uninsulated roof deck	Insulated roof deck	+ $700
2x4 framing, 16-in. spacing	2x6 advanced framing, 24-in. spacing	- $250
Clear glass windows	Low-e, spectrally selective windows	+ $500
4-ton air conditioner	2-ton air conditioner	- $1000
Natural ventilation	Controlled ventilation	+ $100
Total cost of upgrades		- $200

*Estimated costs for production builders. Actual costs vary depending on specific features and supplier discounts. (Negative indicates cost savings, positive indicates additional costs.)



Source: DOE Building Technologies Program 2010

Opportunity: Renewables



Opportunities: Renewables

- At some point, it is more cost effective to make energy than to save it
- Solar Water Heating
- Solar Photovoltaic
- Incentives often tip economics (www.dsireusa.org)

Solar Water Heating System Types

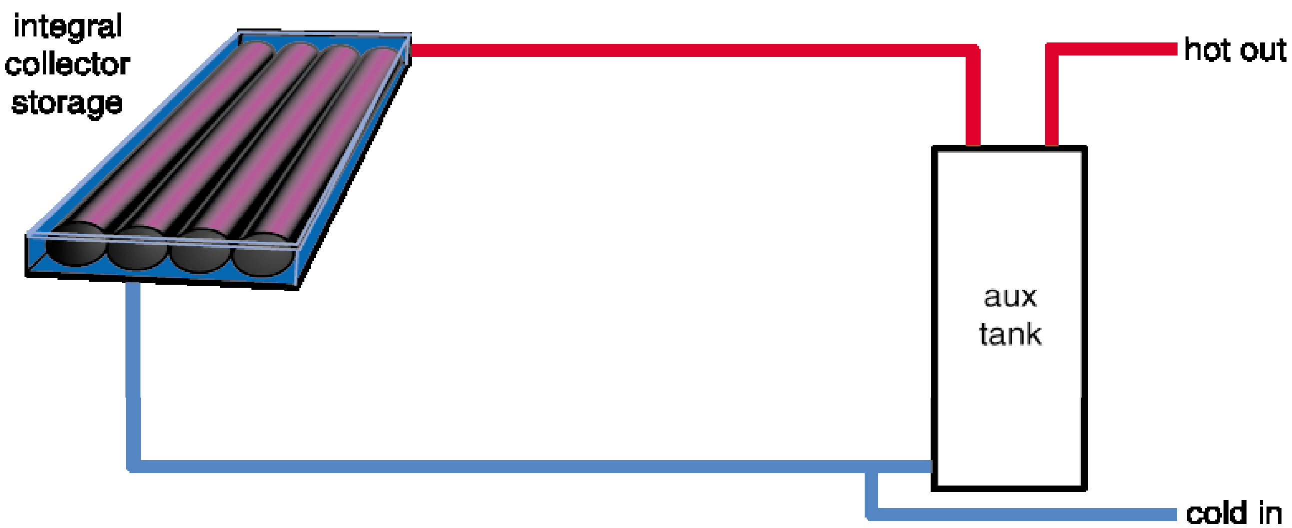
Active Systems

- Open Loop:
  - Direct
  - Drain Down
- Closed Loop:
  - Drain Back
  - Antifreeze

Passive Systems

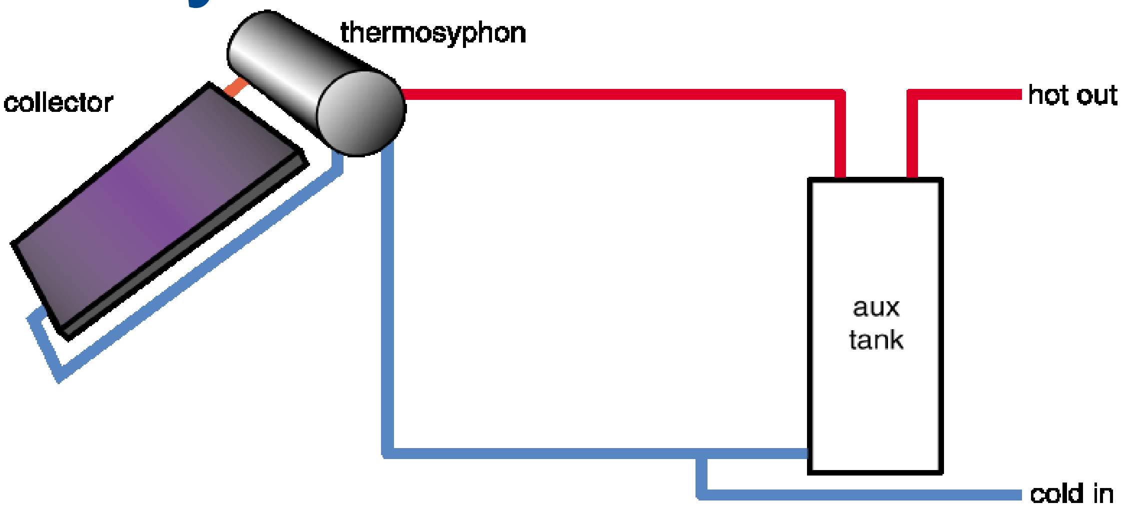
- Integral Collector Storage
- Thermosiphon

Passive, Integral Collector Storage (ICS) Direct System



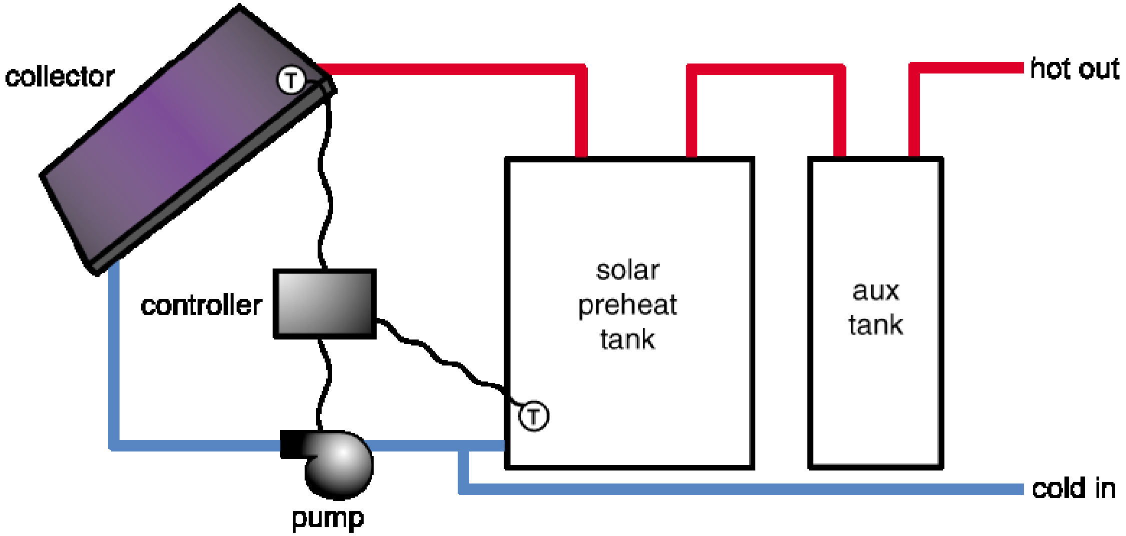
- Moderate freeze protection (pipes at risk)
- Minimal hard water tolerance
- Very low maintenance requirements

Passive, Thermosyphon, Direct System



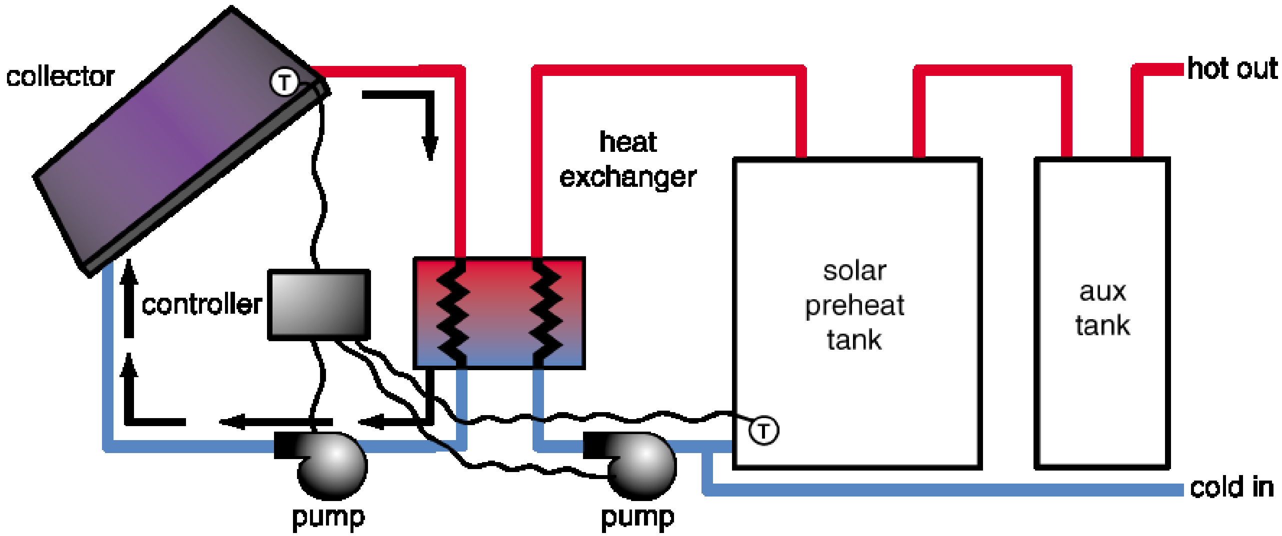
- Auxiliary element can also be in tank above collector, eliminating the auxiliary tank altogether.
- No freeze protection
- Minimal hard water tolerance
- Low maintenance requirements

Active, Open-loop, Pumped Direct System



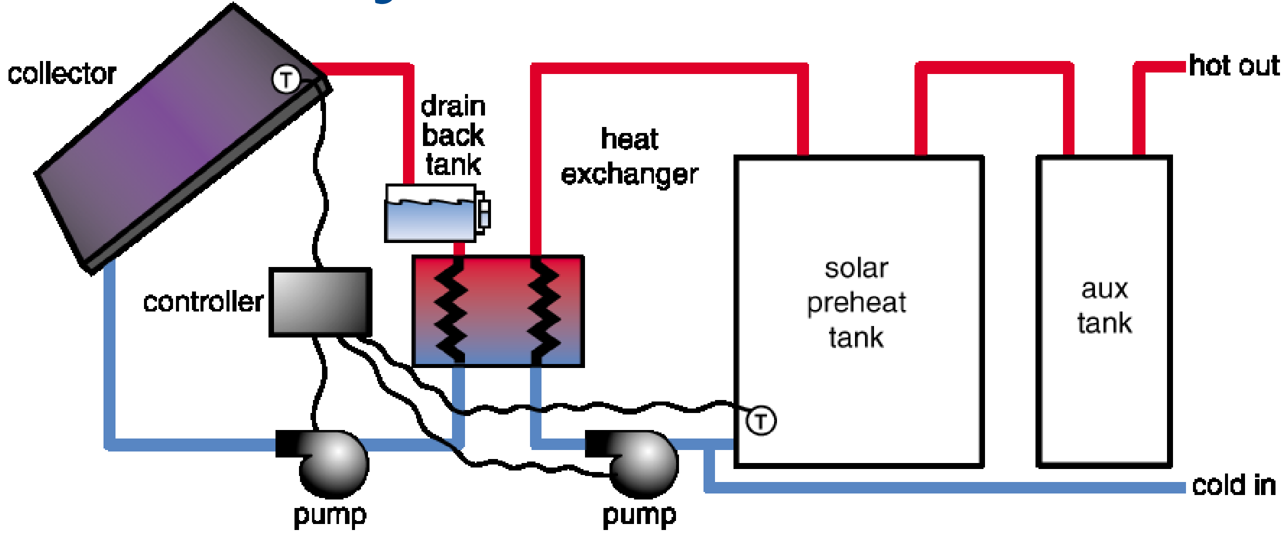
- No freeze protection
- Minimal hard water tolerance
- High maintenance requirements

Active, Closed-loop (antifreeze), Indirect System



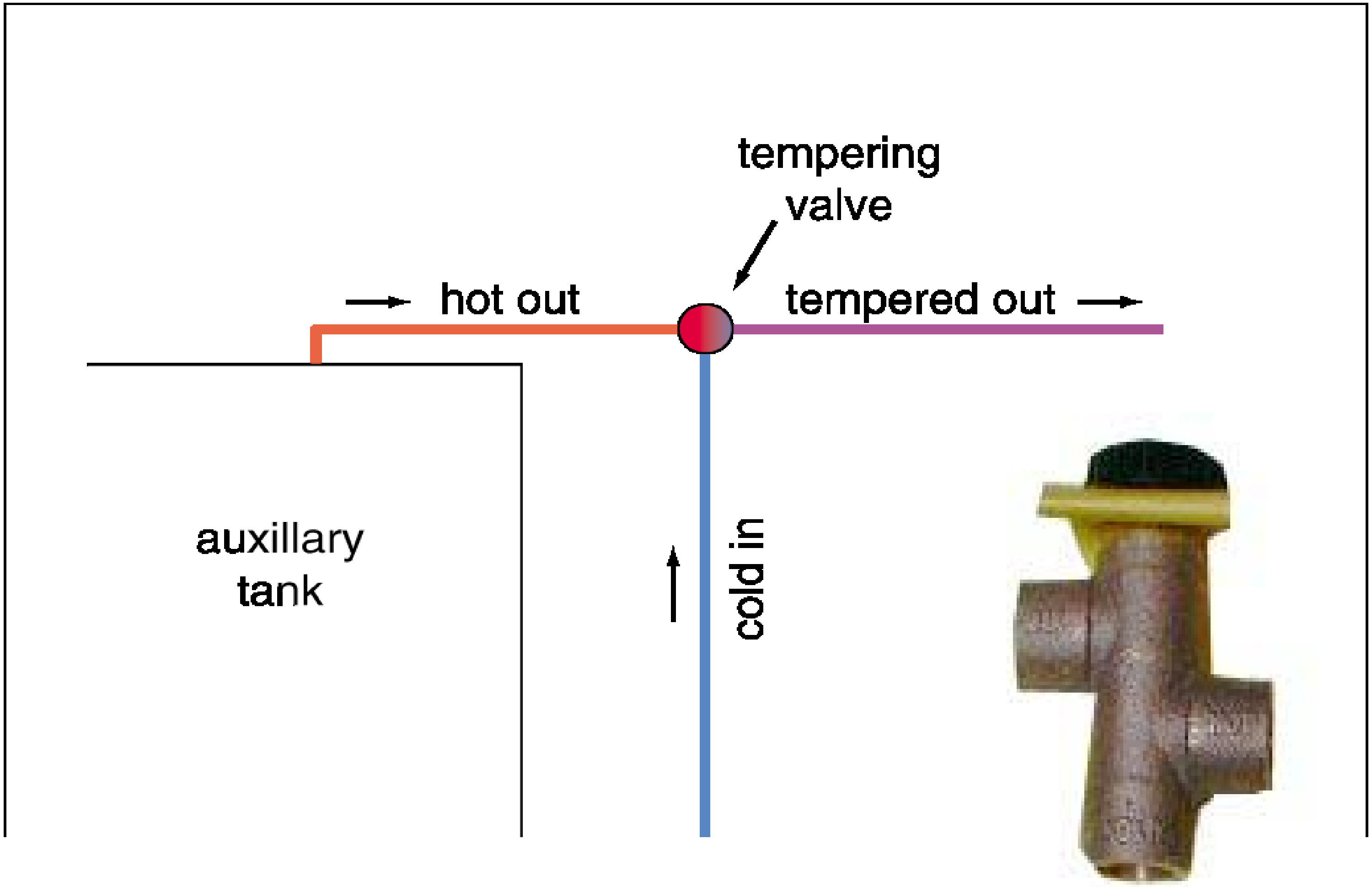
- Excellent freeze protection
- Good hard water tolerance
- High maintenance requirements

Active, Closed-loop, Drainback, Indirect System

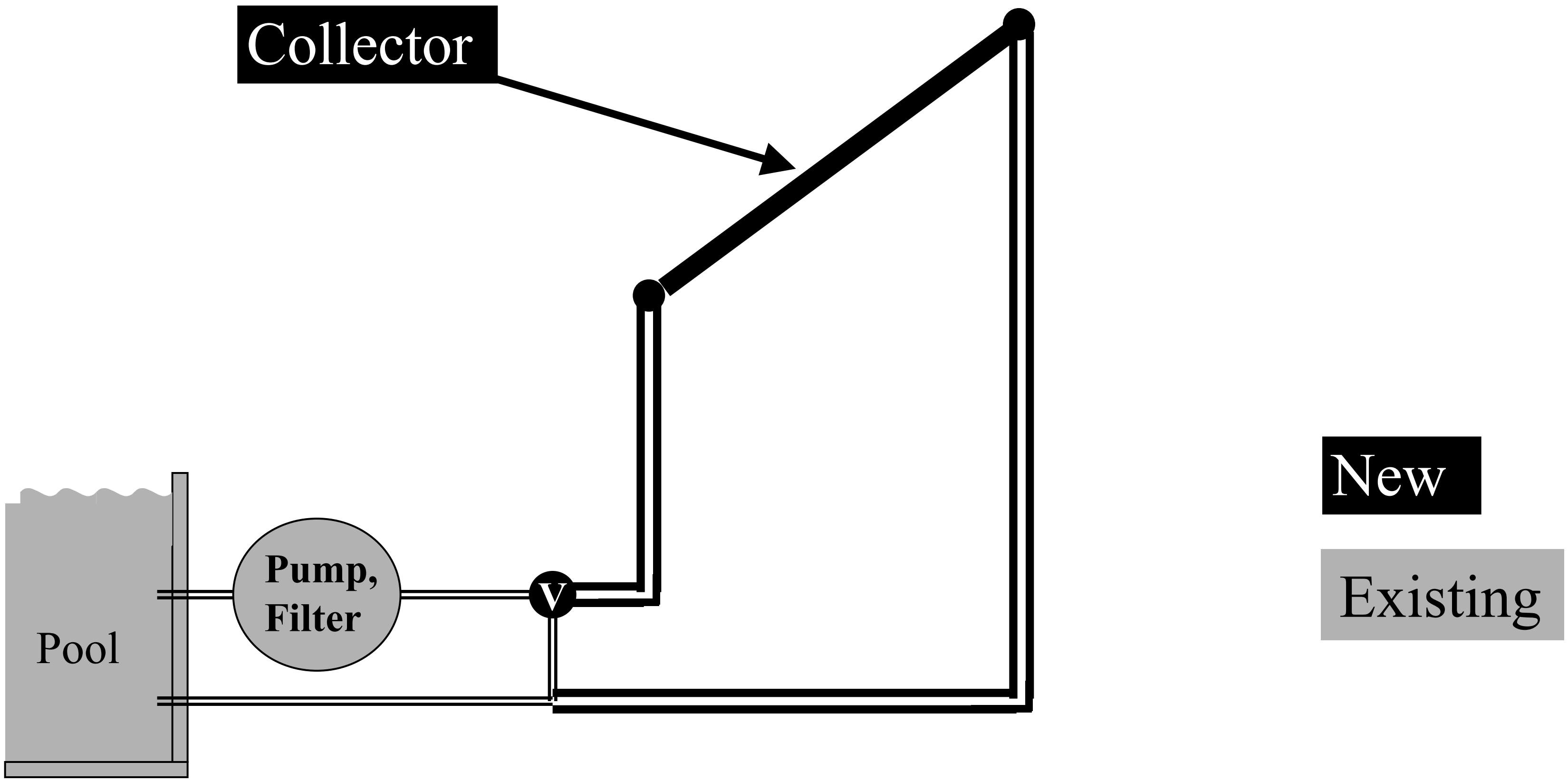


- Good freeze protection
- Good hard water tolerance
- High maintenance requirements

Tempering Valve to Prevent Scalding:
Extremely Important for Safety!

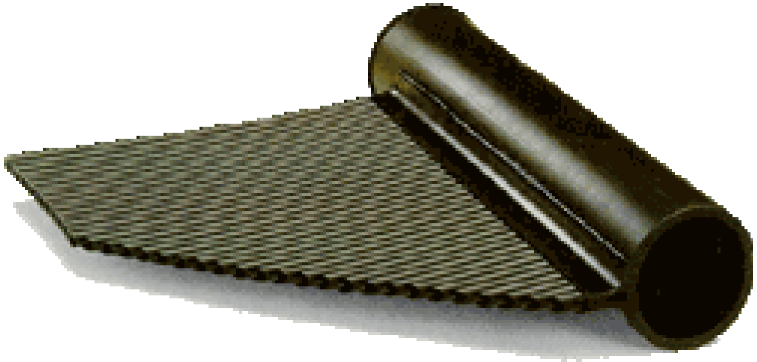


Low Cost Solar: Pool Heating



Solar Pool Collectors/System

Inexpensive unglazed polymer collectors



Inexpensive balance-of-system (uses pool pump, pool is storage,…)

Unglazed Collectors

Unglazed Collectors for **pool heating**

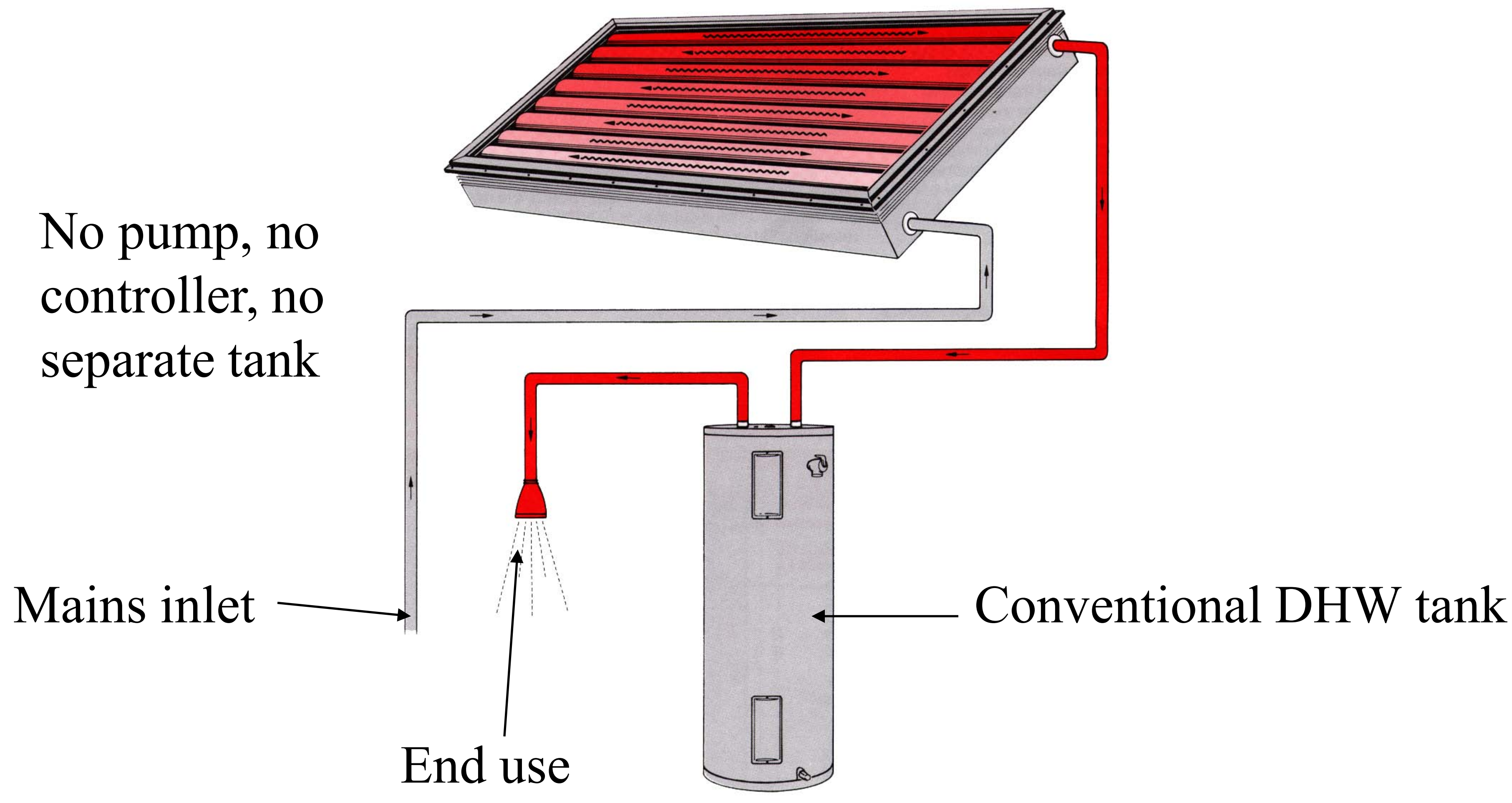
- Good thermal performance
  - Higher optical gain vs. glazed

- Good economics
  - Inexpensive polymer collectors (< $10/m^2 FOB wholesale)
  - Simple balance-of-system
  - Long-lived: > ~20 year lifetime
  - Short payback: ~ 5 yrs vs. gas

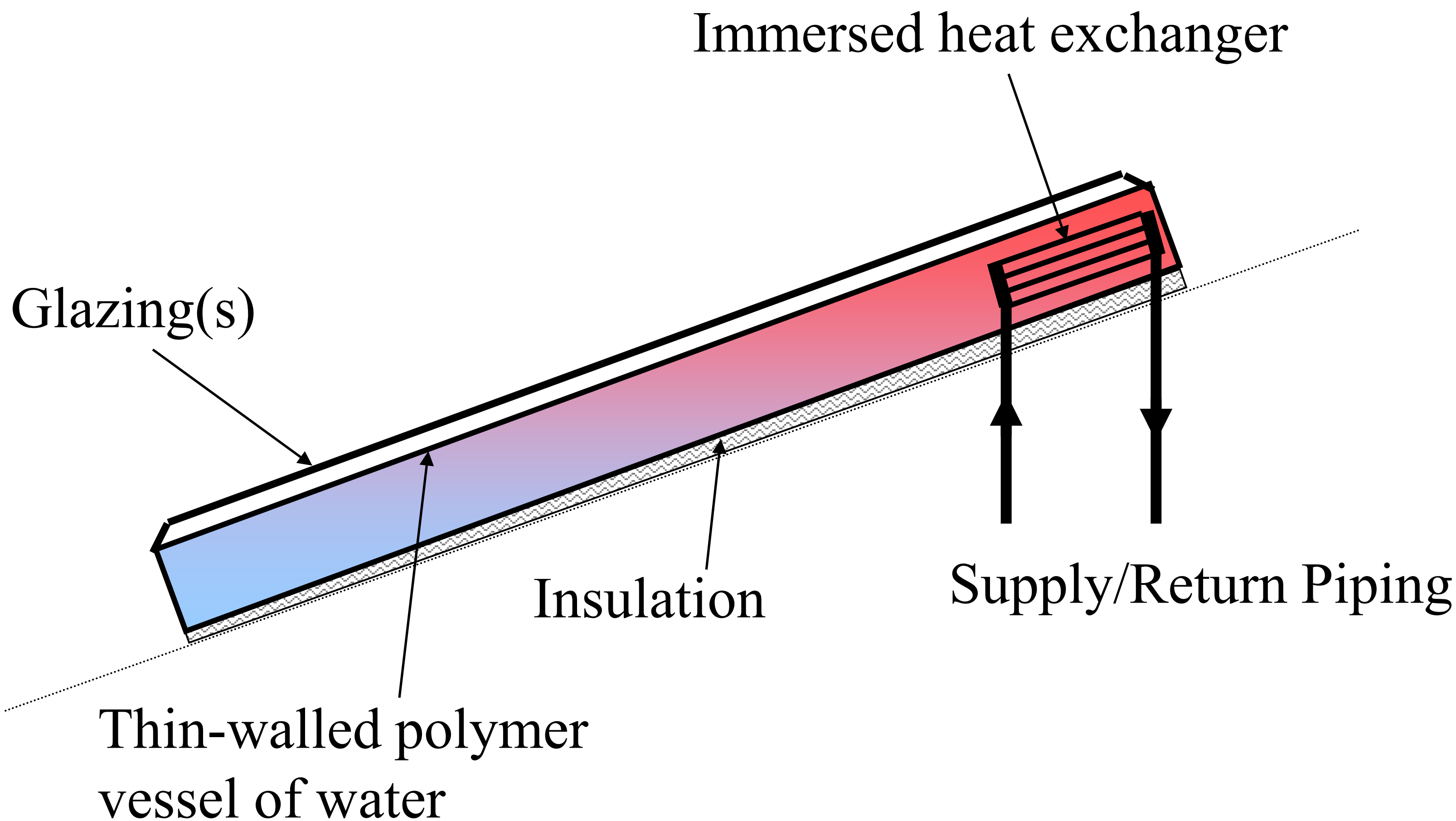
$\Rightarrow$ Robust market: > 1 million m^2/year installed in U.S.

Low Cost Solar: ICS System

No pump, no controller, no separate tank



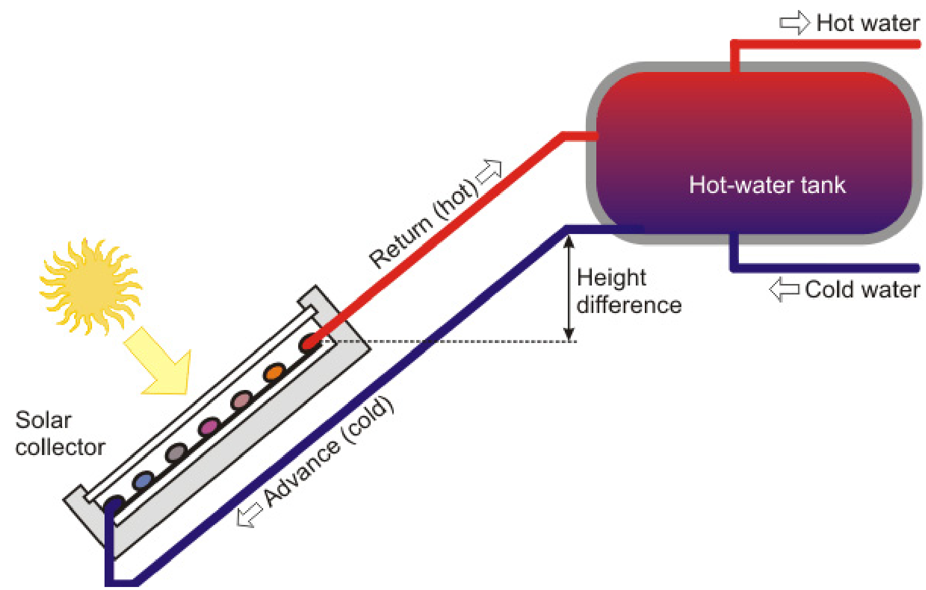
Unpressurized ICS



ICS Systems

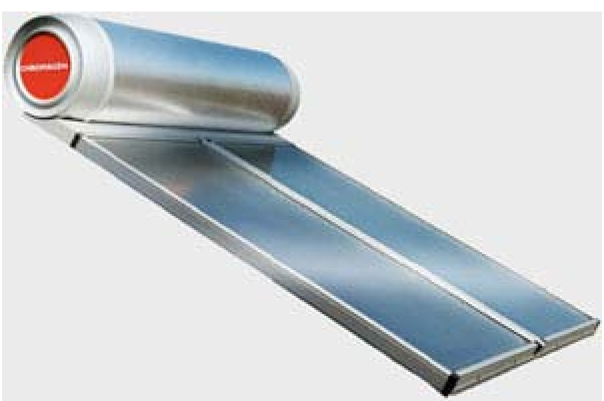
Low Cost Solar: Thermosiphon

- Simple and inexpensive
- No pump, no controller
- World-wide experience
- Most appropriate for non-freezing climates

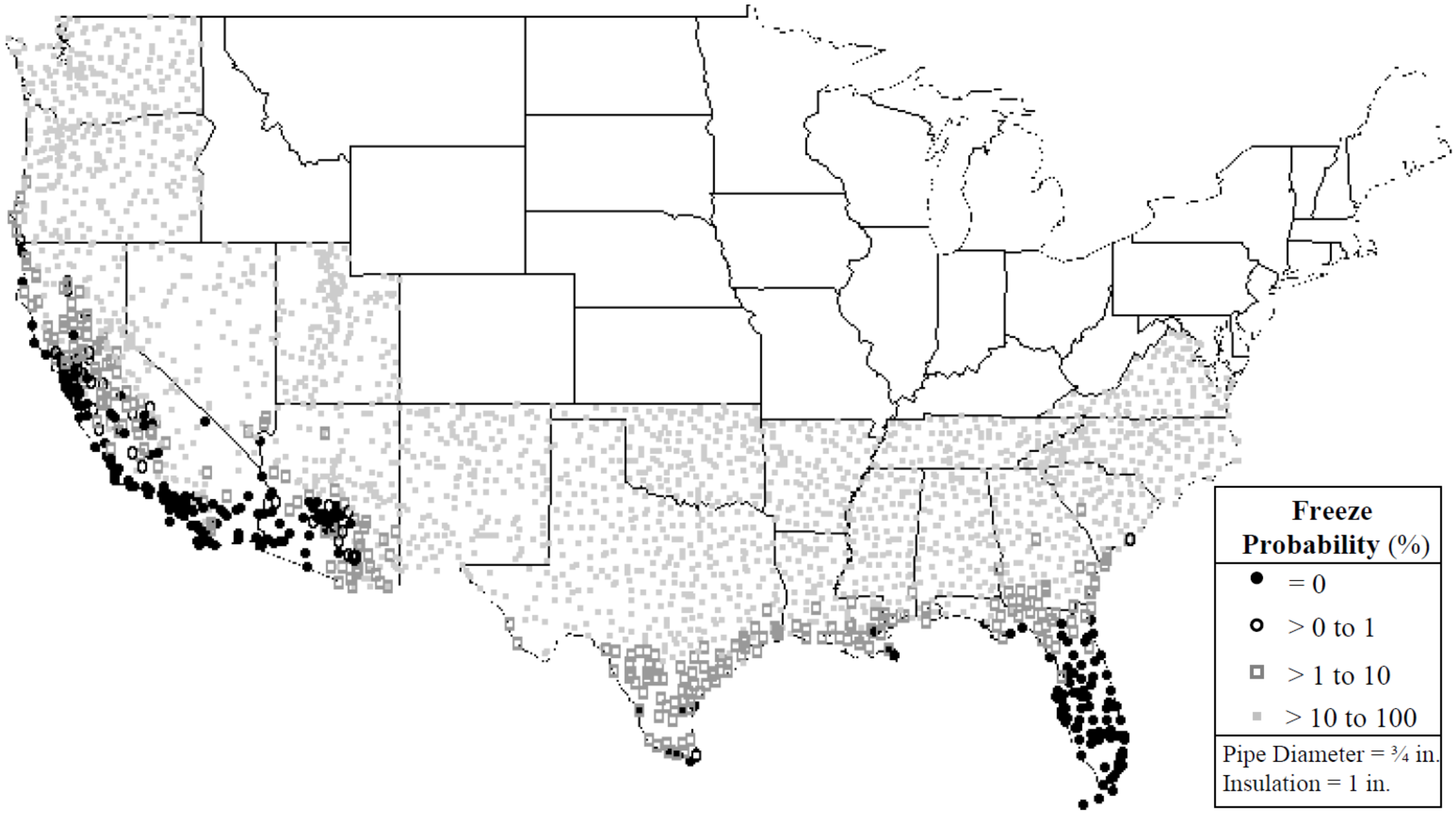


Thermosiphon

They don’t have to be this ugly



Probability of Pipe Freezing



Salasovich, J., Burch, J., and Barker, G., “Pipe Freeze Probability for Passive-solar Water Heating Systems in the United States”, *Proc. ASES 2004*, ASES, Boulder, CO.

PV System Applications

Grid Applications

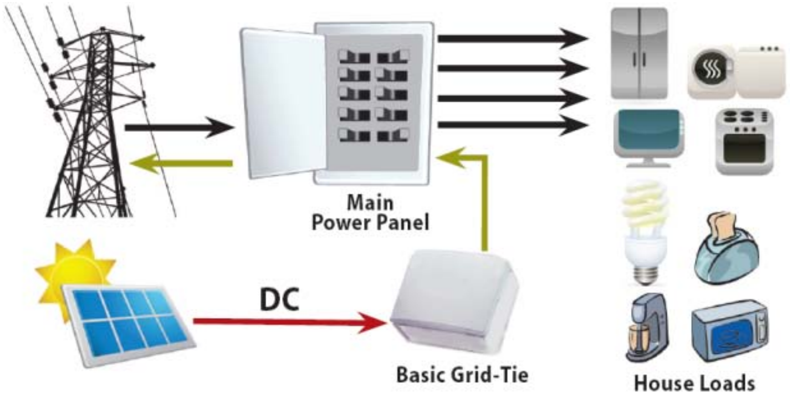
- Convert DC power to AC power with inverter
- Inverter manages protection and synchronization with grid
- Direct consumption by load
- If excess power from PV, sell energy to utility grid
- If insufficient power from PV, buy energy from grid

Off-Grid Applications

- Power for DC and AC loads
- Batteries to store energy
- Inverter and charge controller to manage energy flow
- Direct consumption by loads
- If excess power from PV, store in batteries
- If insufficient power from PV, draw from batteries
- If insufficient energy in batteries, use generator or utility grid if available

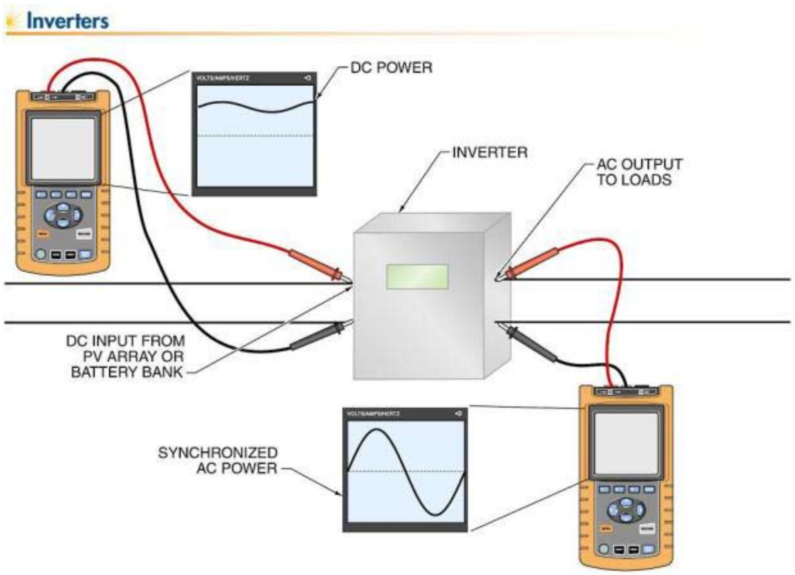
Grid-Tied Applications

- Simple connection of PV to conventional electrical distribution system through grid-tie inverter
- Either net meter, which runs backwards when selling, or dual meters, which separately monitor energy production and consumption
- No backup when grid goes down
- Very few modifications to existing building electrical distribution system
- Least expensive solution



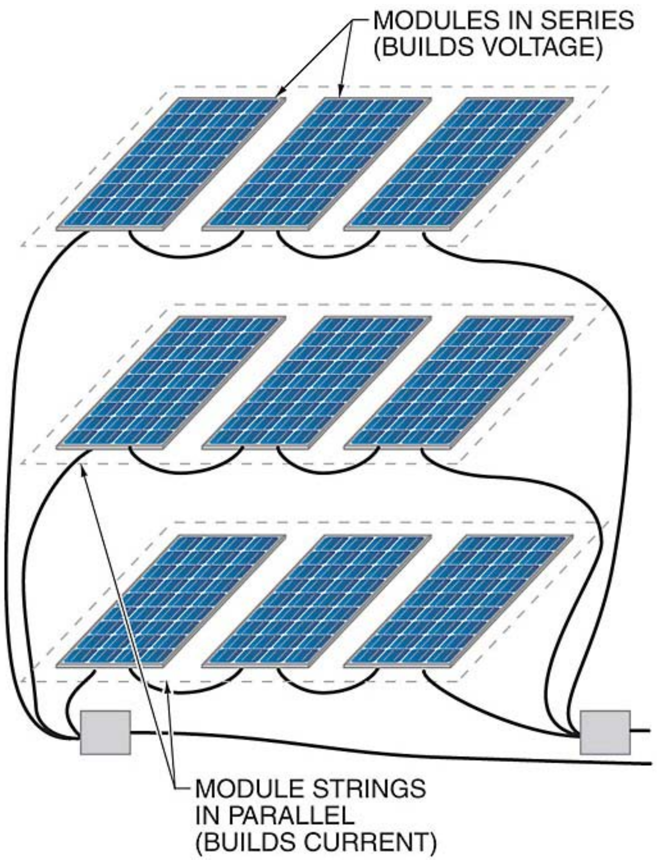
Grid-Tie Inverters

- Rated by power output and number of phases
- Typically accept input voltage 200-400 VDC
- DC-DC converter to adjust variable PV voltage to match 240 VAC voltage
- DC-AC converter to generate AC waveform
- Synchronize frequency
- Prevent power flow onto grid when grid is down
- Net conversion efficiency about 97%, less at lower DC voltages

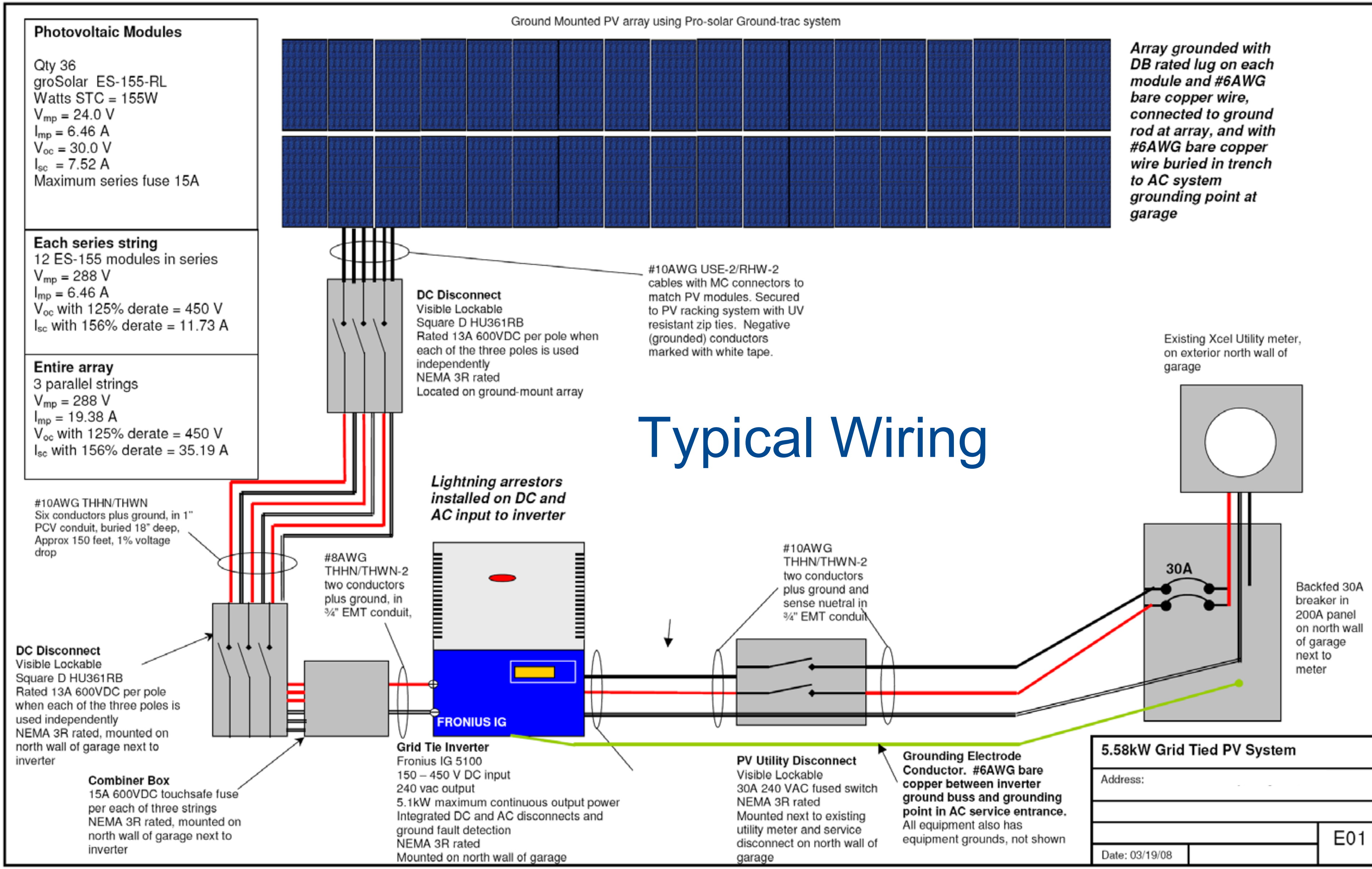


PV Design and Sizing

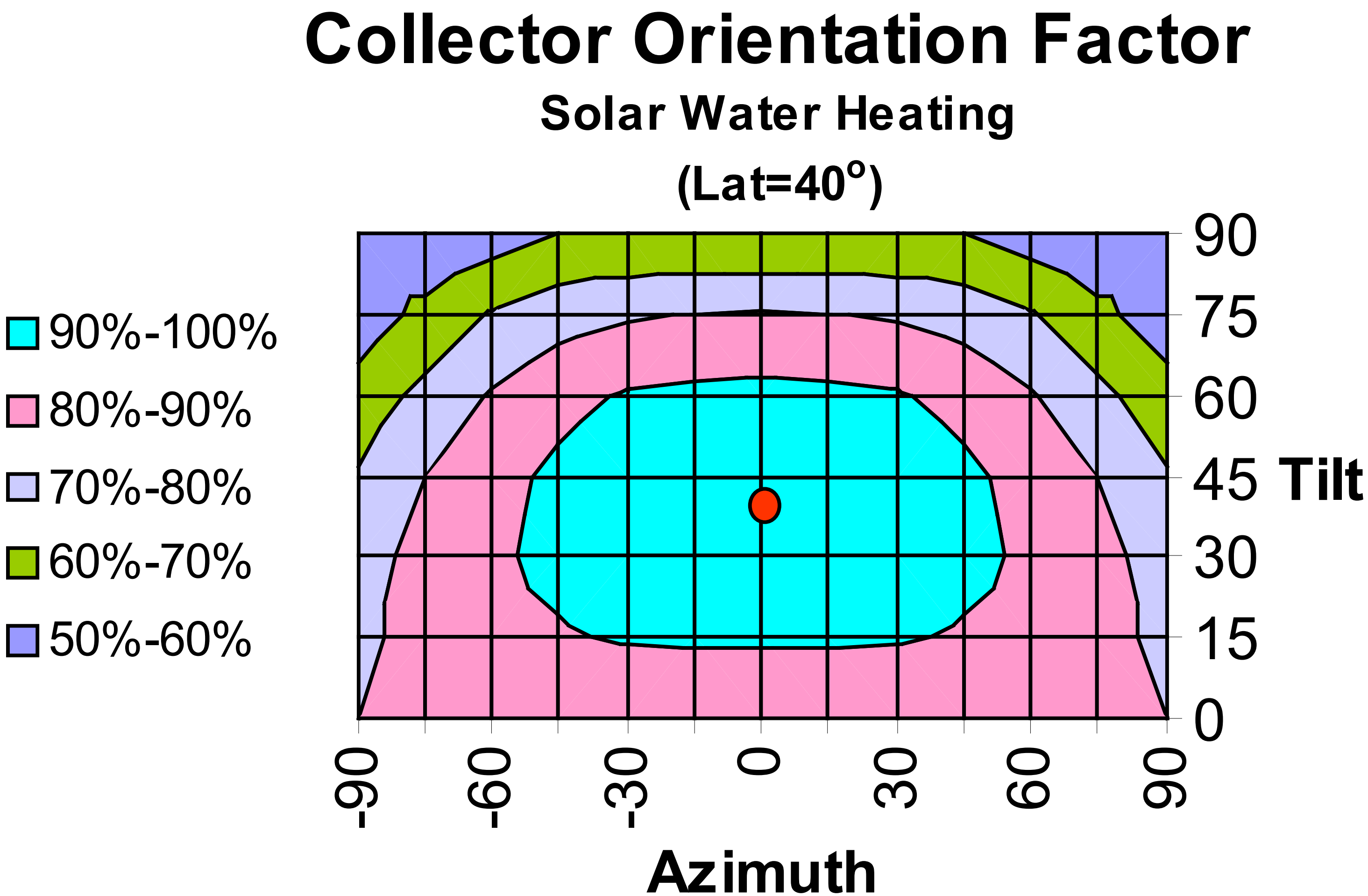
- Arrays designed with modules in series to produce Voc ≈ 400 VDC
  - Higher voltage = less wiring losses
  - Not exceed voltage limits of wires and components (600 V in US)
- Parallel strings to achieve desired peak power
- Sizing based on available area and budget
- Sometimes sized to provide net zero energy, i.e., annually produce as much energy as the building consumes



Typical Wiring



Tip: Wide Orientation Range is OK



Summary

- Existing homes represent single biggest opportunity for US energy savings
- Homeowner is decision-maker
- Low hanging fruit with energy efficiency retrofits, especially during home improvement
- Renewables are available and often cost effective, especially with incentives (http://www.dsireuse.org)