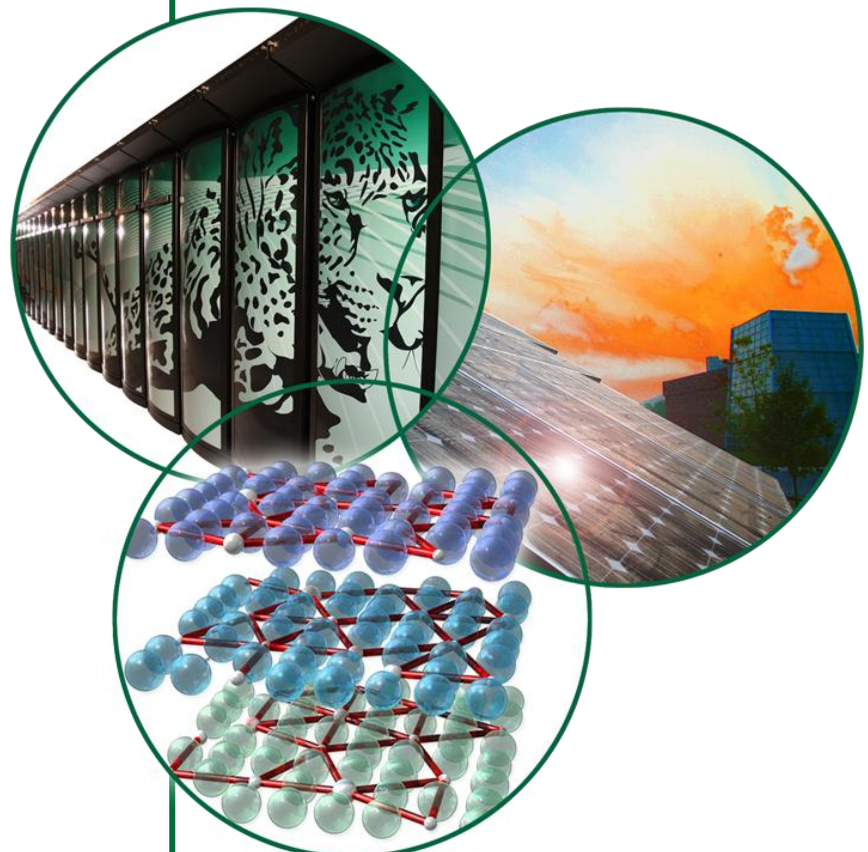
Roofing Systems in the 21st Century; DOE's Research Program to Reduce their Energy Impact



Andre Desjarlais

Oak Ridge National Laboratory

24 May 2012

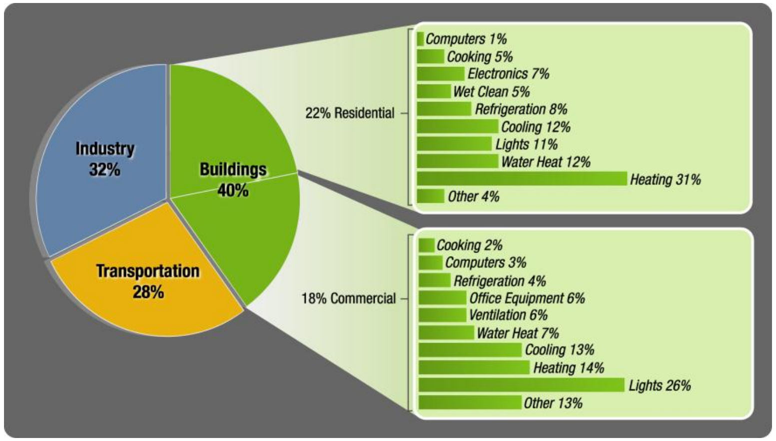
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

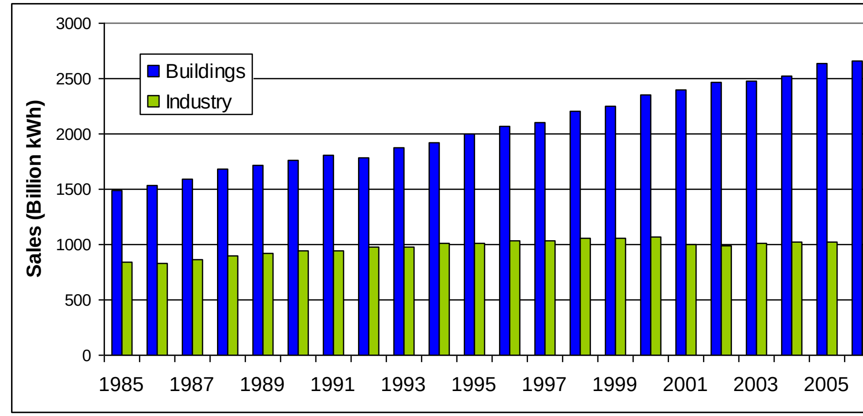
Buildings energy use is large and growing

40% of U.S. Primary Energy Consumption (39% of U.S. Carbon Emissions)



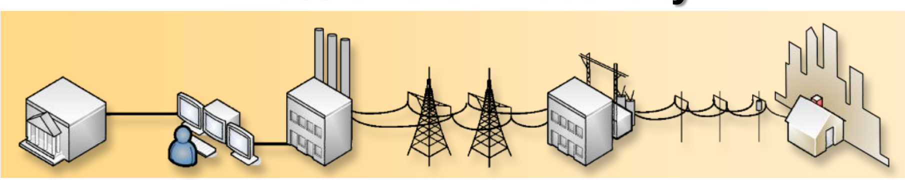
Source: 2007 Buildings Energy Data Book. Tables 1.1.3, 1.2.3, 1.3.3

Buildings Drive Electricity Supply Investment

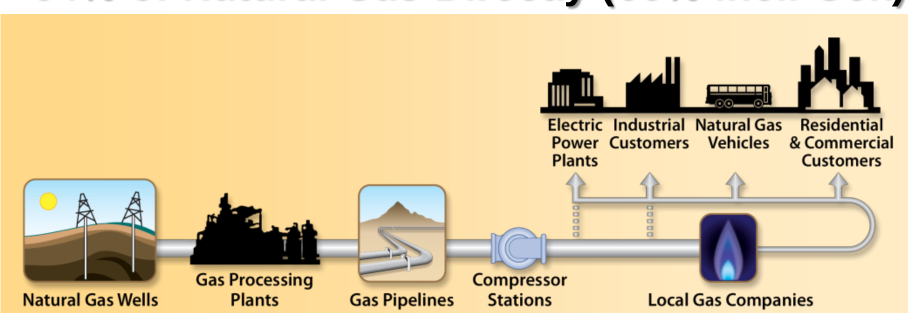


Source: EIA Annual Energy Review, Table 8.9, June 2007

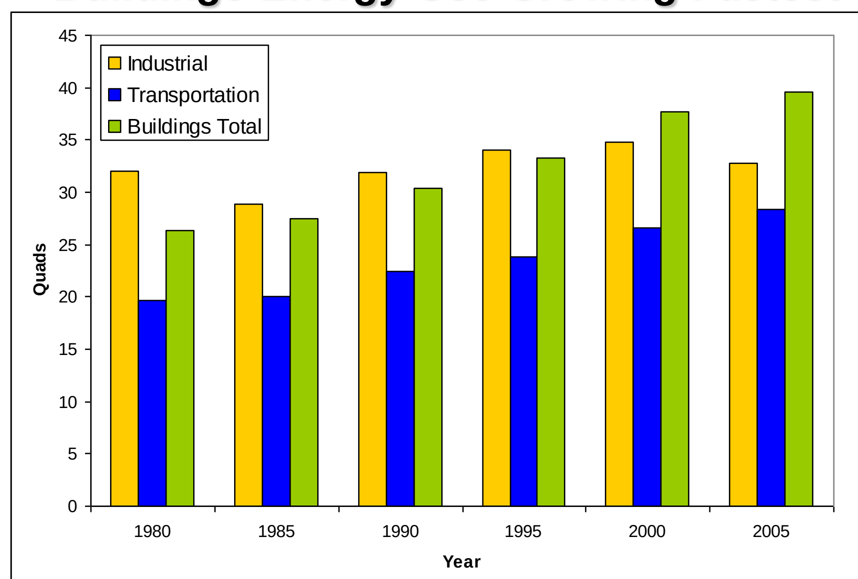
73% of U.S. Electricity



34% of Natural Gas Directly (55% Incl. Gen)



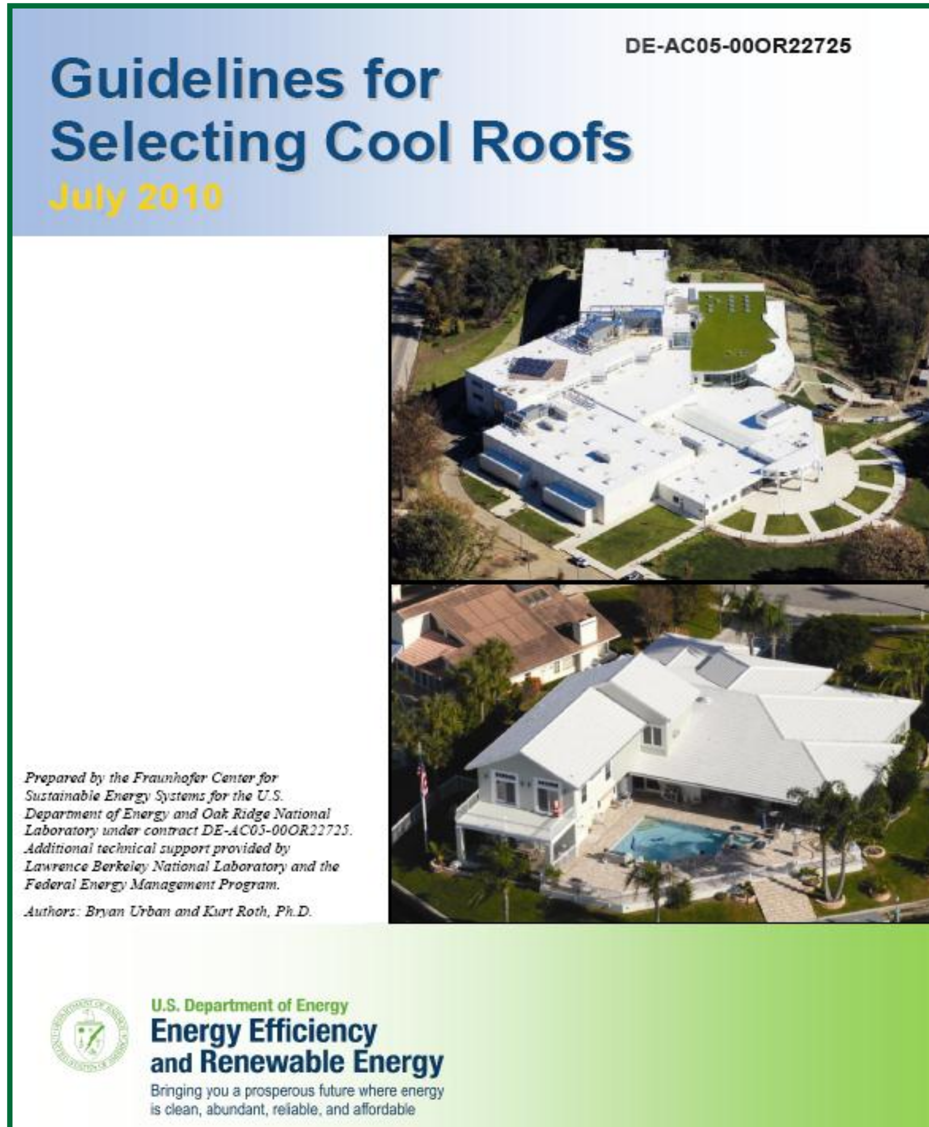
Buildings Energy Use Growing Fastest



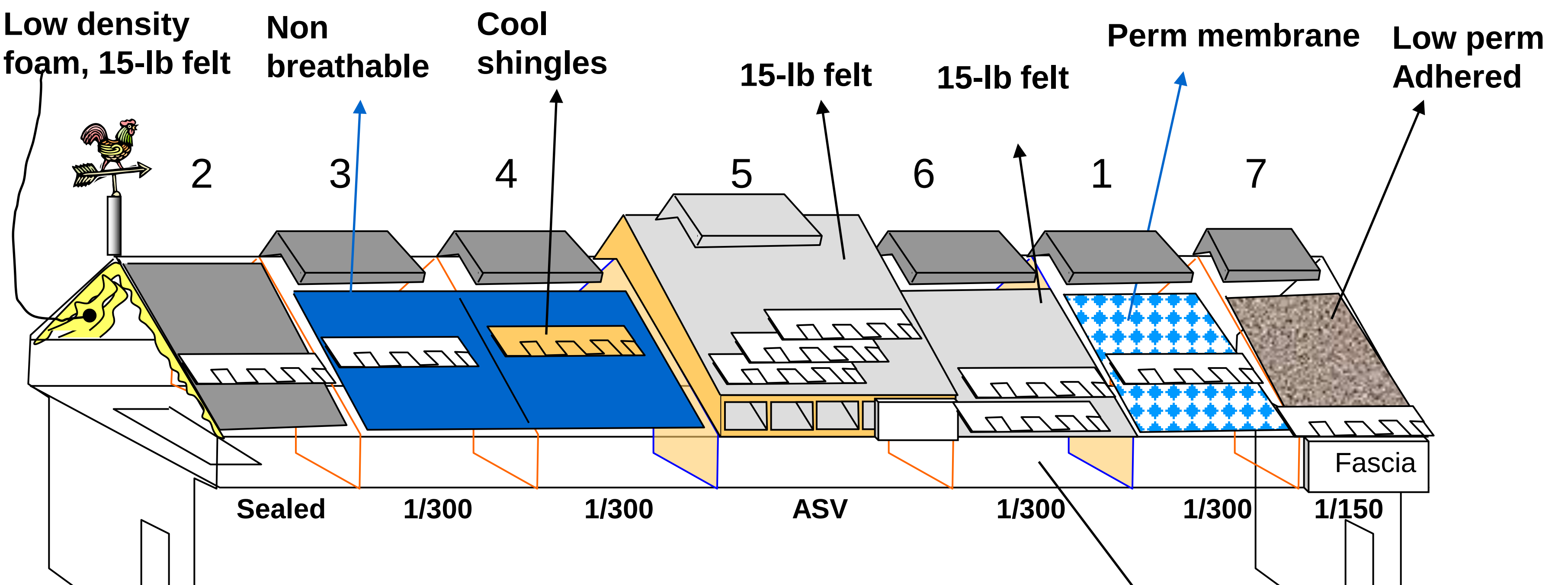
Roofs and attics project is a highly leveraged public-private partnership

FY11-12 key tasks and milestones

- Field study on attic performance
- Hot climate roof and attic design guidelines
- Advances in cool roof technologies
- Impacts of radiant barrier systems
- PV roof integration

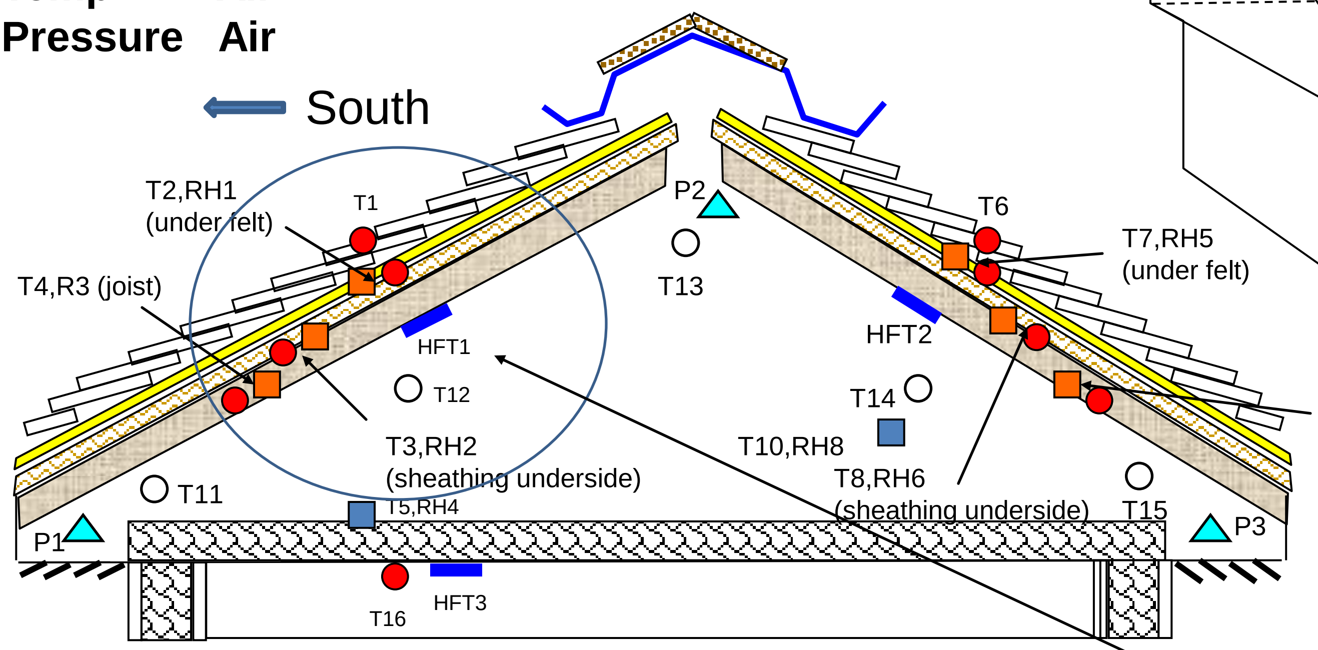


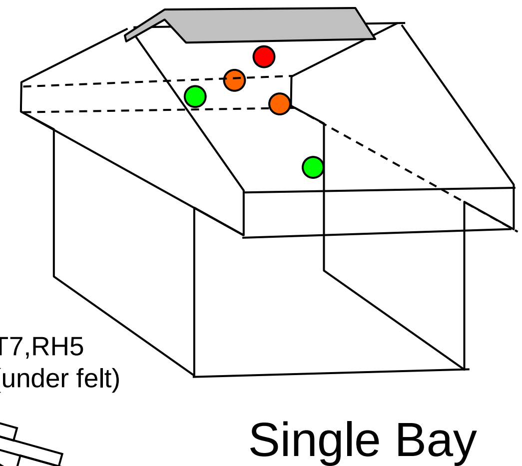
NET facility used to evaluate attic systems



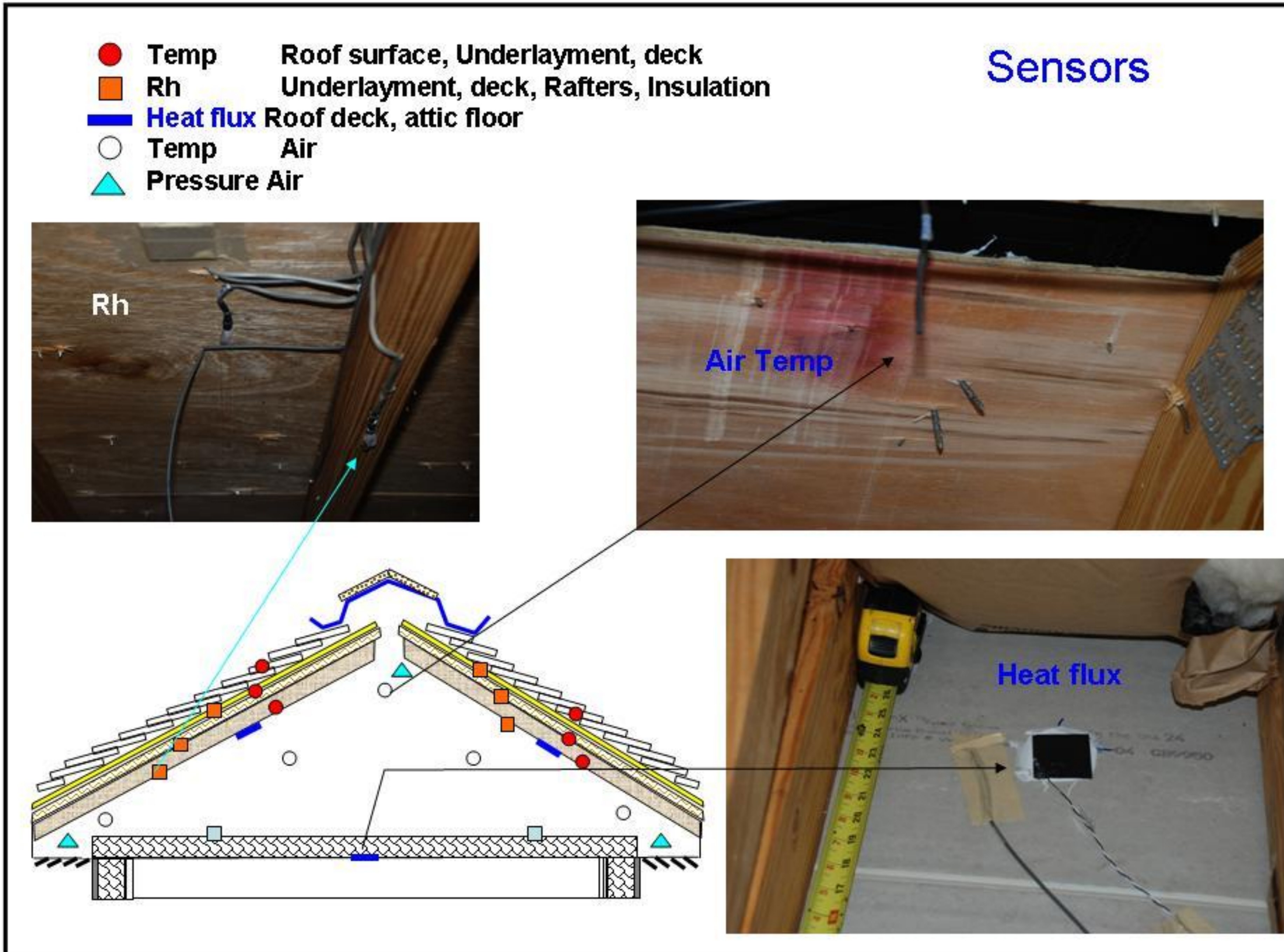
Instrumentation plan

- ● Temp — Roof surface, underlayment, deck
- ■ Rh — Underlayment, deck, rafters, Insulation
- ▬ Heat flux — Roof deck, attic floor
- ○ Temp — Air
- △ Pressure — Air

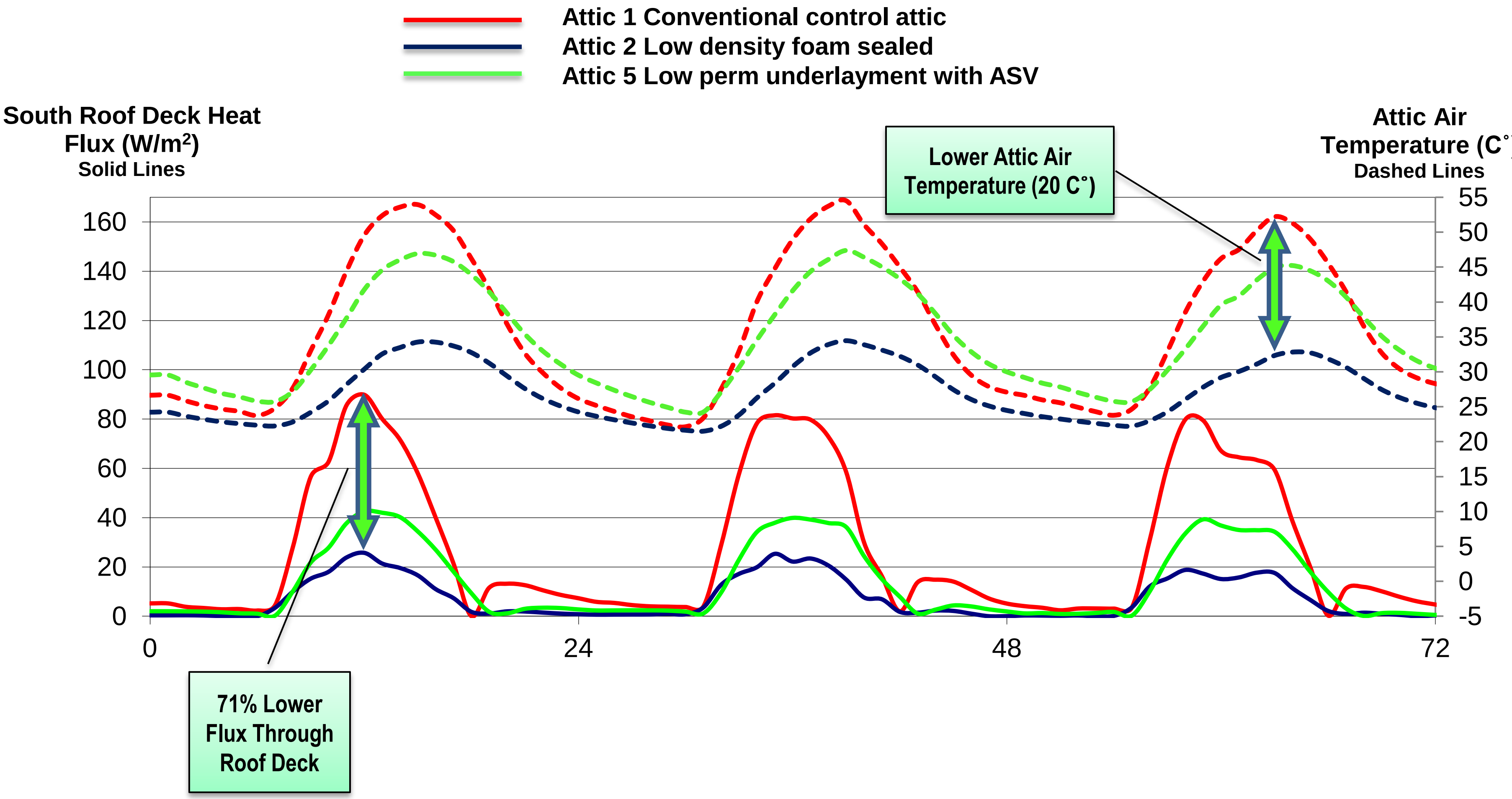




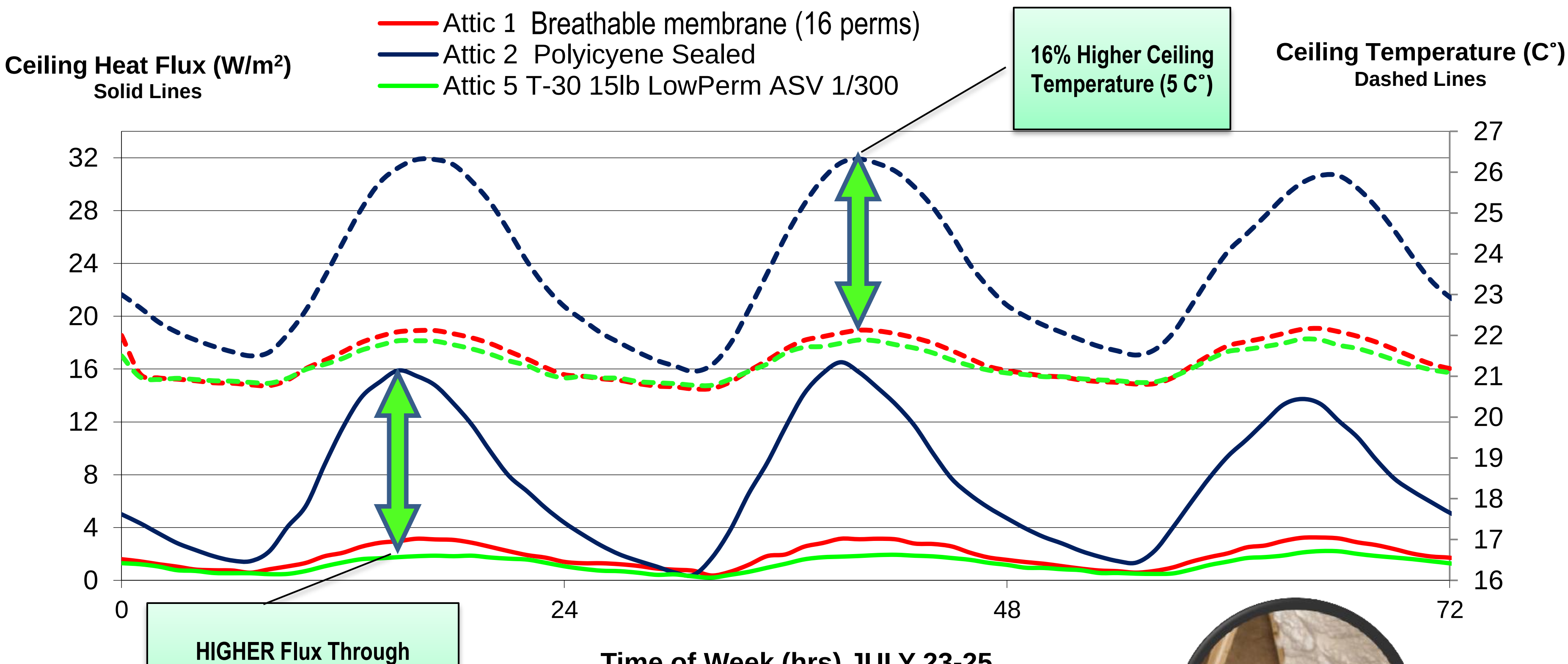
- In each bay
- 8 temperature sensors, 6 Rh sensors, 3 heat flux sensors
- Total 17 sensors per bay + 7 for air temperature and Rh
- 3 attic pressure and 3 sensors for insulation = 30 sensors per bay


Sensors
Temp Roof surface, Underlayment, deck
Rh Underlayment, deck, Rafters, Insulation
Heat flux Roof deck, attic floor
Temp Air
Pressure Air
Rh
Air Temp
Heat flux

Sealed attic (R_{US}-22) has lowest roof deck heat flux



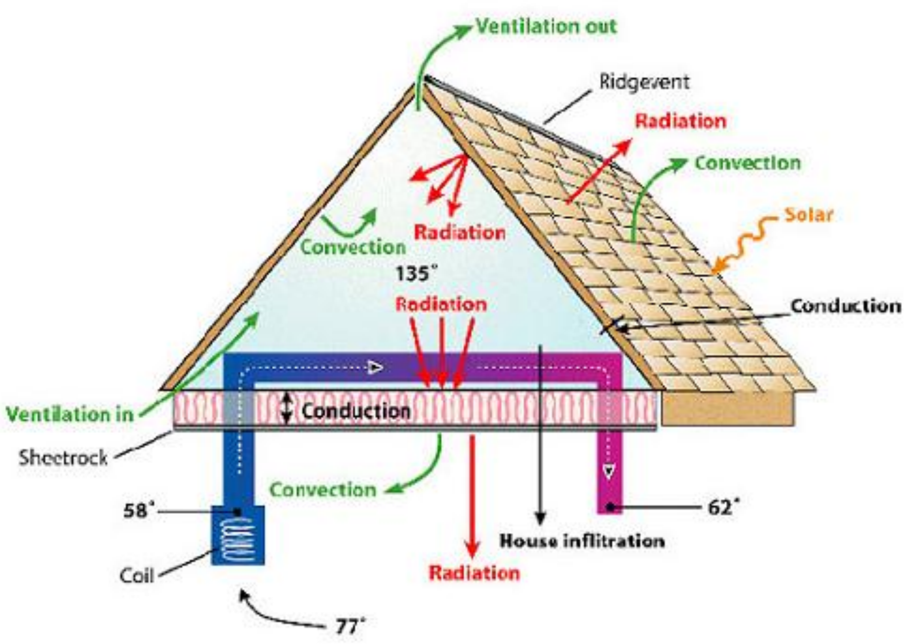
Sealed attic (R_{US}-22) has highest ceiling heat flux



AtticSIM/Energy Plus simulation model

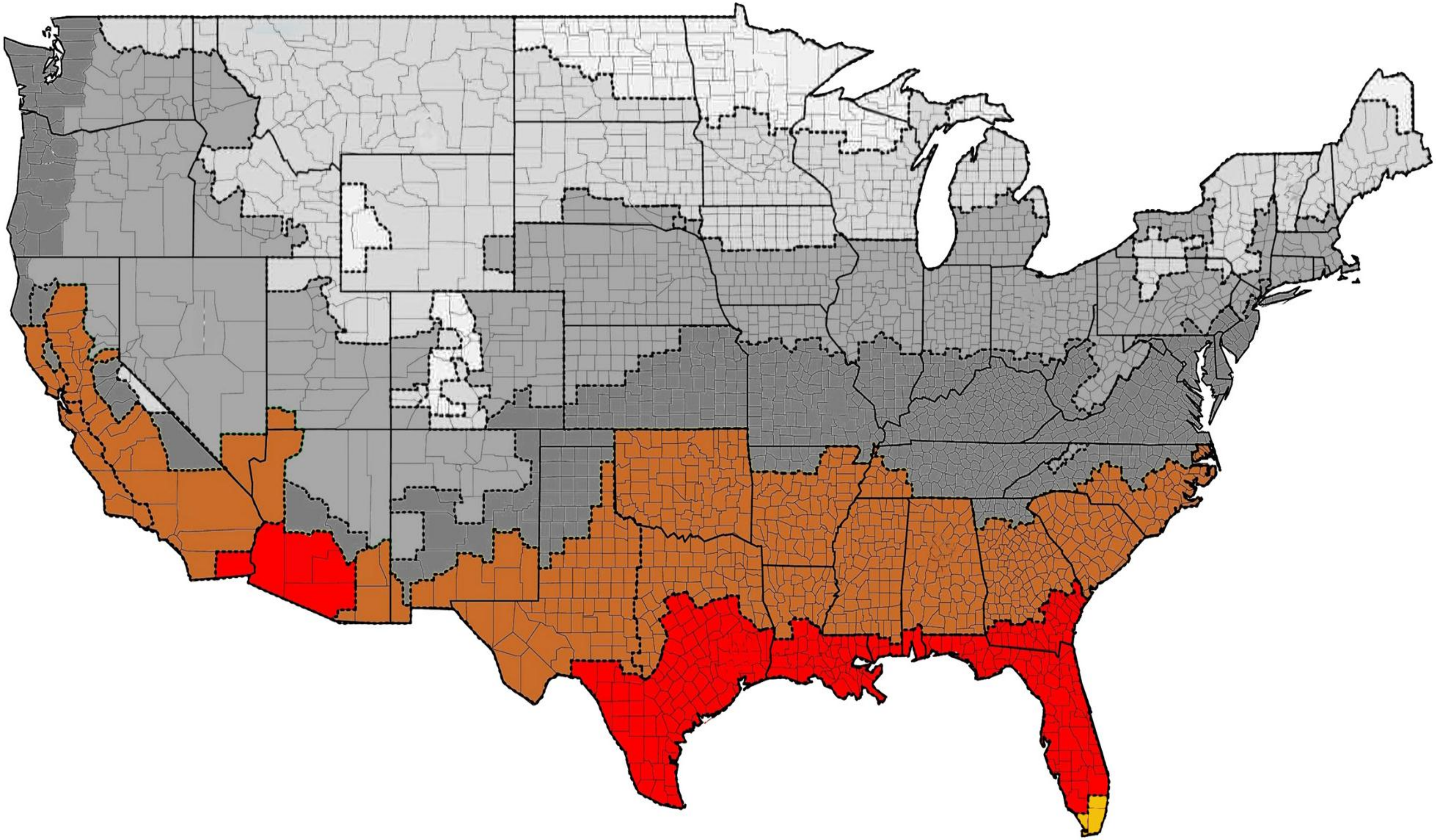
ASTM C 1340-99 Standard For Estimating Heat Gain of Loss Through Ceilings Under Attics

Roof Energy Balance

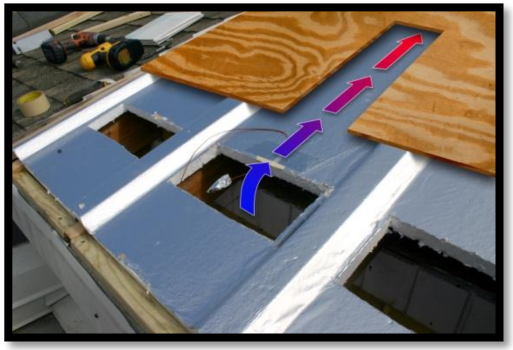


Miller et al. (2007), "*Natural Convection Heat Transfer in Roofs with Above-Sheathing Ventilation*."

Hot climates: ASHRAE zones 1, 2, and 3



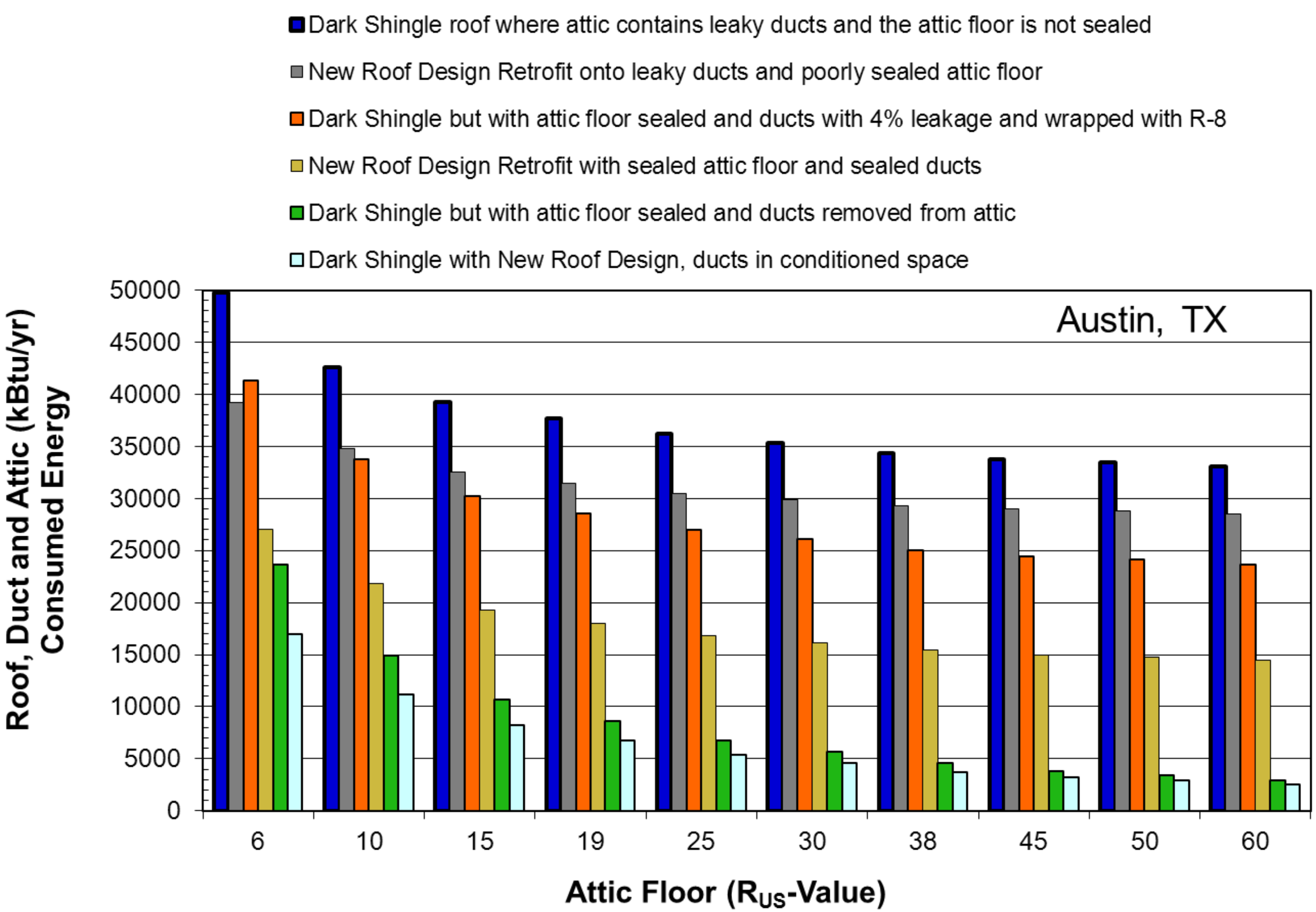
Roof and attics design



Insulated and Ventilated Shingle Roof
Conventional or cool color shingle; 1-in. (0.0254-m) air space made by profiled and foil-faced 1-in. (0.0254-m) EPS insulation placed above deck (retrofit practice) or fitted between roof rafters (new construction); two low-e surfaces.

AtticSim/EnergyPlus estimated energy savings

Duct R-5.5 with 10% air leakage; thermostat 70 Heat / 74 Cool; 1:300 vent area



Retrofit options hot climate

Retrofit System	Seasonal Energy Use		Annual Energy Cost	Simple Payback
	Cooling (kWh)	Heating (Therms)	$ per square foot	(yrs)
Dark Shingle roof, R-10 ceiling insulation, attic has 10% leaky ducts, attic floor leaks 1.3 ACH	1761	234	$0.35	
Dark Shingle roof, R-45 ceiling insulation, attic has 10% leaky ducts, attic floor leaks 1.3 ACH	1409	184	$0.28	19
Dark Shingle roof, R-10 ceiling insulation, duct repaired 4% leak, attic floor sealed	1355	192	$0.28	10
Dark Shingle roof, R-45 ceiling insulation, duct repaired to 4% leak, attic floor sealed	840	99	$0.16	11
New Attic Design, R-30 ceiling insulation, R-8 duct repaired 4% leak, attic floor sealed	**633**	**94**	**$0.14**	**16**
Dark Shingle roof, R-01 ceiling insulation, 10% leaky duct, attic deck sealed with R-20 spray foam	668	64.2	$0.11	23*

* ePlus estimates sealed attic incurs $90 added cost because HVAC runs longer for sealed attic with 10% leaky duct as compared to New Design with 4% inspected duct.

Austin, TX

New construction hot climate

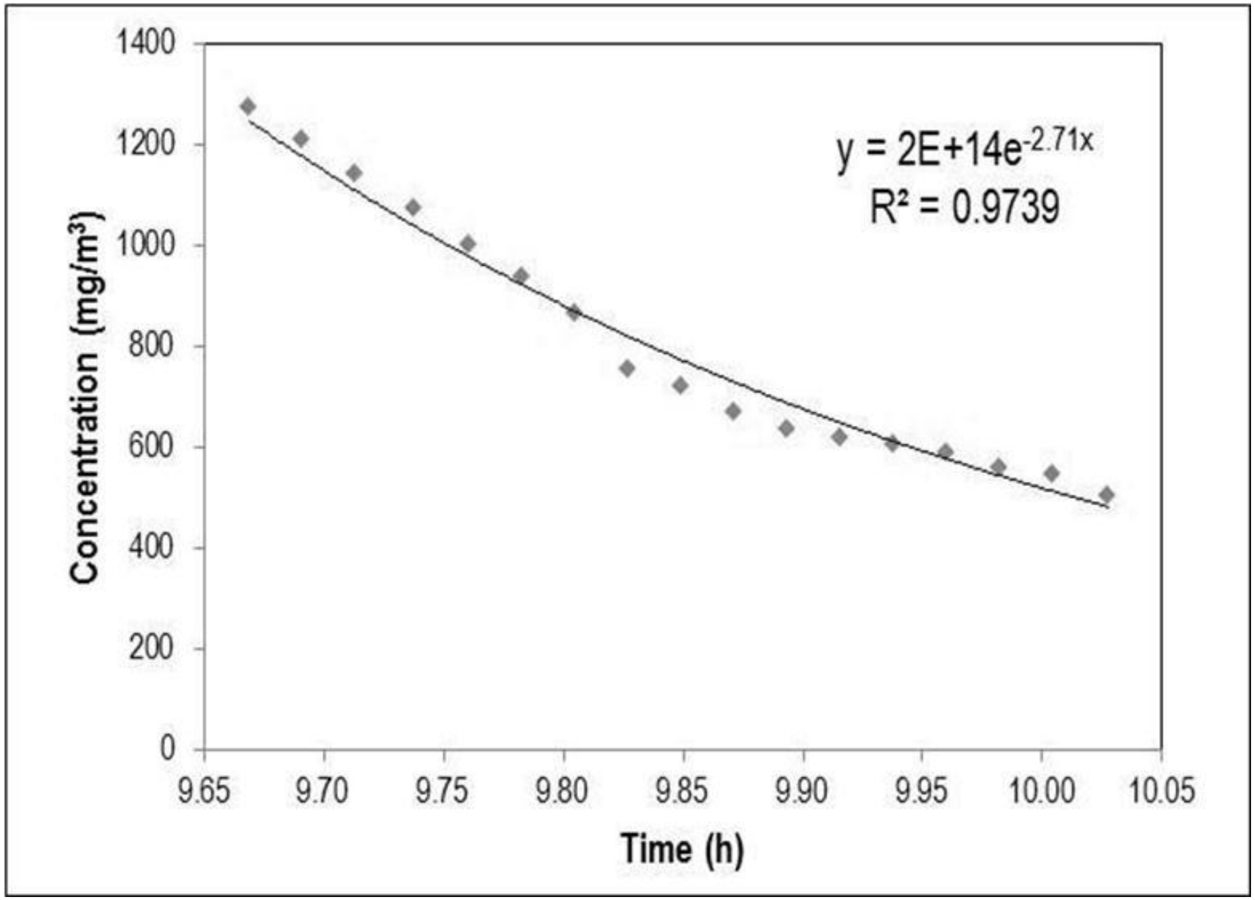
New Construction (IECC 2006 Code)	Seasonal Energy Use		Annual Energy Cost	Simple Payback
	Cooling (kWh)	Heating (Therms)	$ per square foot	(yrs)
Dark Shingle roof, R-30 ceiling insulation, R-8 insulated duct with 4% leak, attic floor sealed**	1045	148	$0.22	
Dark Shingle roof, R-01 ceiling insulation, 10% leaky duct, attic deck sealed with R-20 spray foam	668	64	$0.11	40
New Attic Design, R-30 ceiling insulation, R-8 duct inspected with 4% leak, attic floor sealed	633	94	$0.14	18
New Attic design, R-30 ceiling insulation, No duct in attic, attic floor sealed	121	35	$0.04	8

** Roof and Attic Assembly assumes perfect compliance with building code. California Energy Commission Title 24 specifies an inspected duct as having 4% leakage.

Austin, TX

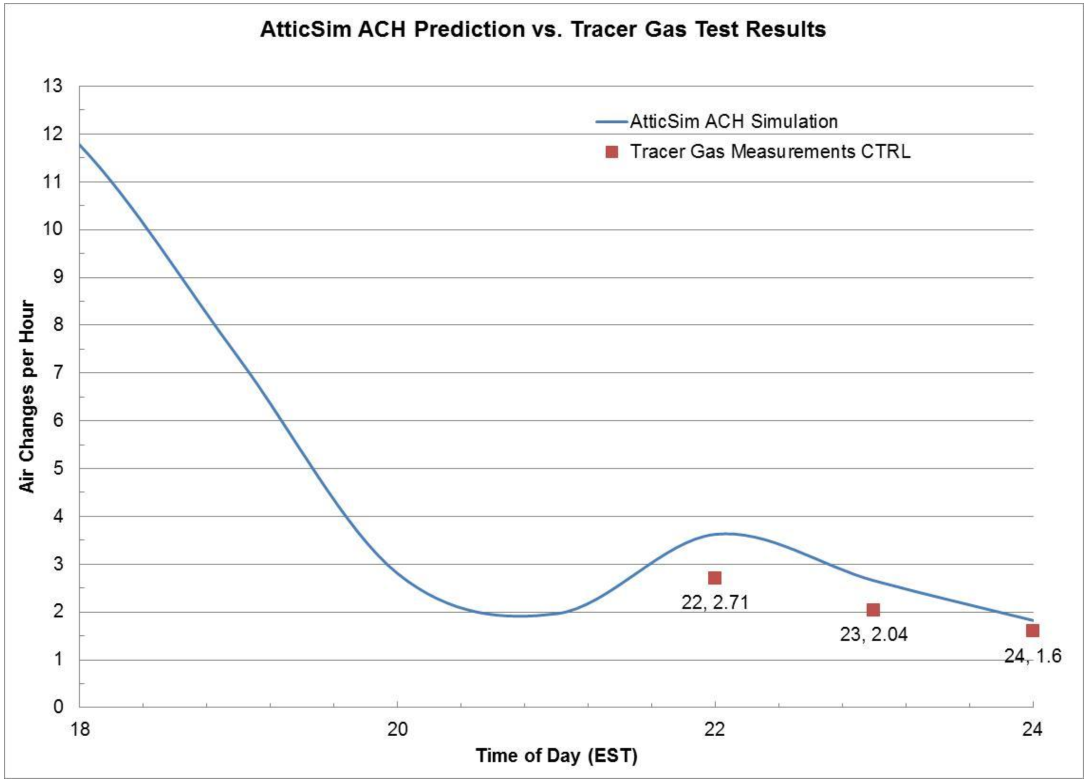
Tracer gas testing used to compute ACH of attics

Regression analysis for decay rate of concentration yields ACH of 2.71

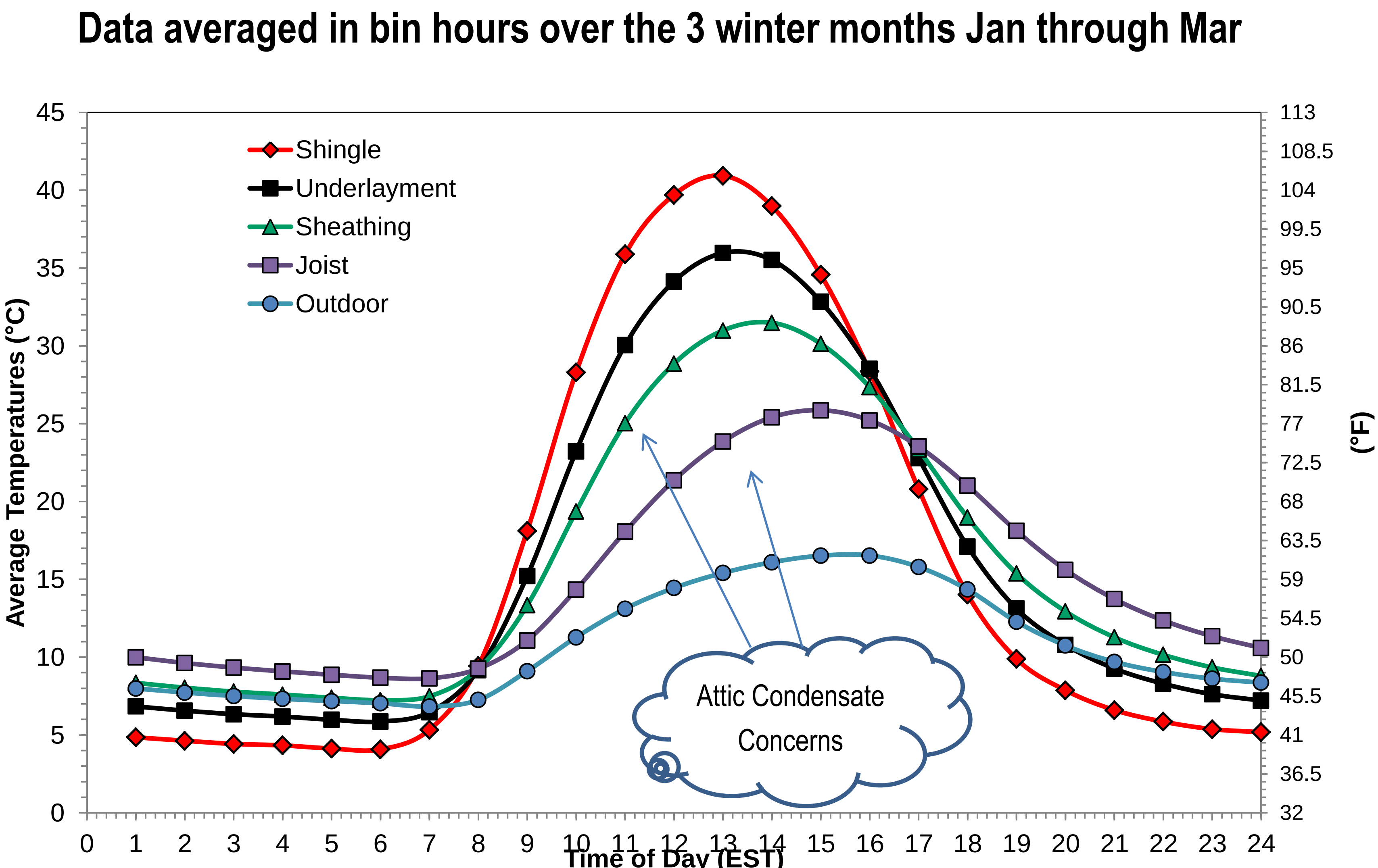


Ventilation benchmark

- Major assumption in using the AtticSim tool is the accuracy of the ventilation prediction.
- Simulations were run for test period when gas tracer analysis performed.



Control roof winter temperature profile



Winter surface condensation potential

Attic	Hours $T_{sheath}<T_{dp}$ (2015 total)	% Time for Condensation on Sheathing	Hours $T_{joist}<T_{dp}$ (2015 total)	% Time for Condensation on Joist
03 - NB	110	5.5%	72	3.6%
04 - CS	103	5.1%	62	3.1%
01 - CTRL	102	5.1%	48	2.4%
06 - RB	83	4.1%	26	1.3%
07 - FF	75	3.7%	32	1.6%
05 - ASV	20	1.0%	10	0.5%

Cool roof roadmap

- Outline of upcoming DOE work on cool roofs
- Includes
  - Buildings level
  - Urban Level
  - Global Level
  - International activities

www.eereblogs.energy.gov/buildingenvelope

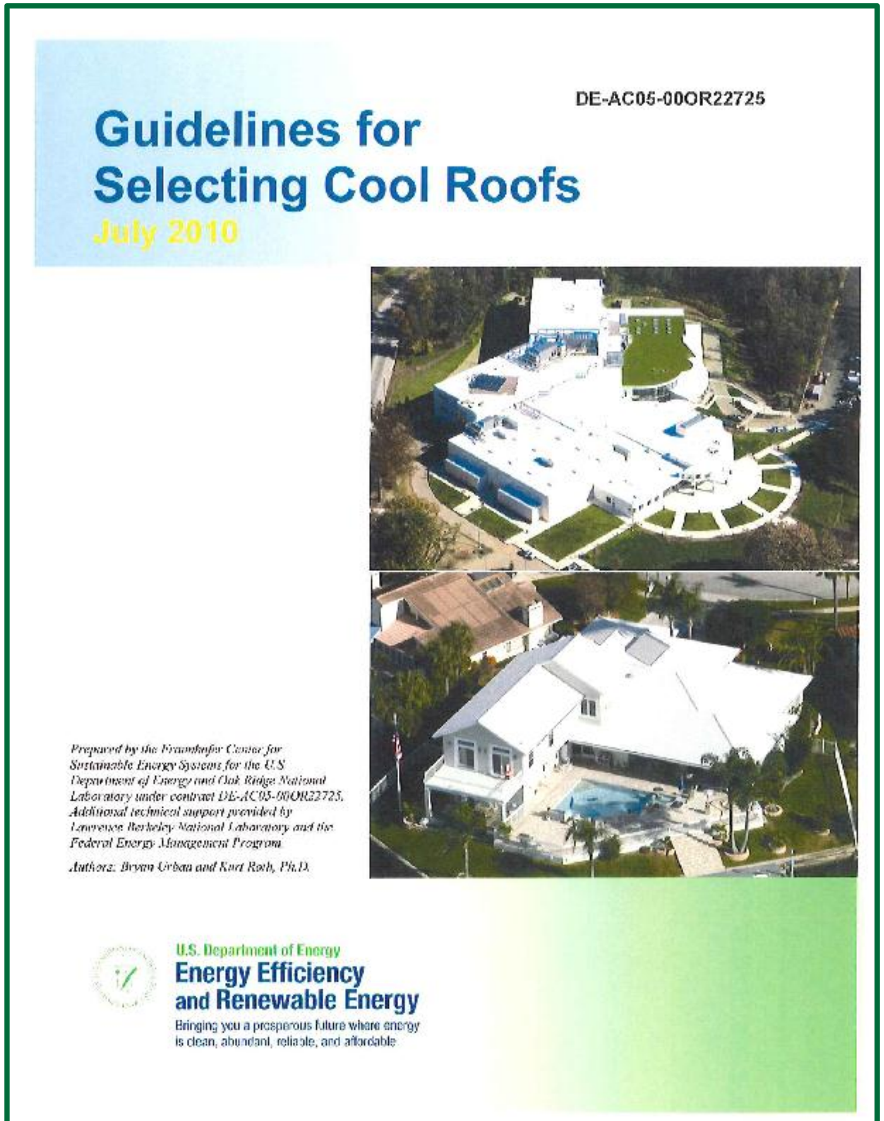
Buildings level

- **Key accomplishments:**
  - **Cool roof selection guide**
  - **Cool roof calculator**
  - **DOE cool roof policy**
- **Key upcoming work**
  - **Aged rating protocol**
  - **Advanced materials**

81C

34C

Cool roof selection guide



DE-AC05-00OR22725

Guidelines for
Selecting Cool Roofs
July 2010

Prepared by the Fraunhofer Center for Sustainable Energy Systems for the U.S Department of Energy and Oak Ridge National Laboratory under contract DE-AC05-00OR22725. Additional technical support provided by Lawrence Berkeley National Laboratory and the Federal Energy Management Program

Authors: Bryan Urban and Kurt Roth, Ph.D.

U.S. Department of Energy
Energy Efficiency
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Roof savings calculator

- Collaboration by ORNL and LBNL with funding from DOE and CEC
- Provides cool roof assessments and advanced roof options
- Runs full simulations
- See RoofCalc.com

Roof Savings Calculator (RSC)

Beta Release v0.7

Oak Ridge National Laboratory
Lawrence Berkeley National Laboratory

Introduction
The Roof Savings Calculator was developed as an industry-consensus roof savings calculator for commercial and residential buildings using whole-building energy simulations. It is built upon the DOE-2.1E engine for fast energy simulation and integrates AtticSim for advanced modeling of modern attic and cool roofing technologies. An annual simulation of hour-by-hour performance is calculated for the building properties provided based on weather data for the selected location. Annual energy savings reported are based upon heating and cooling loads and thus this calculator is only relevant to buildings with a heating and/or cooling unit.

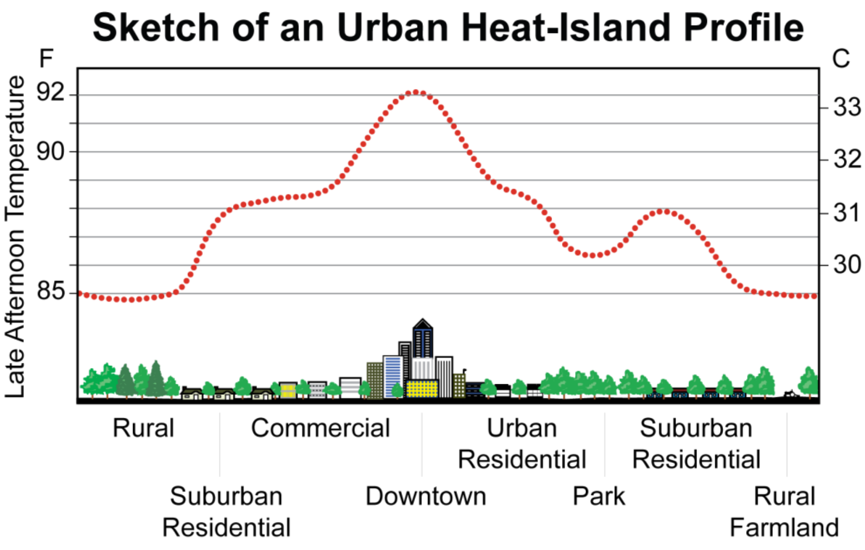
Roof Savings Calculator
To begin, please select from the following options:

DOE cool roof policy

- A low-sloped roof (pitch less than or equal to 2:12) must be designed and installed with a minimum 3-year aged solar reflectance of 0.55 and a minimum 3-year aged thermal emittance of 0.75 in accordance with the Cool Roof Rating Council program, or with a minimum 3-year aged solar reflectance Index (SRI) of 64 in accordance with ASTM Standard E1980-01. Steep-sloped roofs (pitch exceeding 2:12) must have a 3-year aged SRI of 29 or higher.
- Requires R30 Insulation
- Required unless determined to be not economical by life cycle cost analysis

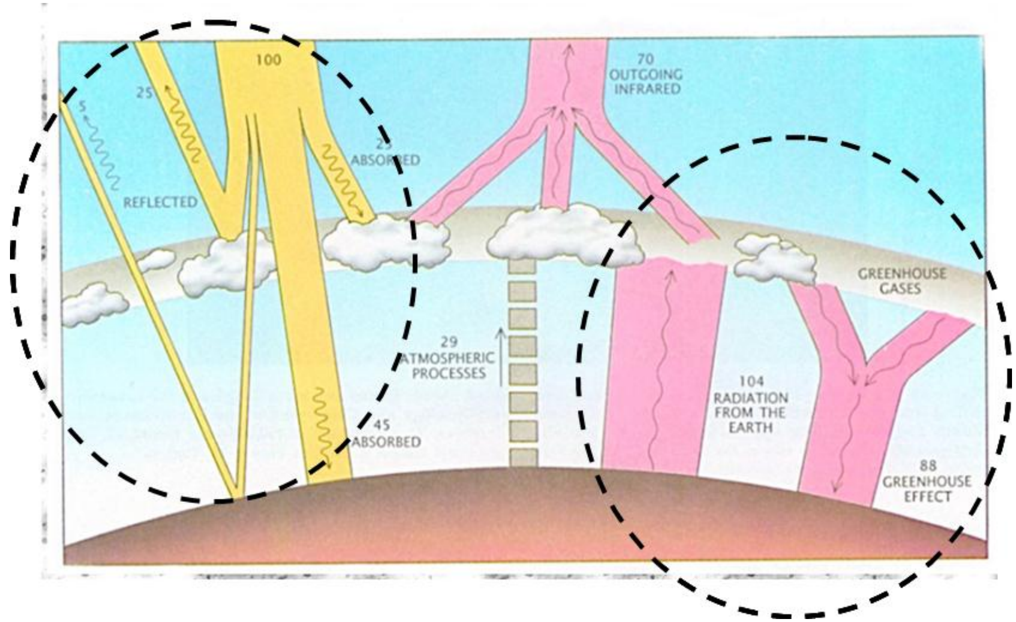
Urban level

- **Key accomplishments:**
  - **Major literature review**
- **Key upcoming work**
  - **Study of urban pollution abatement**



Global level

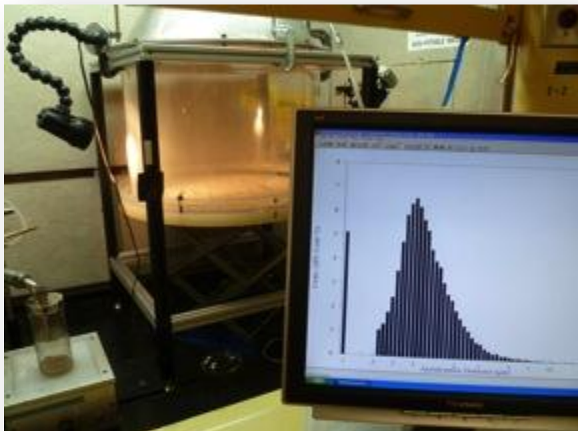
- Key Accomplishments:
  - Peer Review Panel
- Key Upcoming Work
  - Validation of Global cooling models
  - India Project

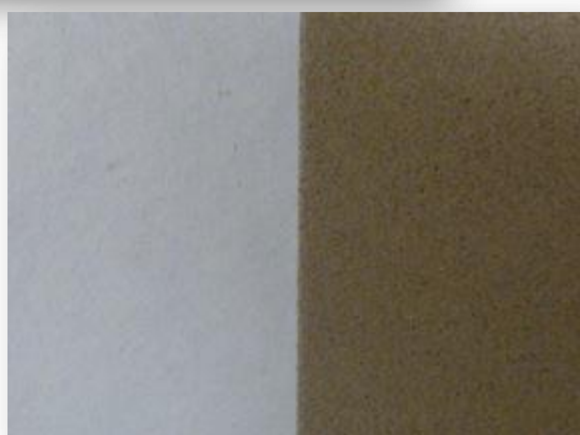


Source: IPCC

Total emitted CO_2 offset for cool roofs and cool pavements = 44 GT CO_2

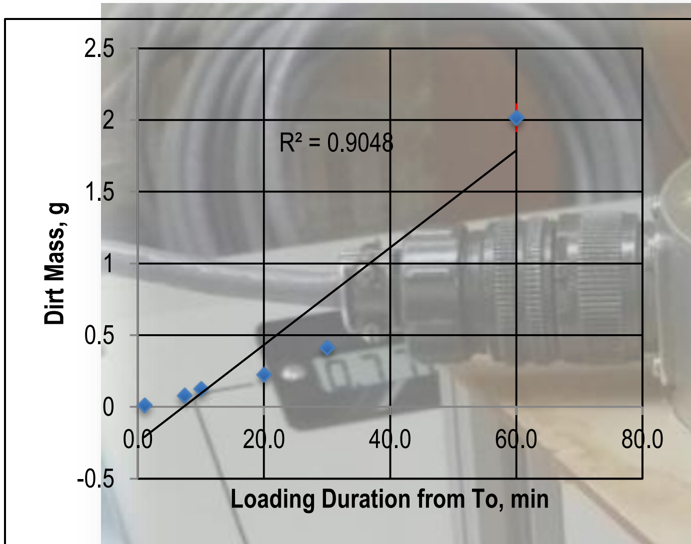
Design load chamber for simulating and accelerating roof contamination rate

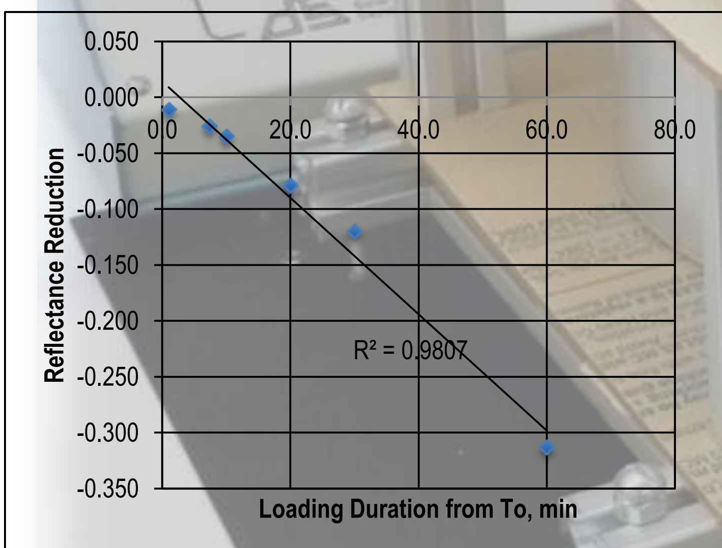




- Chamber built for accommodating a sample size up to 15” in dia. or multiple samples of smaller area size
- Real-time monitoring capability for contaminant loading
- Easy access to sample for reflectance measurement and loading verification
- Design for loading dry and or wet contaminants

Loading and reflectance reduction rates

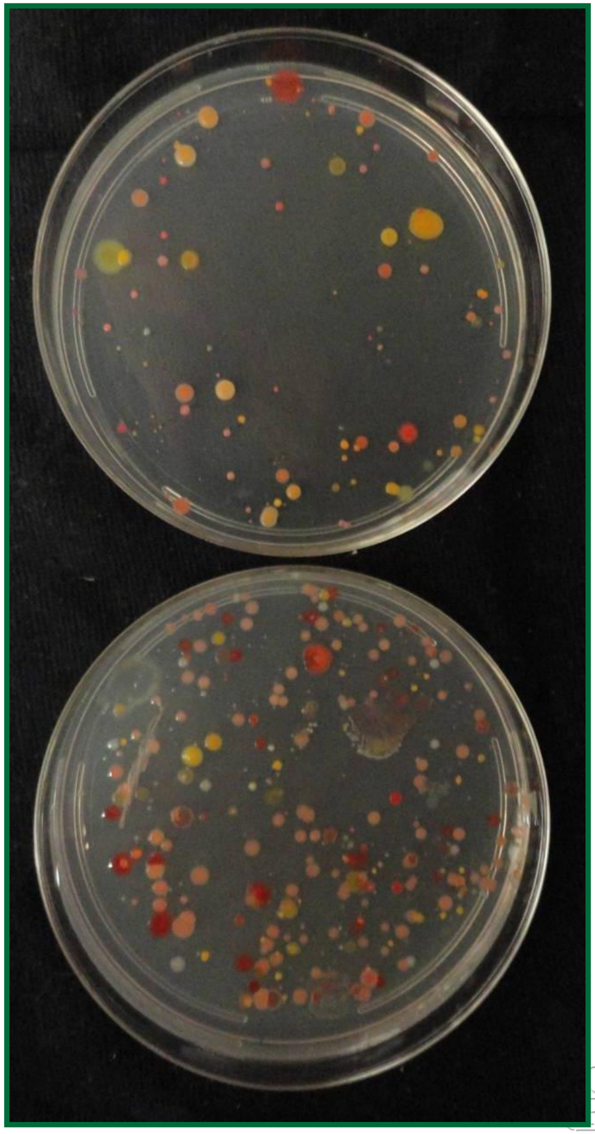




- Hi-fidelity simulation of atmospheric dust loading using real-world test dusts, e.g., Arizona test dust(ISO 12103-1 standard)
- Total surface reflectance measurement tested on Arizona test dust Mass loading function linear (R^2>0.9) following deposition theory
- Reflectance reduction also linear following dust load (R^2 > 0.98)

Microbial analyses

- Sampling protocols for cultivation and nucleic acid analysis was tested at sites in TN, PA, and FL.
- One sample from each site is undergoing 454 sequencing analysis

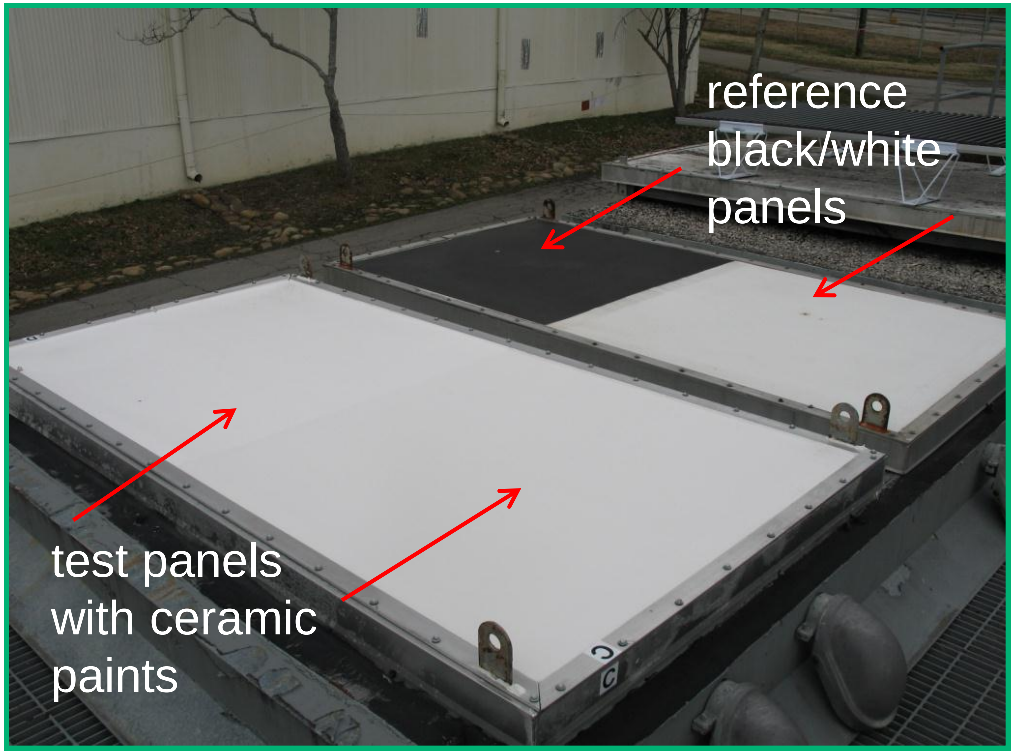


Chamber acquired to accelerate microbial growth

- Chamber controls solar radiation, temperature, humidity, wetting cycle acquired to perform exposure testing
- Specimens loaded with dust and inoculated with microbes will be inserted in chamber and evaluated

Cool roof coatings with ceramics

- Cool roof coatings are promoted based on the presence of ceramic particles.
- Unclear that particles improve performance.
- Tests begun in March 2010 of four cool roof coating products.
- Temperature and heat flux through the roof measured to quantify performance.

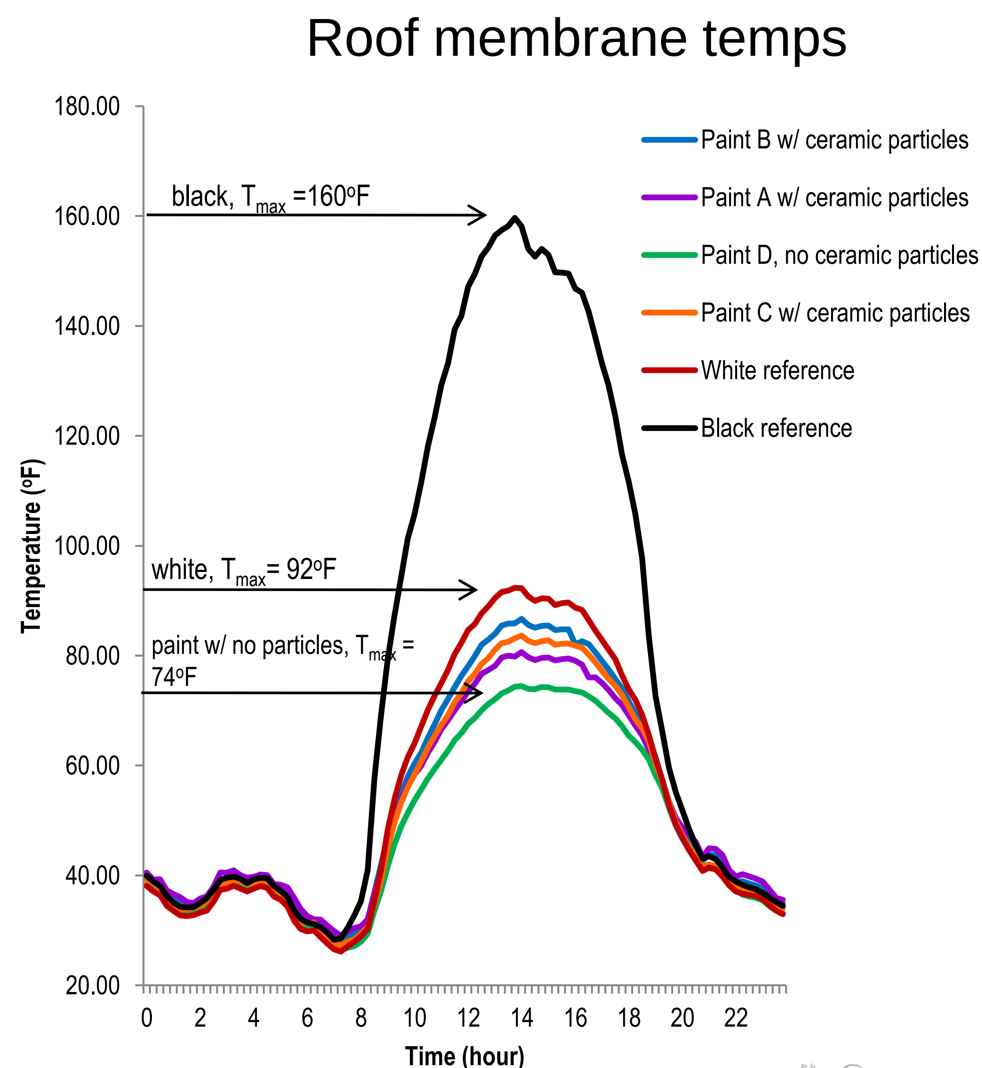


Cool roof coating results

Sample data for sunny day, April 16, 2010

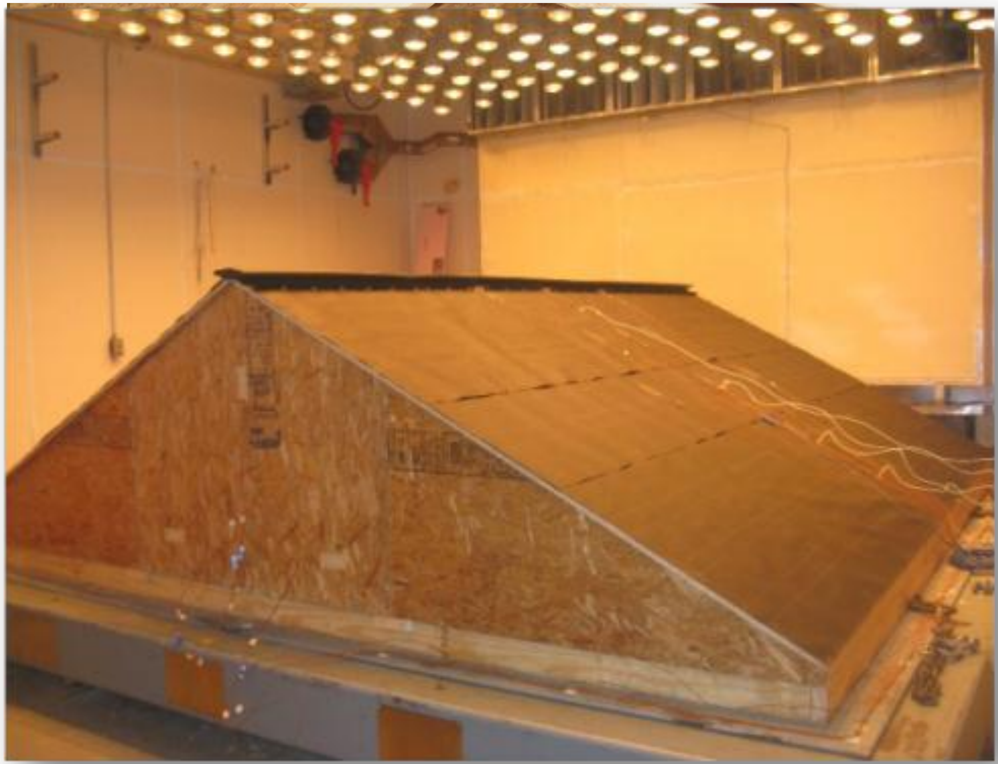
A coating with no ceramic beads ($SR_{initial}$ = 0.88) keeps roof cooler than paints with ceramic particles ($SR_{initial}$ about 0.8) .

…and requires less cooling than other samples and heating penalty only relative to the black surface.



Performance of attic radiant barrier systems

Attic 1 Oriented strand board (OSB) without radiant barrier (RB), ε = 0.89
Attic 2 OSB with perforated foil faced RB, ε = 0.03
Attic 3 RB stapled to rafters, ε = 0.02
Attic 4 Spray applied low-e paint on roof deck and rafters, ε = 0.23



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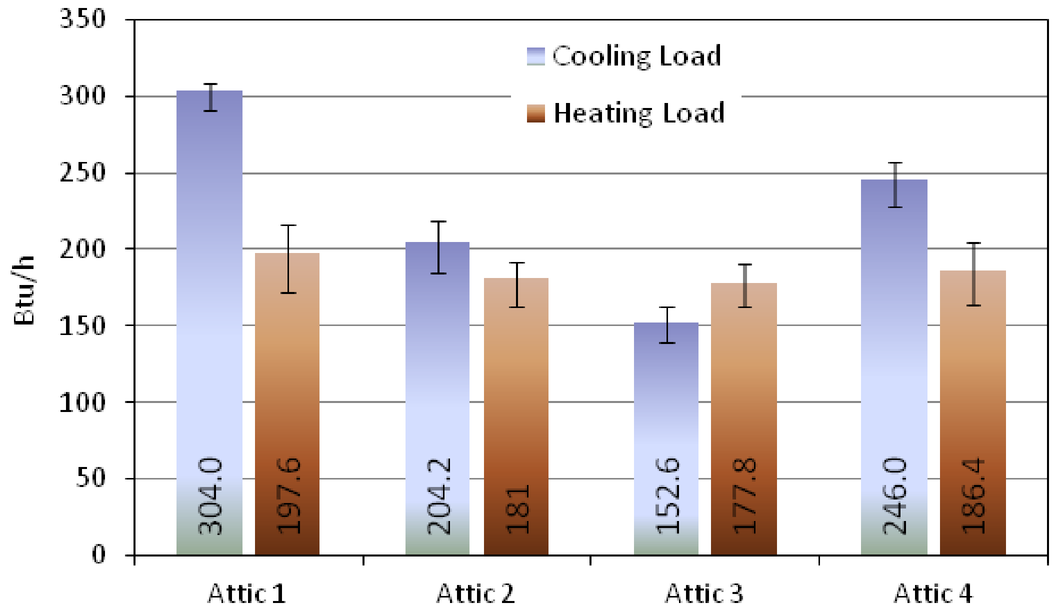
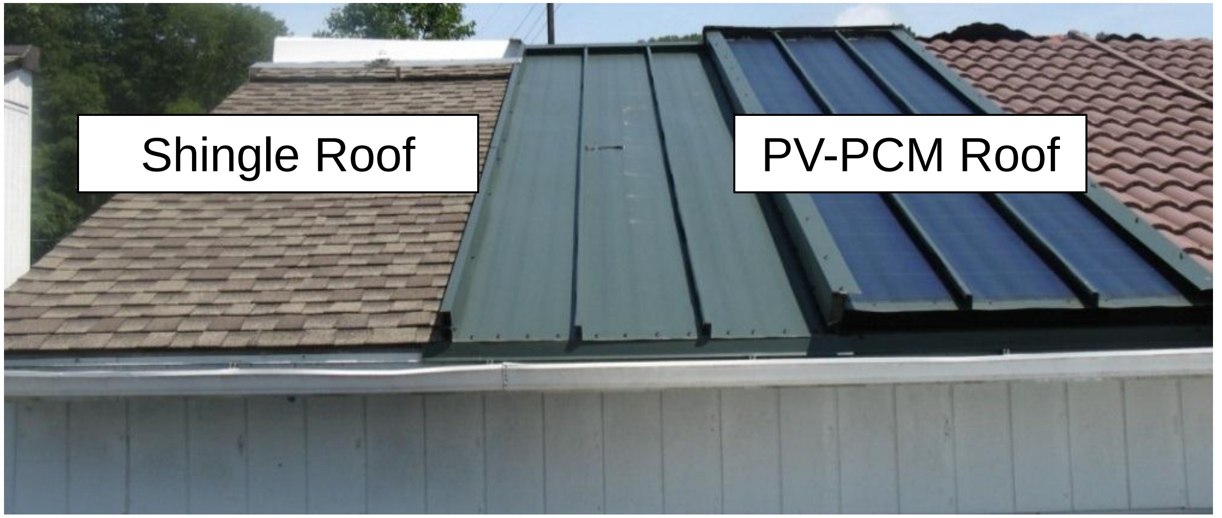
Performance of attic radiant barrier systems

- **Cooling load through attics 2, 3, and 4 were 33%, 50%, and 19% lower than the load from attic 1 during summer daytime conditions**
- **During winter conditions, a 6 to 10% reduction in heat loss through the ceiling was observed**



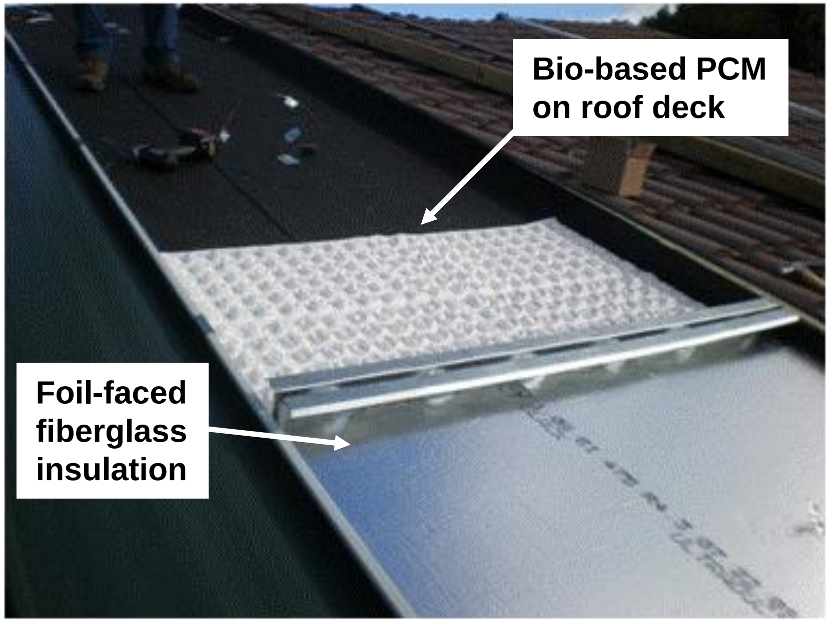
- The test attic had R_{US} 13 fiberglass batt insulation on the floor
- Summer daytime condition: climate chamber air temperature 100°F, roof exterior surface temperature 140°F
- Winter Night condition: climate chamber air temperature 32°F

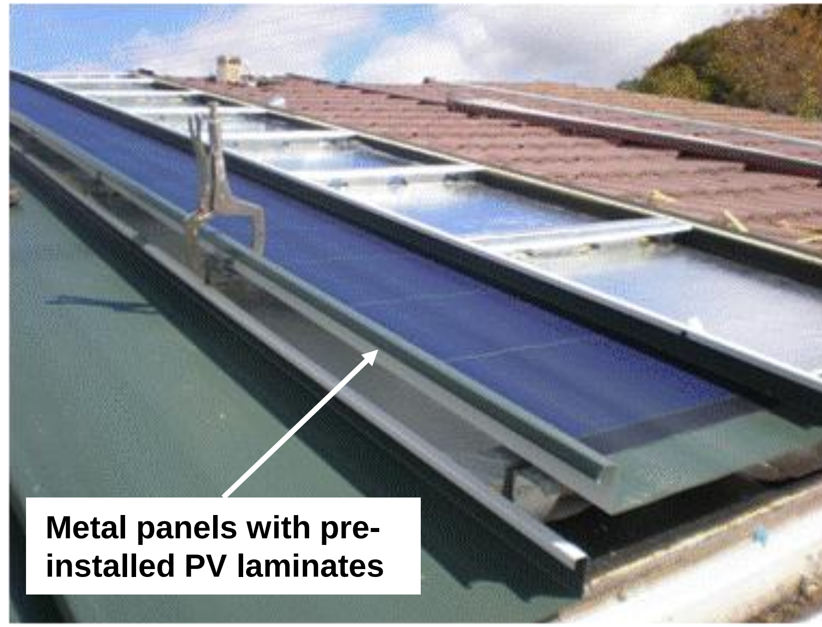
Integrated PV-PCM roof

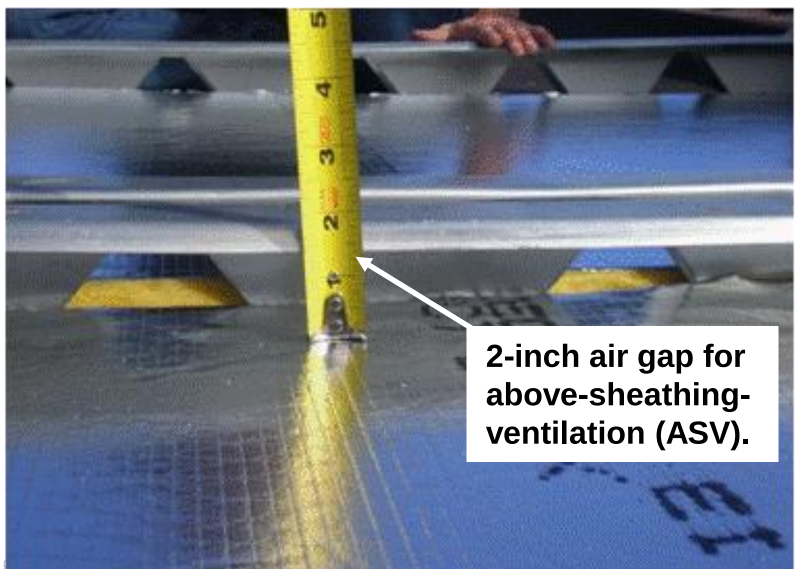


- **Evaluation of a roof system with (PV) laminates integrated with metal panels and PCM.**
- **Collaboration between Metal Construction Association, CertainTeed, Uni-Solar, Phase Change Energy Solutions, and ORNL.**
- **Shingle roof used as control for comparison and evaluation of the PV-PCM roof.**

PV-PCM roof construction

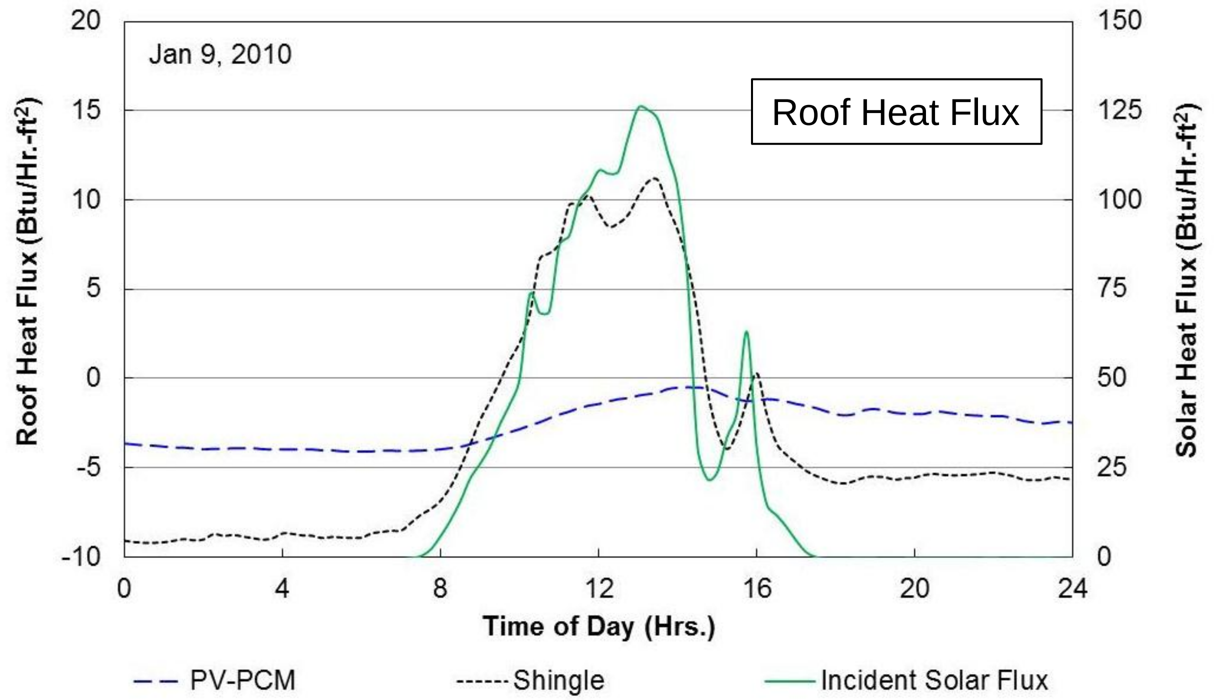


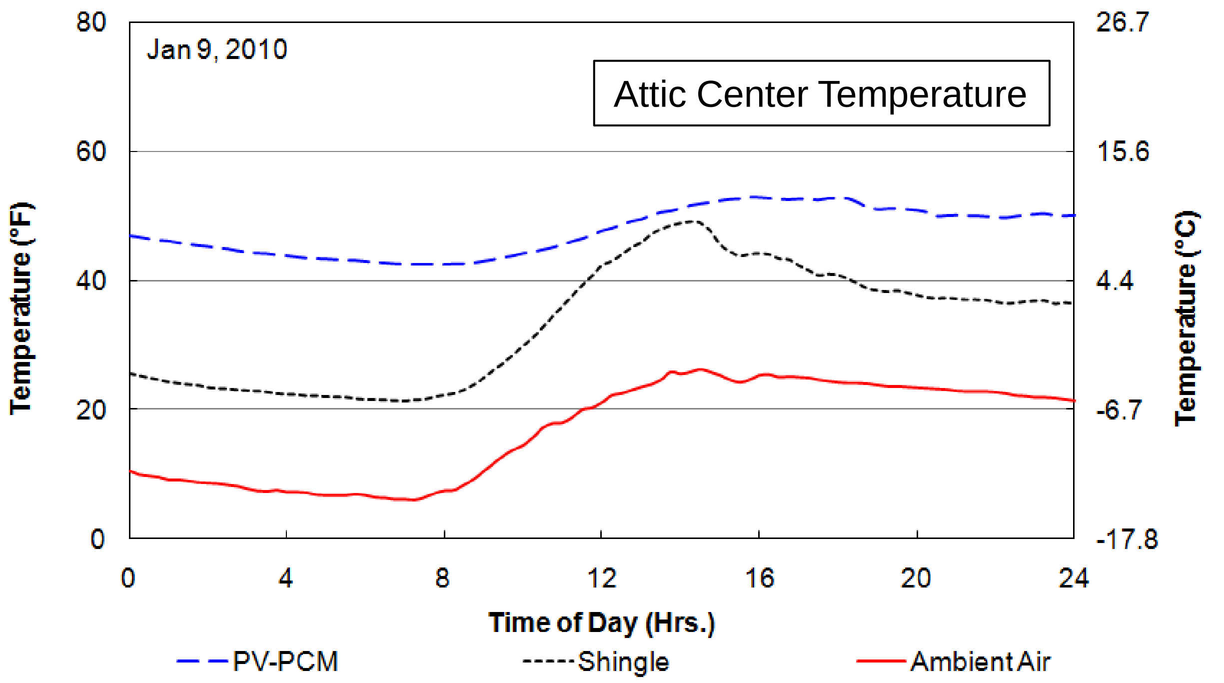




Winter data

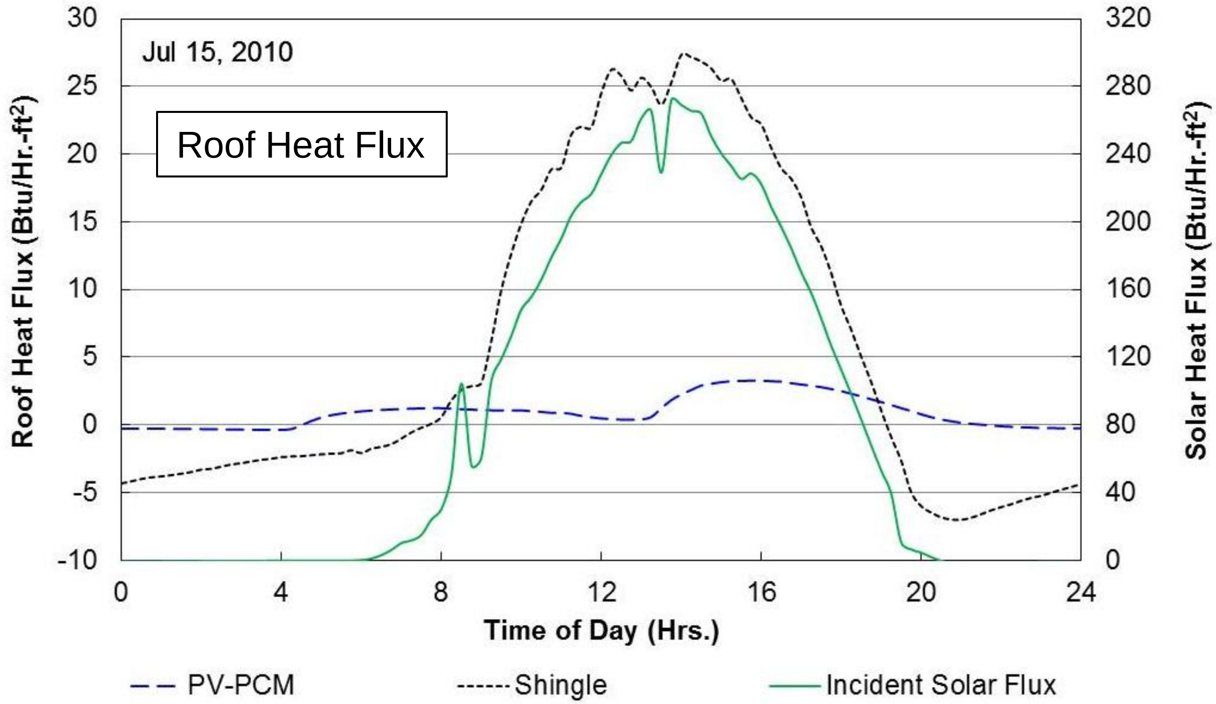
- Substantially lower heat flow through PV-PCM roof, and warmer attic.
- Mid-day heat addition increases the shingle attic temperature; possible heating penalty in PV-PCM.

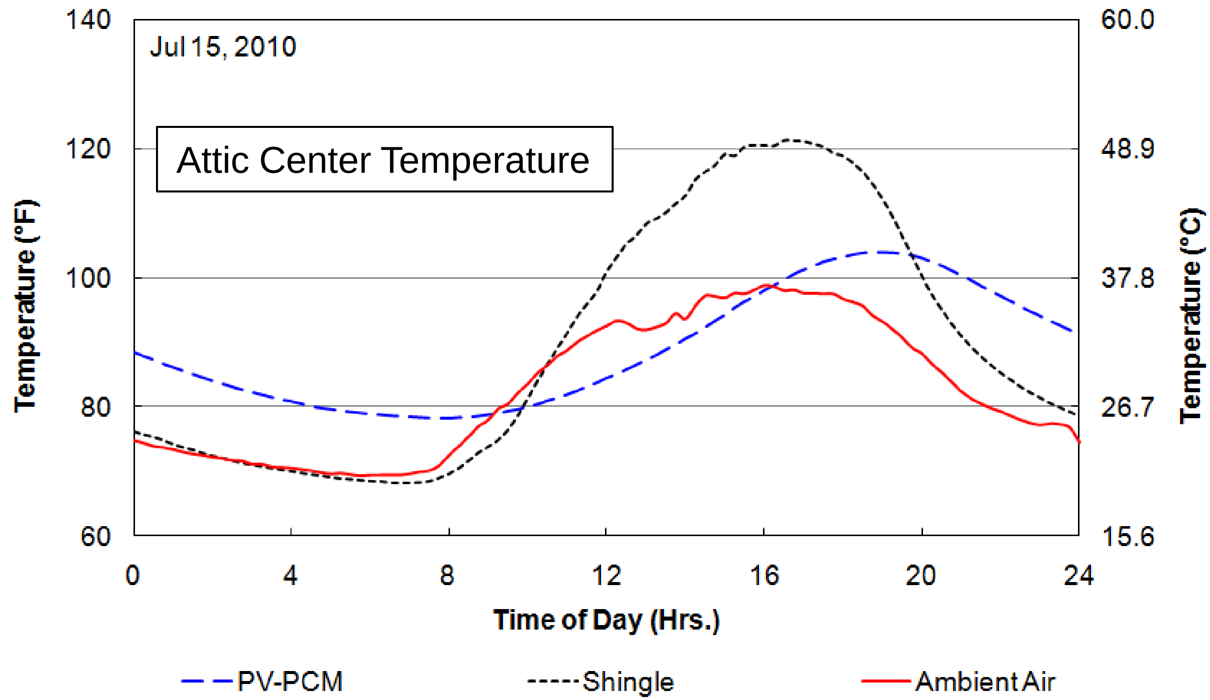




Summer data

- Substantial lower peak daytime heat addition through PV-PCM roof.
- PV-PCM attic temperatures show lower fluctuations; Also evident is a ~2 hr. peak shift.

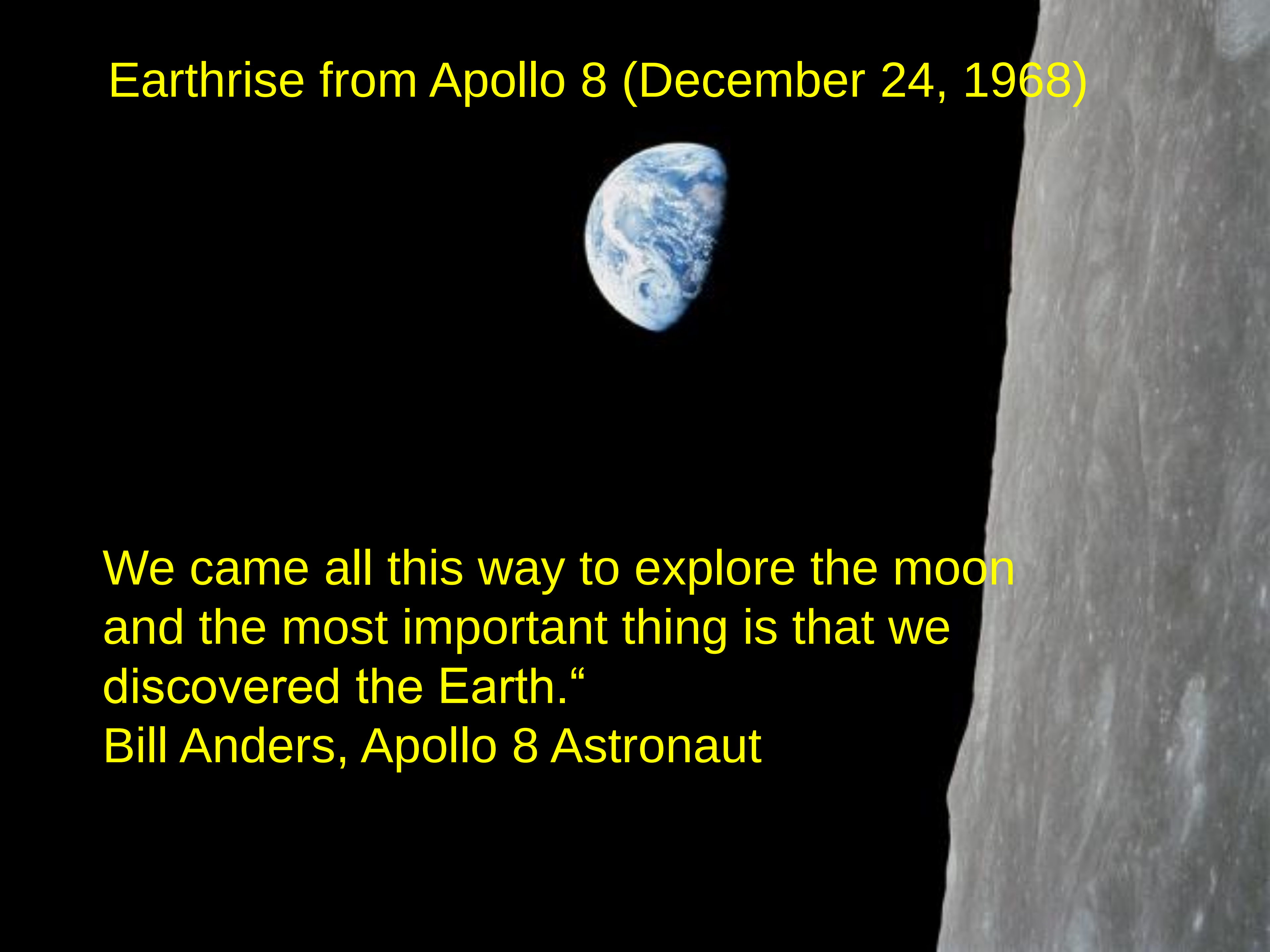




Closing summary

- **Working in partnership with industry, DOE is undertaking both development and enabling research in the roofing market to make available to building owners more energy efficient and affordable roofing system choices.**

Earthrise from Apollo 8 (December 24, 1968)



We came all this way to explore the moon and the most important thing is that we discovered the Earth.“

Bill Anders, Apollo 8 Astronaut