Cool roofs and more: Heat island countermeasures to cool Central California communities

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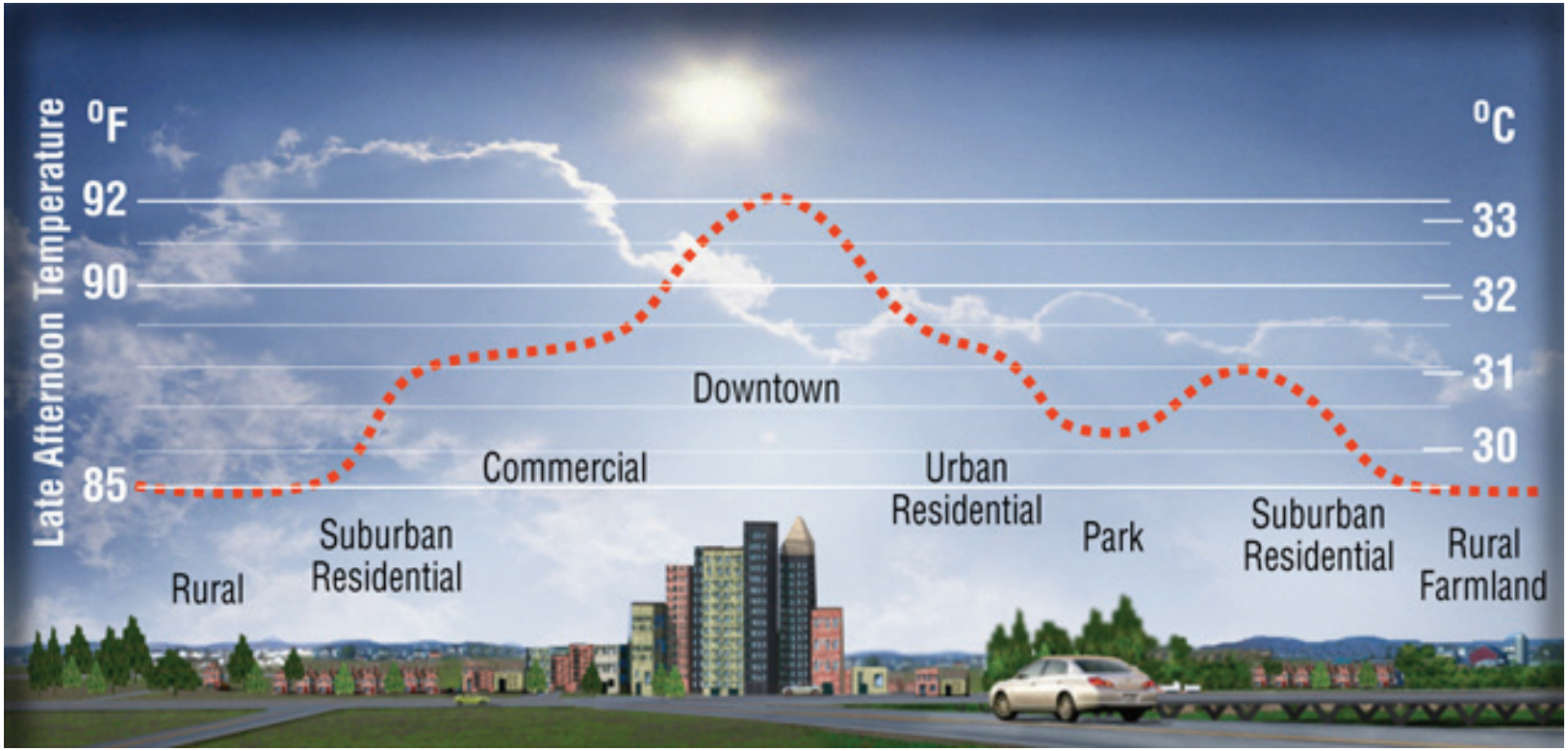
1. The Urban Heat Island

Hot town—summer in the city

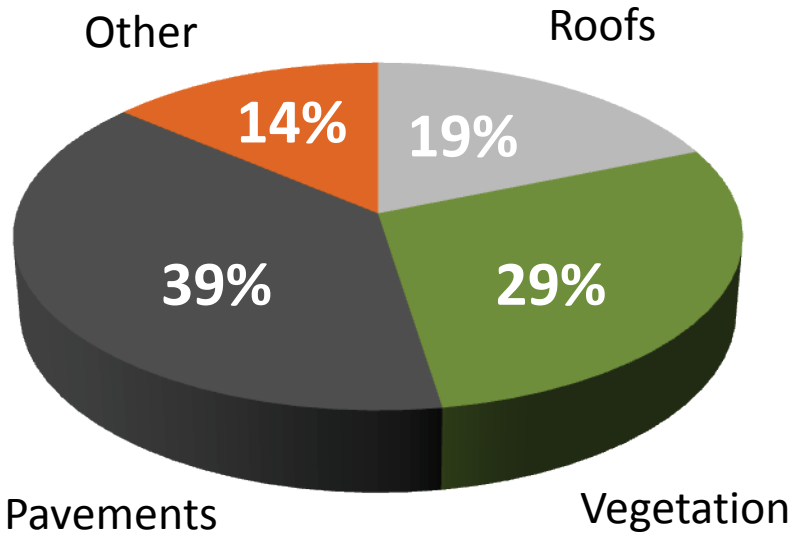


a summer urban heat island

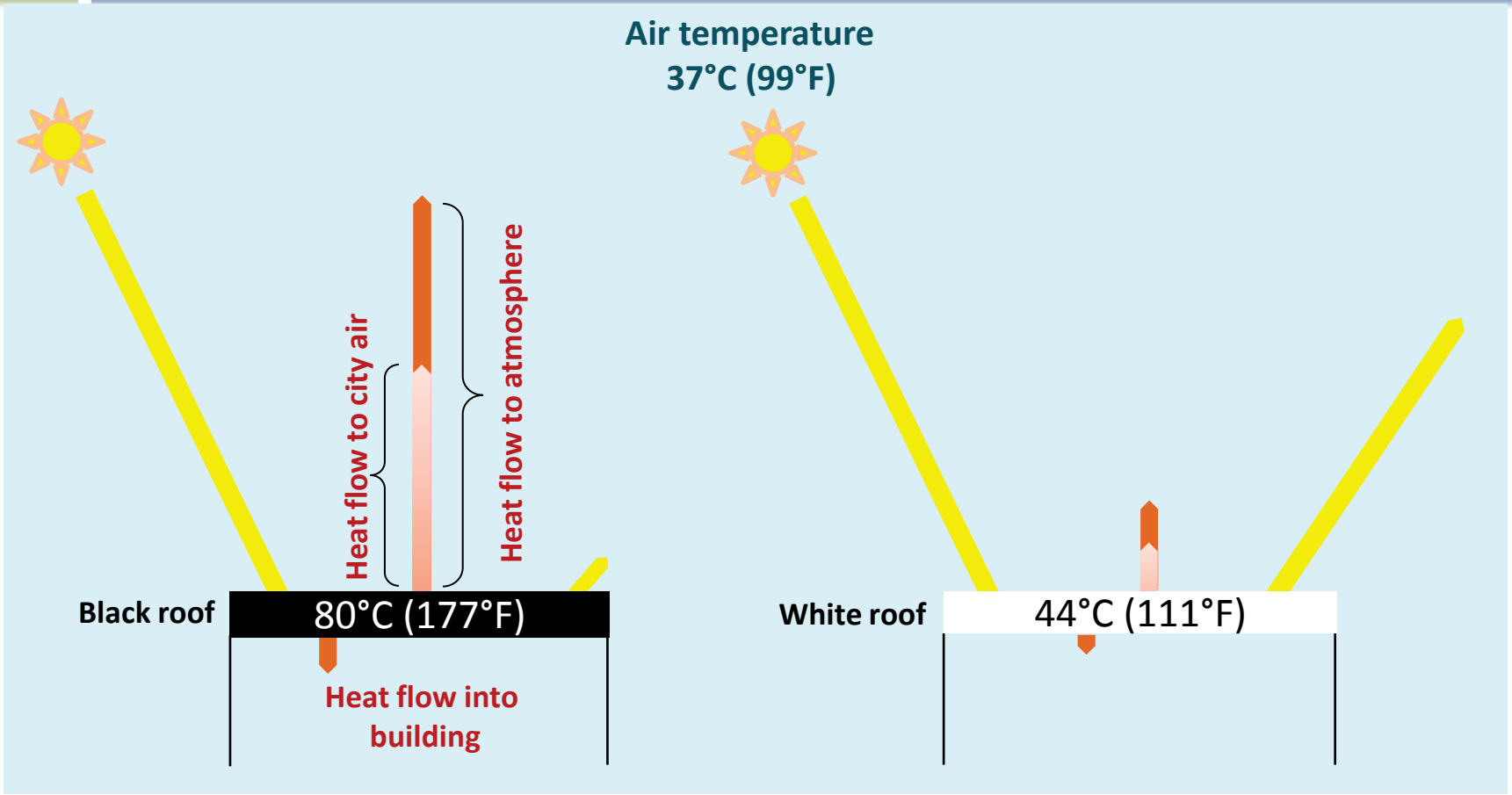
What makes cities warm?

Sacramento, California (≈ 1 km^2)

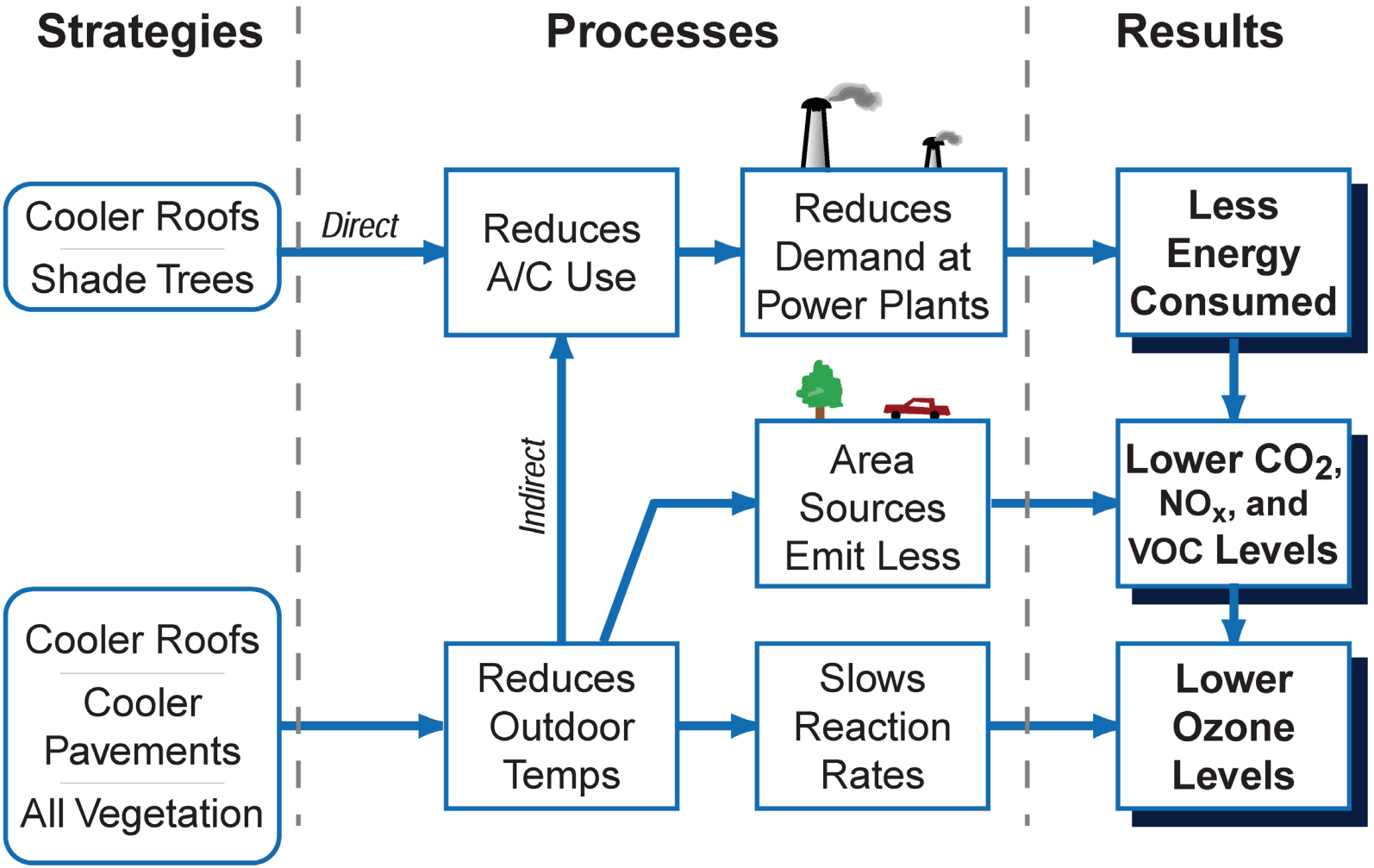
One reason:
many dark surfaces.



Roofs with high solar reflectance cool our buildings, cities, and planet



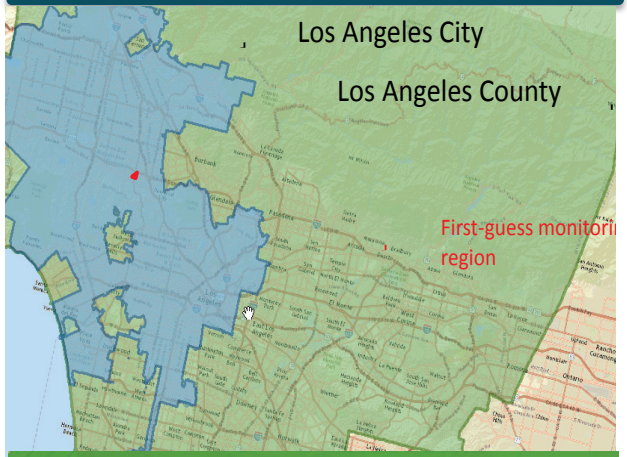
Cool strategies include roofs, pavements, trees—and soon walls

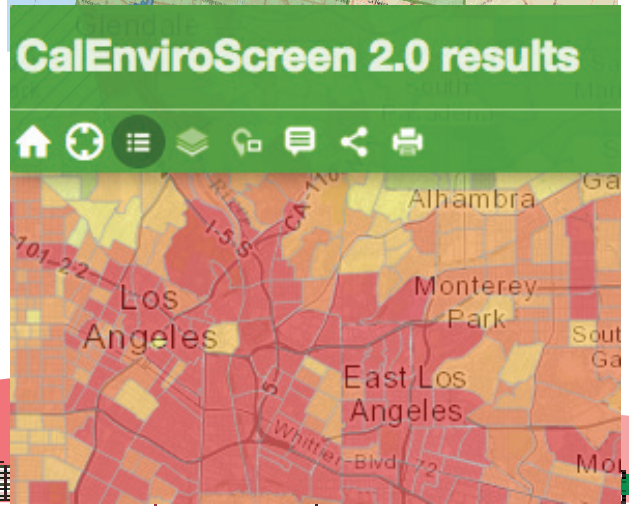


2. Finding Opportunities to Cool Our Cities

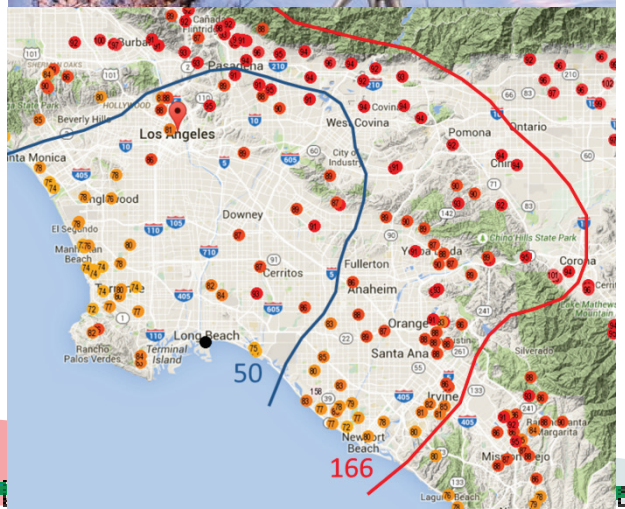
LBNL, USC, and Altostratus will monitor the Los Angeles urban heat island

(1) Identify study region

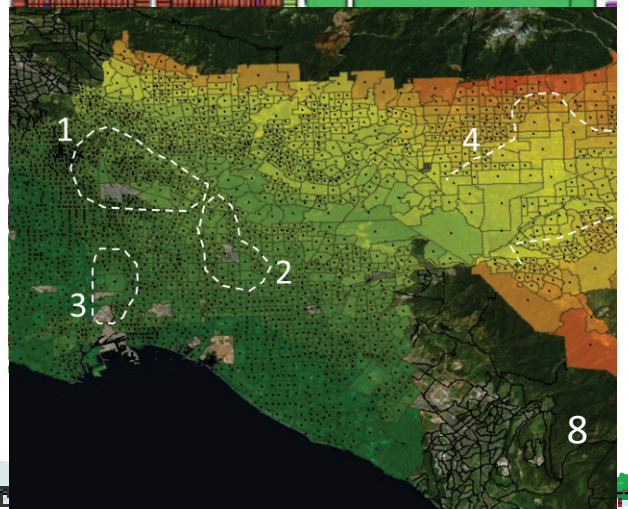




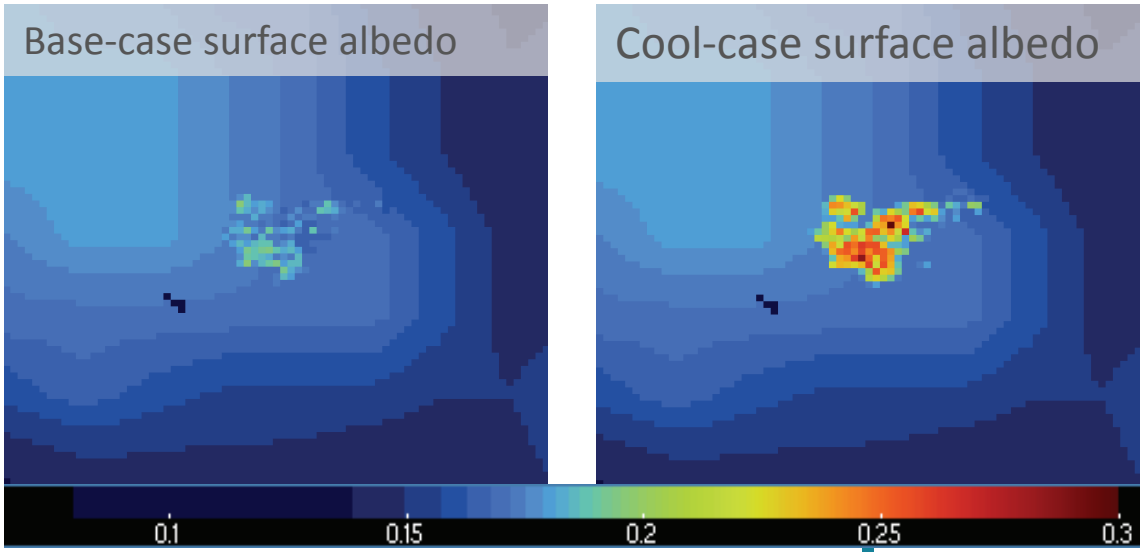
(2) Monitor new & existing weather stations



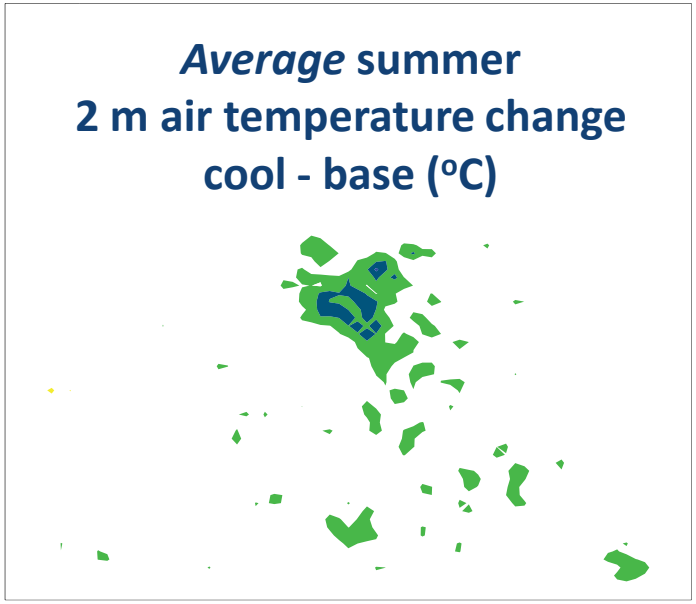
(3) Relate air temperature to land use/land cover



LBNL modeling shows reflective surfaces could cool the air in Bakersfield



Ban-Weiss et al. 2015, *Solar Energy* 115, 791-805



Cool surface case raised pavement albedo to 0.30, pitched roof albedo to 0.35, low-slope roof albedo to 0.60

Reflective surfaces cooled air by 0.3 °C in downtown Bakersfield, 0.1 - 0.2 °C in residential areas

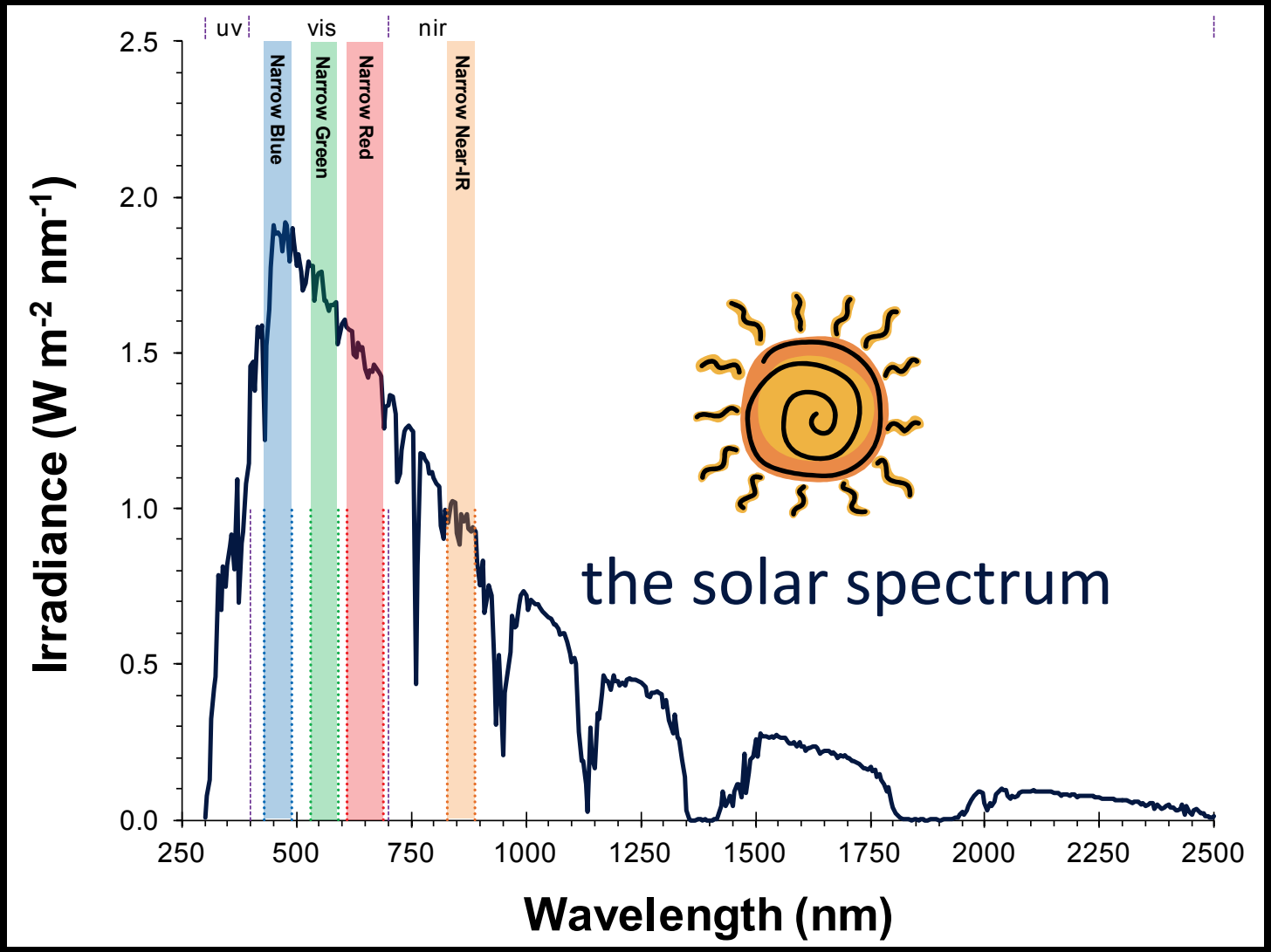
How reflective are California's roofs?

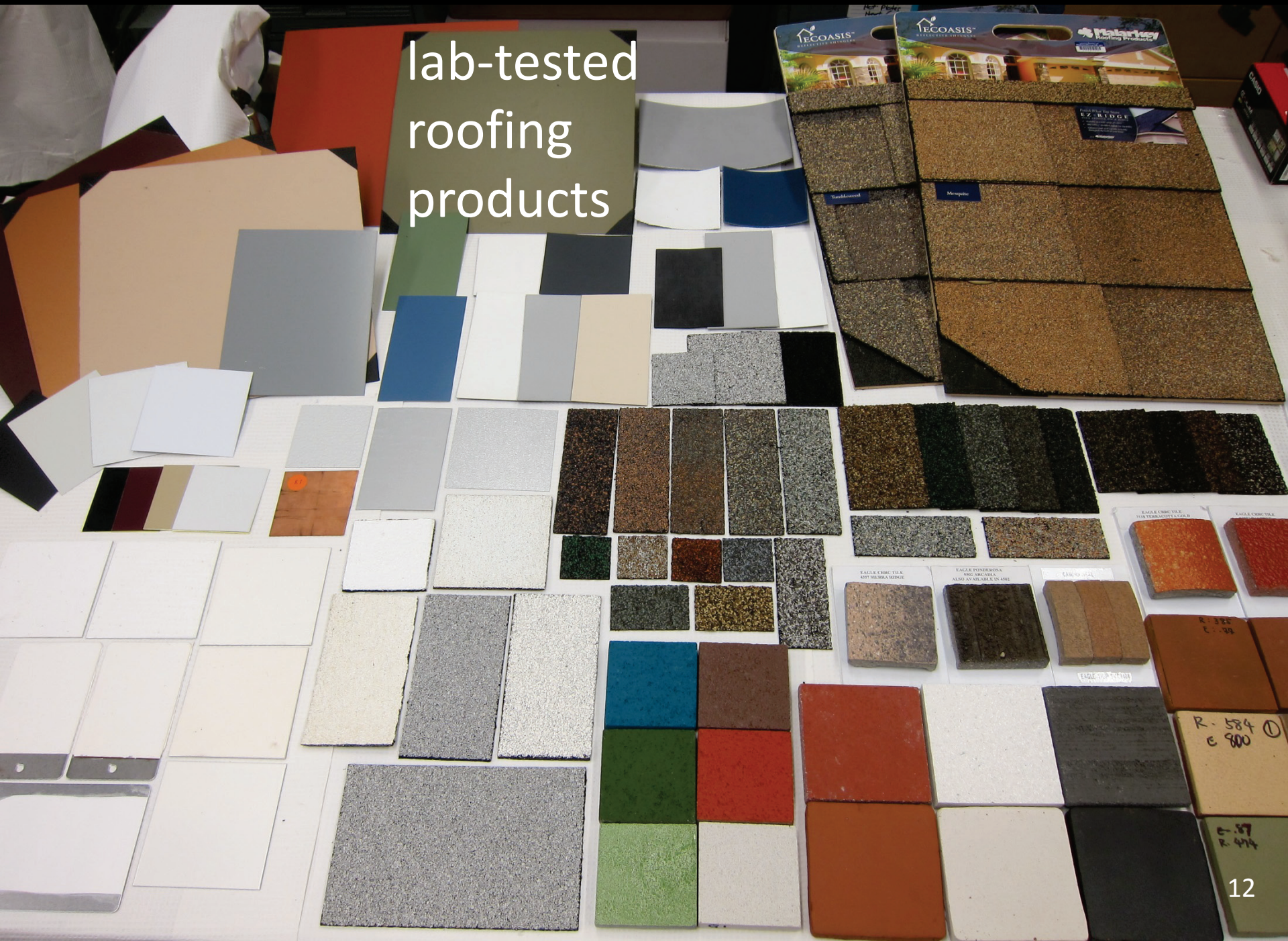
The U.S. Department of Agriculture's
National Agriculture Imagery Program

collects high-resolution images
in blue, green, red, and near-infrared

the images

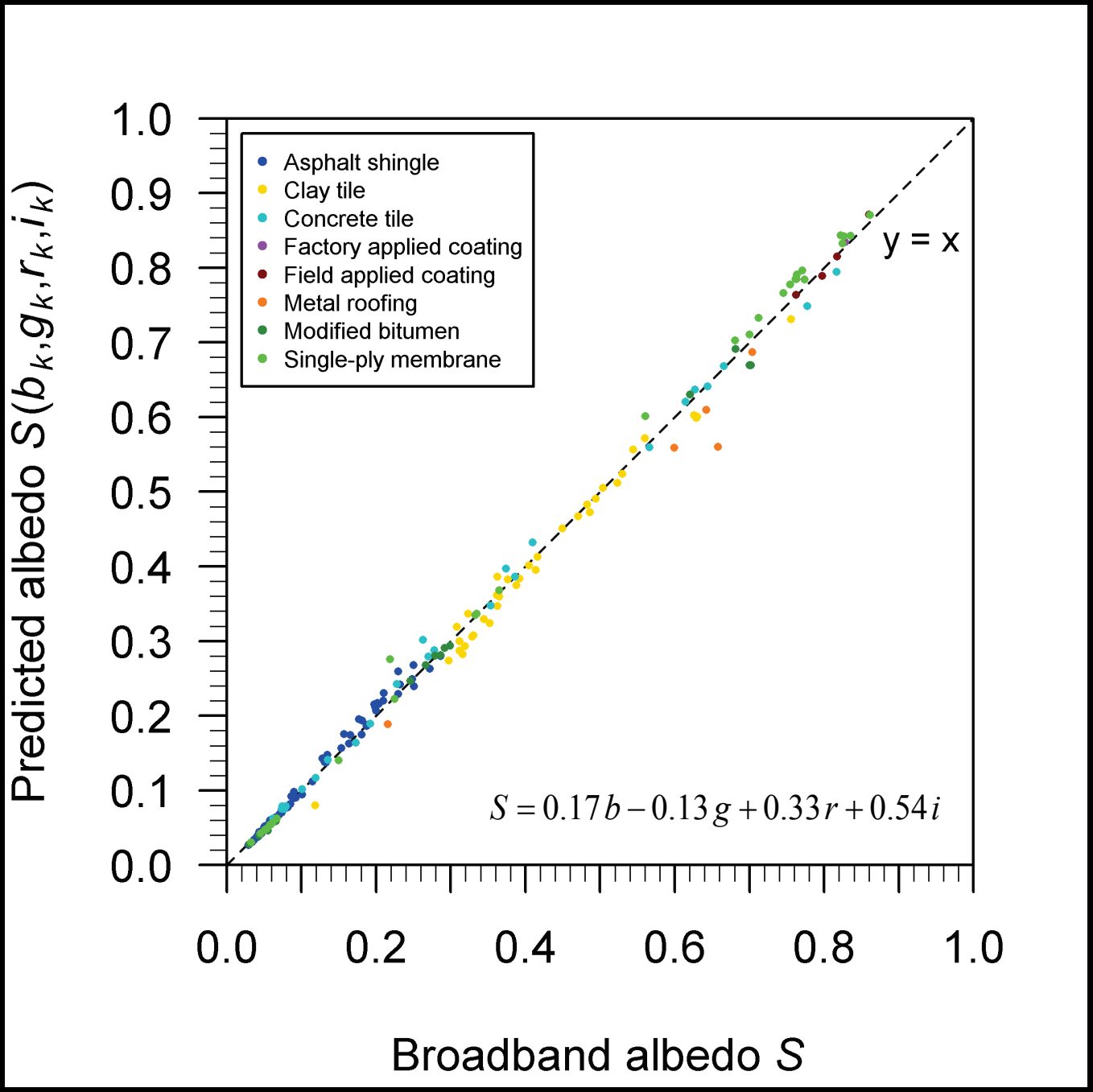
their bands




lab-tested
roofing
products
ECOASIS
ECOASIS
Mesquite
EAGLE CRRC TILE
4557 SIERRA RIDGE
EAGLE PONDEROSA
4502 ARCADIA
ALSO AVAILABLE IN 4502
R - 584
E 800

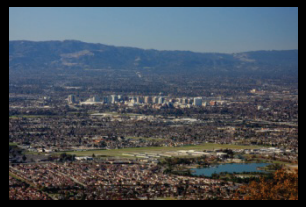
remote measurements

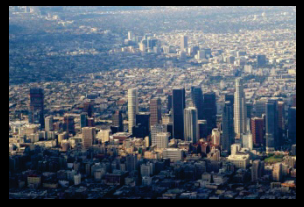
roof albedo?

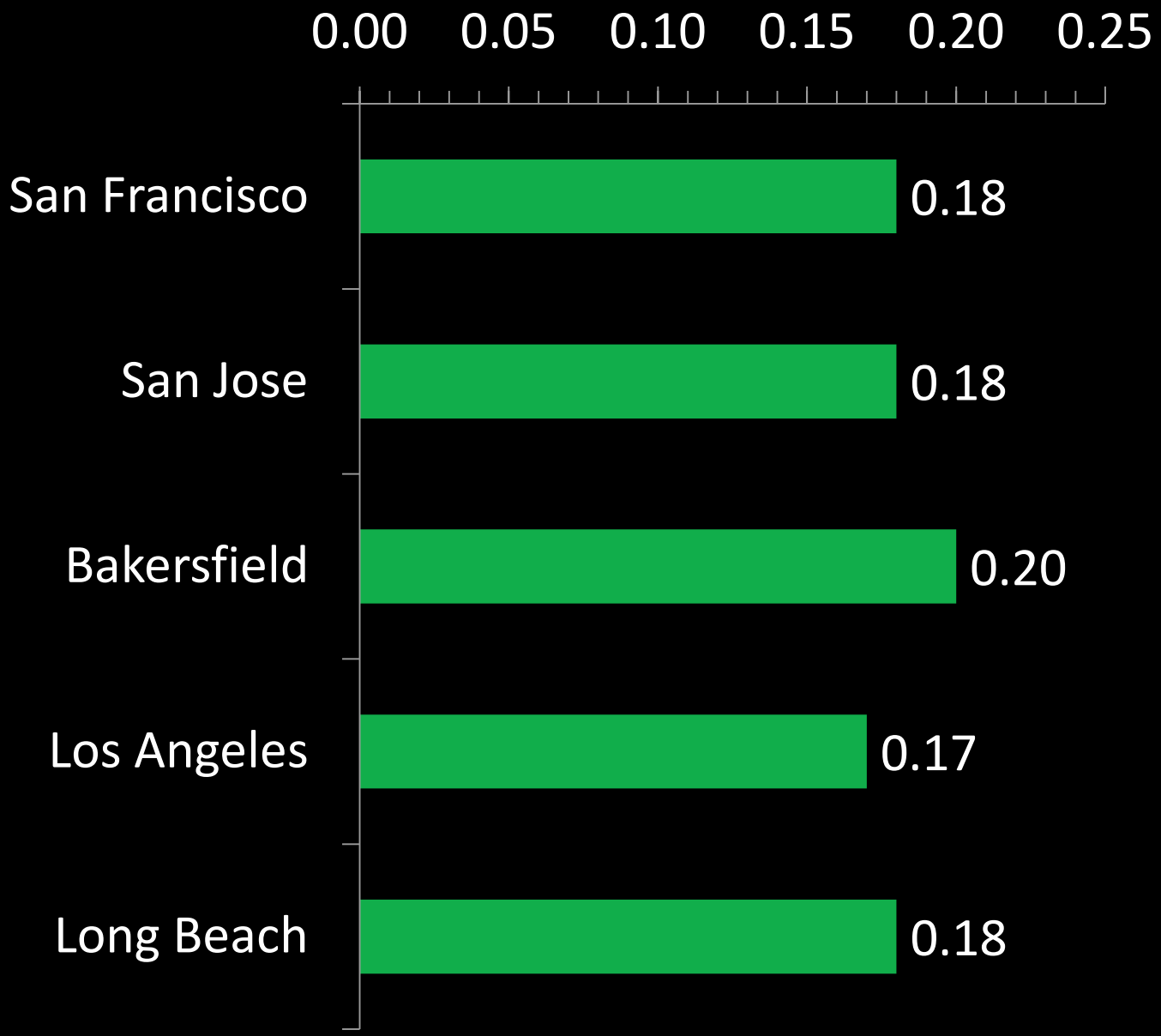


verifying roof albedo with a pyranometer

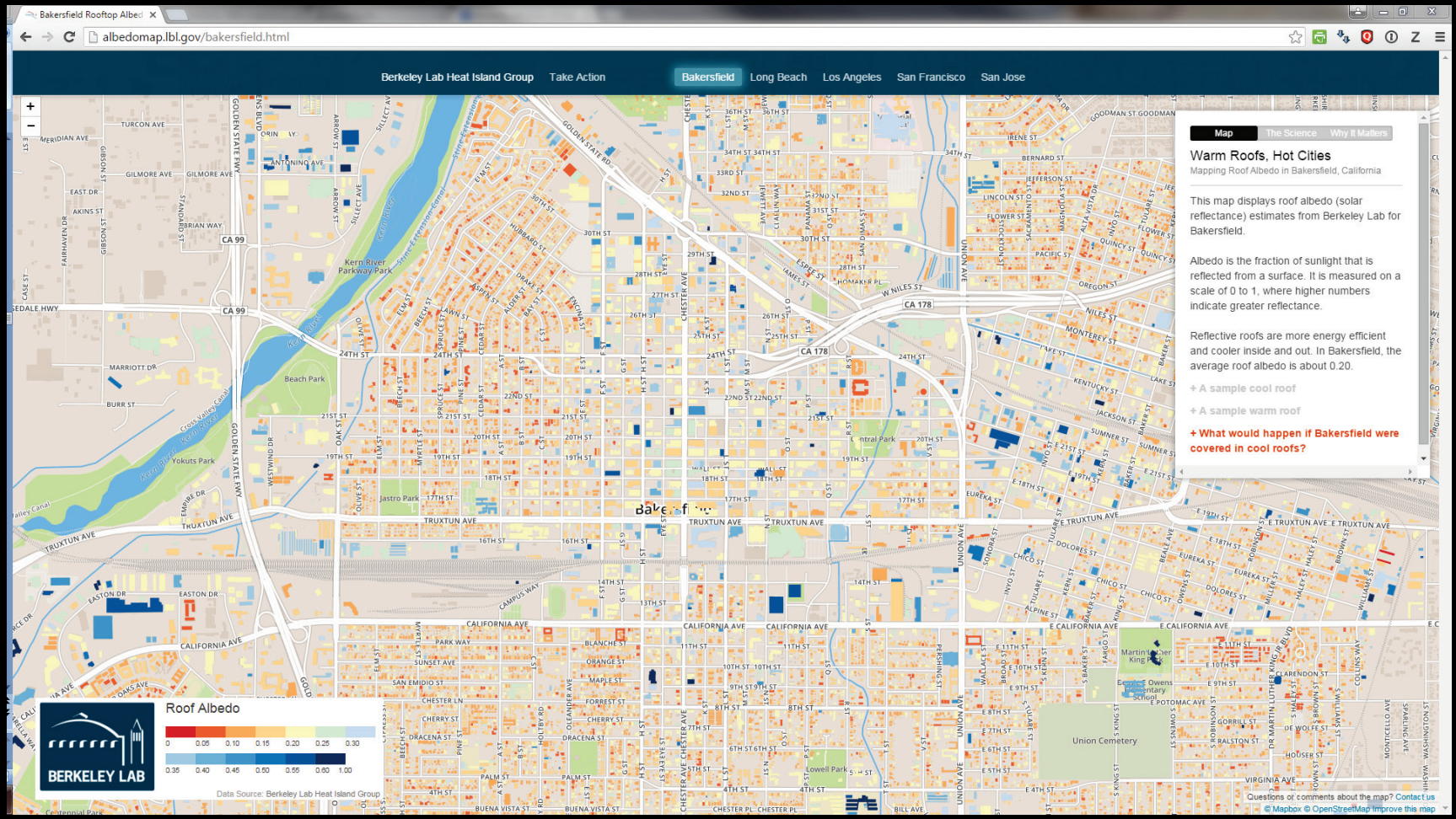
Average roof albedo



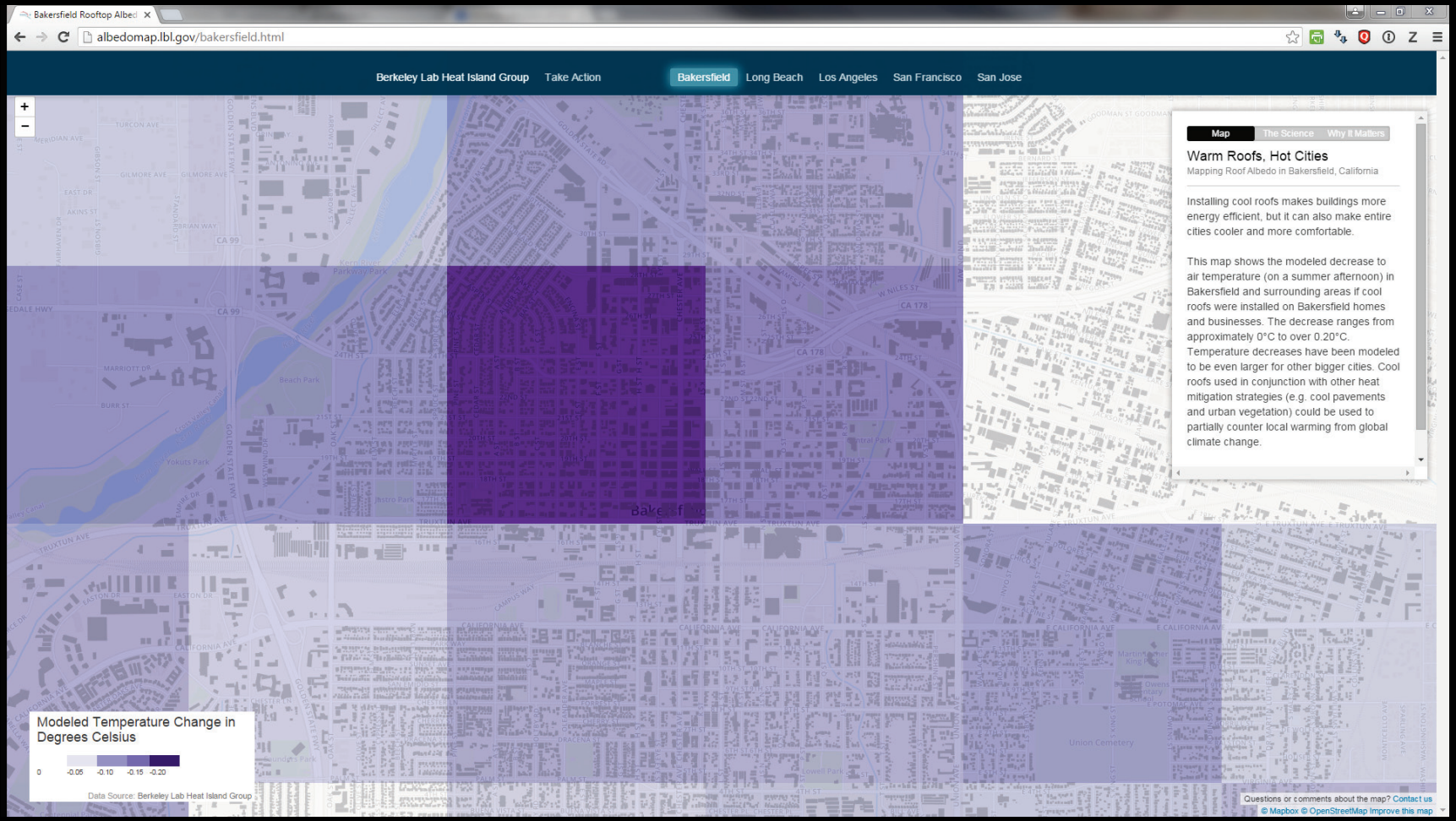




Let's visit Bakersfield with



AlbedoMap.LBL.gov



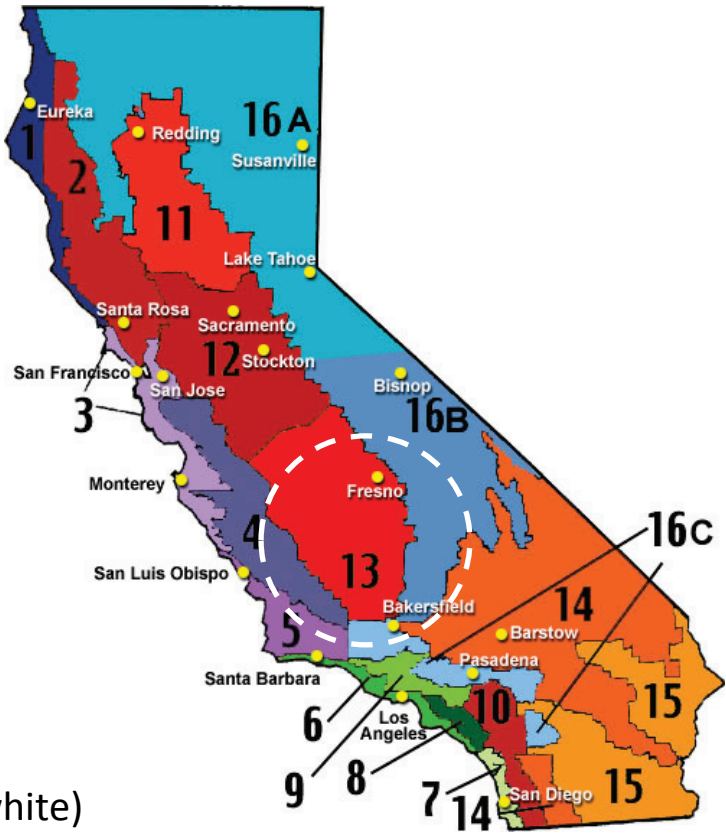
Cool roofs lower Bakersfield air temperature by up to 0.3 °C

3. Cool Roof Requirements and Incentives

2013 Title 24 prescribes cool roofs for all buildings in climate zone 13 (Fresno)

	Min aged SR	Min aged TE	Min aged SRI
Nonres or high-rise res, low slope, all CZ	0.63	0.75	75
Nonres or high-rise res, high slope, all CZ	0.20	0.75	16
Res, low slope, CZs 13 & 15	0.63	0.75	75
Res, high slope, CZ 10 - 15	0.20	0.75	16

climate zone (CZ)



SR = solar reflectance (fraction of incident sunlight reflected, 0 - 1)
TE = thermal emittance (efficiency emitting thermal radiation, 0 - 1)
SRI = solar reflectance index (0 = reference black, 100 = reference white)

PG&E **formerly** offered rebates for exceeding T24 cool roof requirements

Pacific Gas & Electric (PG&E) Multifamily Residential Energy Efficiency Rebate Program

Roof Slope	Rebate level	Min aged SR	Min aged TE	Rebate ($/ft²)
Low (≤2:12), excluding CZ 13	N/A	0.55	0.75	0.20
High (>2:12)	Level 1	0.35	0.75	0.20
	Level 2	0.25	0.75	0.10

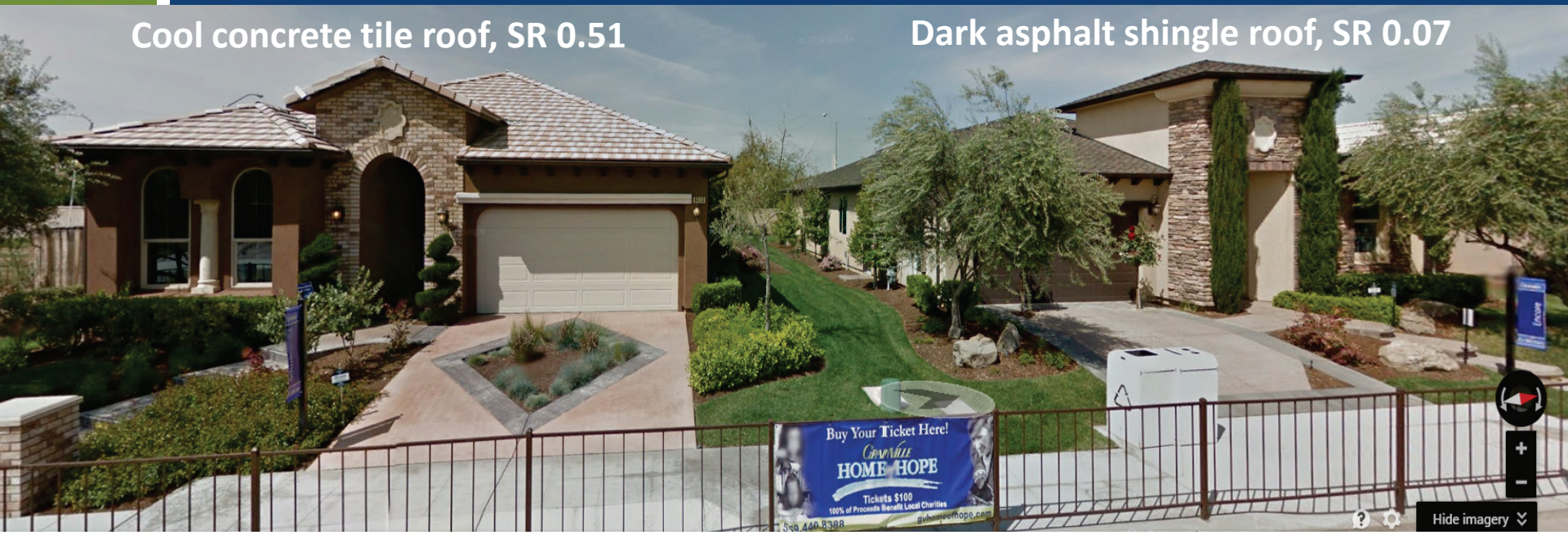
- Installation address must be in qualifying California climate zones (2, 4, 11, 12, or 13). Only steep-slope roofs qualify in climate zone 13. To find your climate zone, visit PG&E's climate zones page.
- Qualifying products: Cool Roof Rating Council rated products.
- Customer must purchase and install qualifying product before December 31, 2014.

Cool roofs can be part of PG&E's current *Advanced Home Upgrade* rebate program

- Rebates calculated using energy modeling software and are based on energy savings.
- Open to single-family detached homes and 2-4 unit buildings.

4. Residential Cool Roof Study in Fresno

LBNL compared the annual energy uses of tile-roofed, shingle-roofed Fresno homes



Why is this study unique?

- Single-family detached
- Same floor area (also ceiling area): 188 m² (2,020 ft²)
- Air conditioning: COP 3.5 (SEER 14)
- Gas furnace efficiency: AFUE 92%
- HVAC ducts located in attic

The tile roof reflects more sunlight and has greater thermal mass than the shingle roof

	Dark asphalt shingle roof	Cool concrete tile roof
Solar reflectance	0.07	0.51
Mass per roof area [kg/m²]	17	47
Thermal capacity per roof area [kJ/m²·K]	22	40

Air flows under elevated tiles, but not below nailed-to-deck shingles

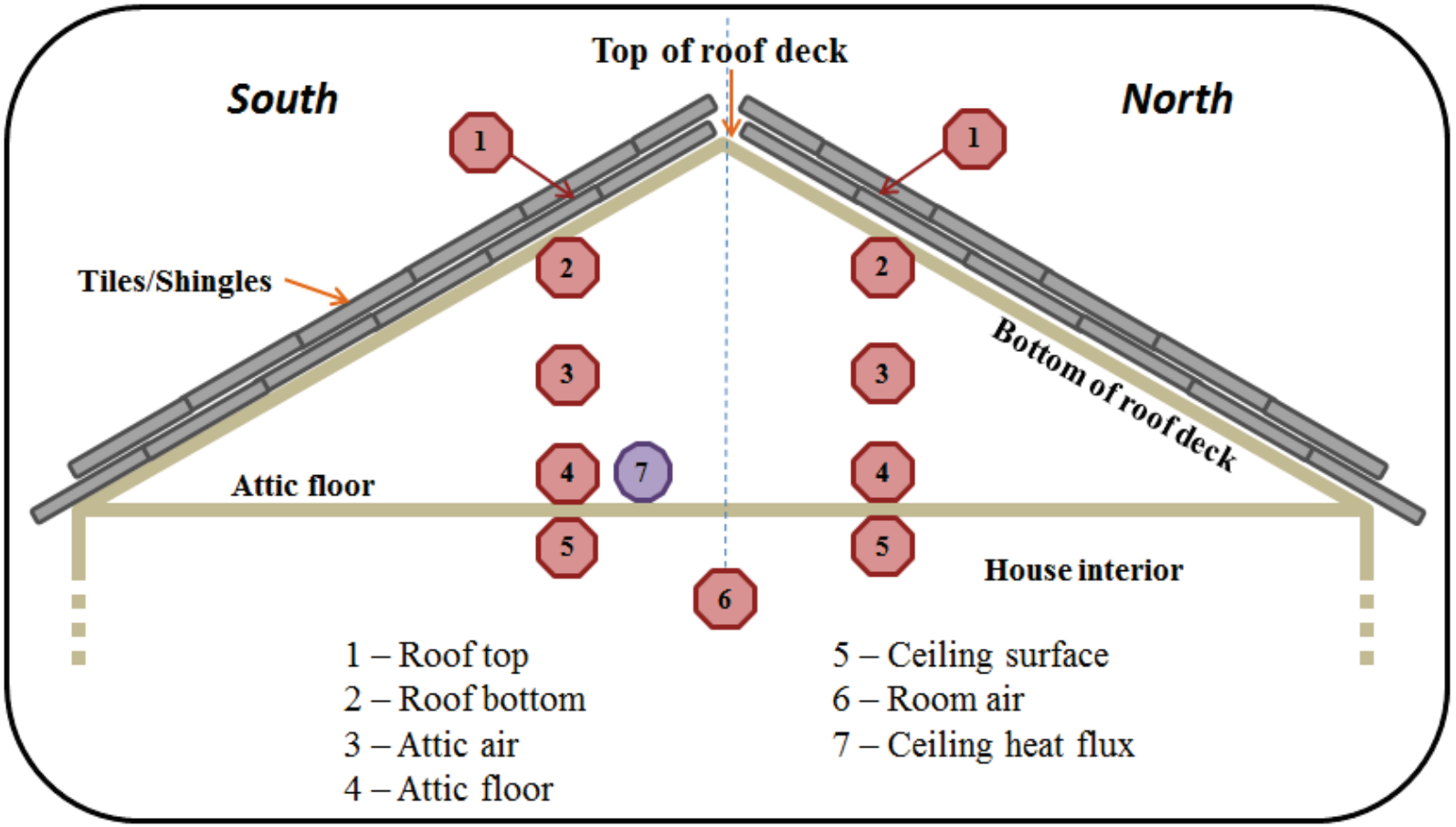
Asphalt shingles are glued and nailed to roof deck

Source: www.hometips.com

Concrete tiles are mounted on battens

Source: www.greenhomeguide.com

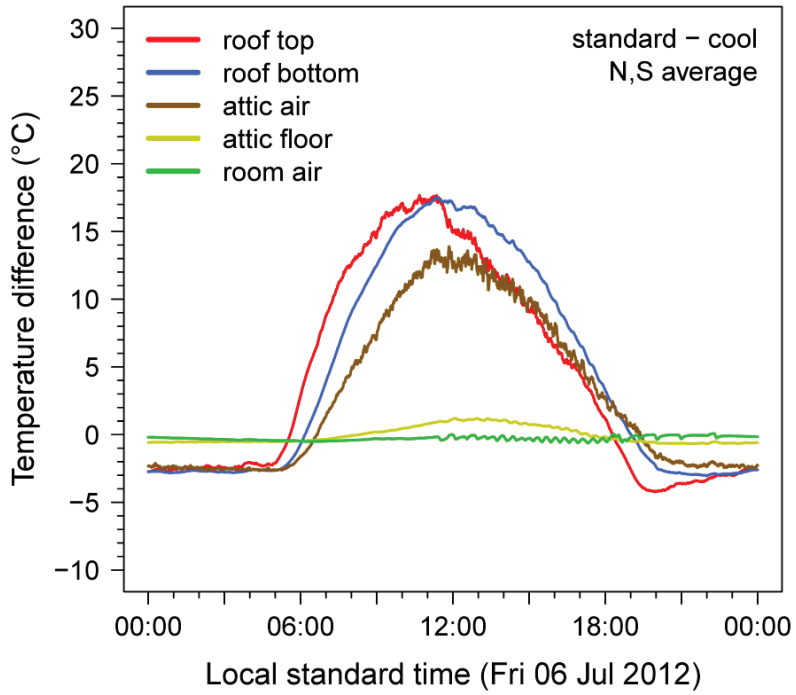
Temperature sensors were arrayed vertically from roof surface to room air



In summer, the standard house was warmer and gained more heat through the ceiling

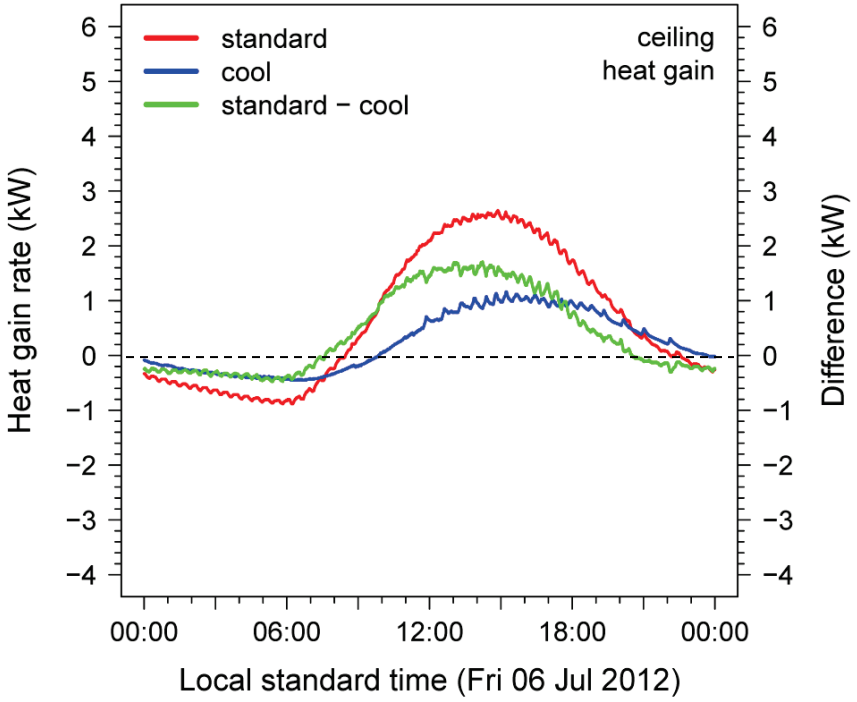
Thermostat schedule:
All day, 25°C (77°F)

Temperature differences by location



The roof and attic were warmer in the standard house than in the cool house.

Ceiling heat gains and differences

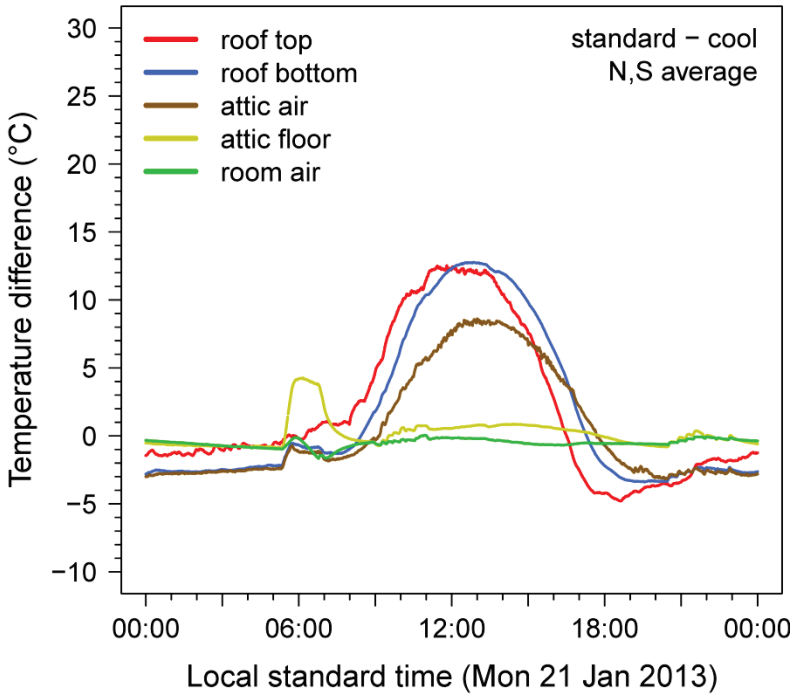


Daytime and daily total heat gains through the ceiling were greater in the standard house.

On winter nights, heat retention by the tile roof house reduced heat outflow through the ceiling

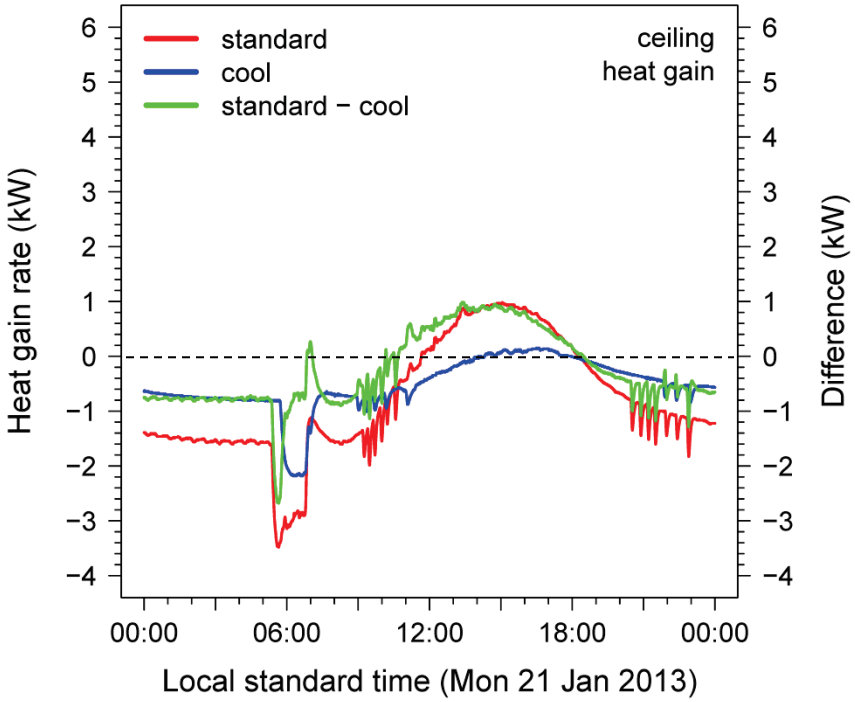
Thermostat schedule:
7am – 11pm, 20°C (68°F) • 11pm – 7am, 13°C (55°F)

Temperature differences by location



Attic air was warmer at night in the cool house.

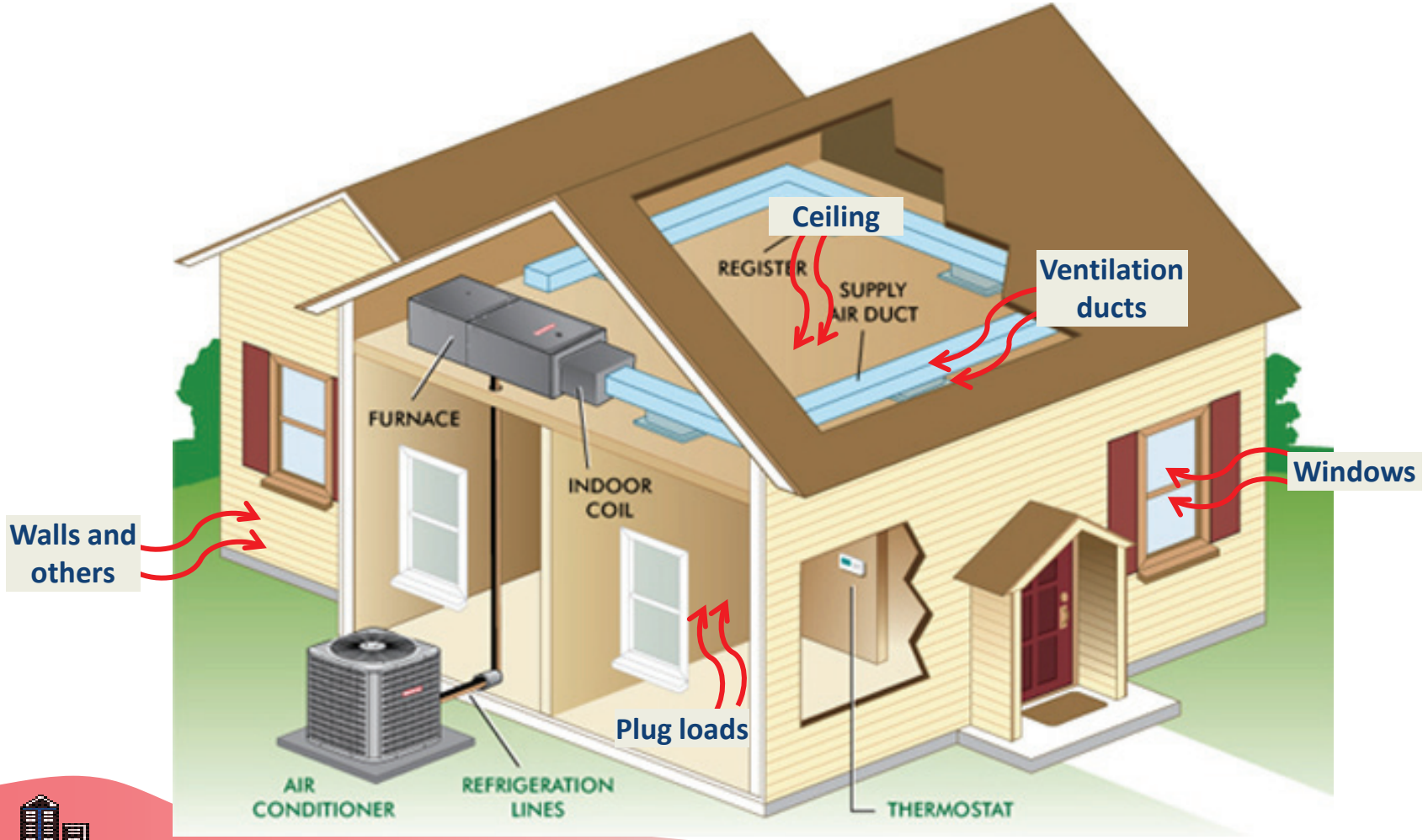
Ceiling heat gains and differences



At night, conditioned space in the cool house lost less heat to the attic.

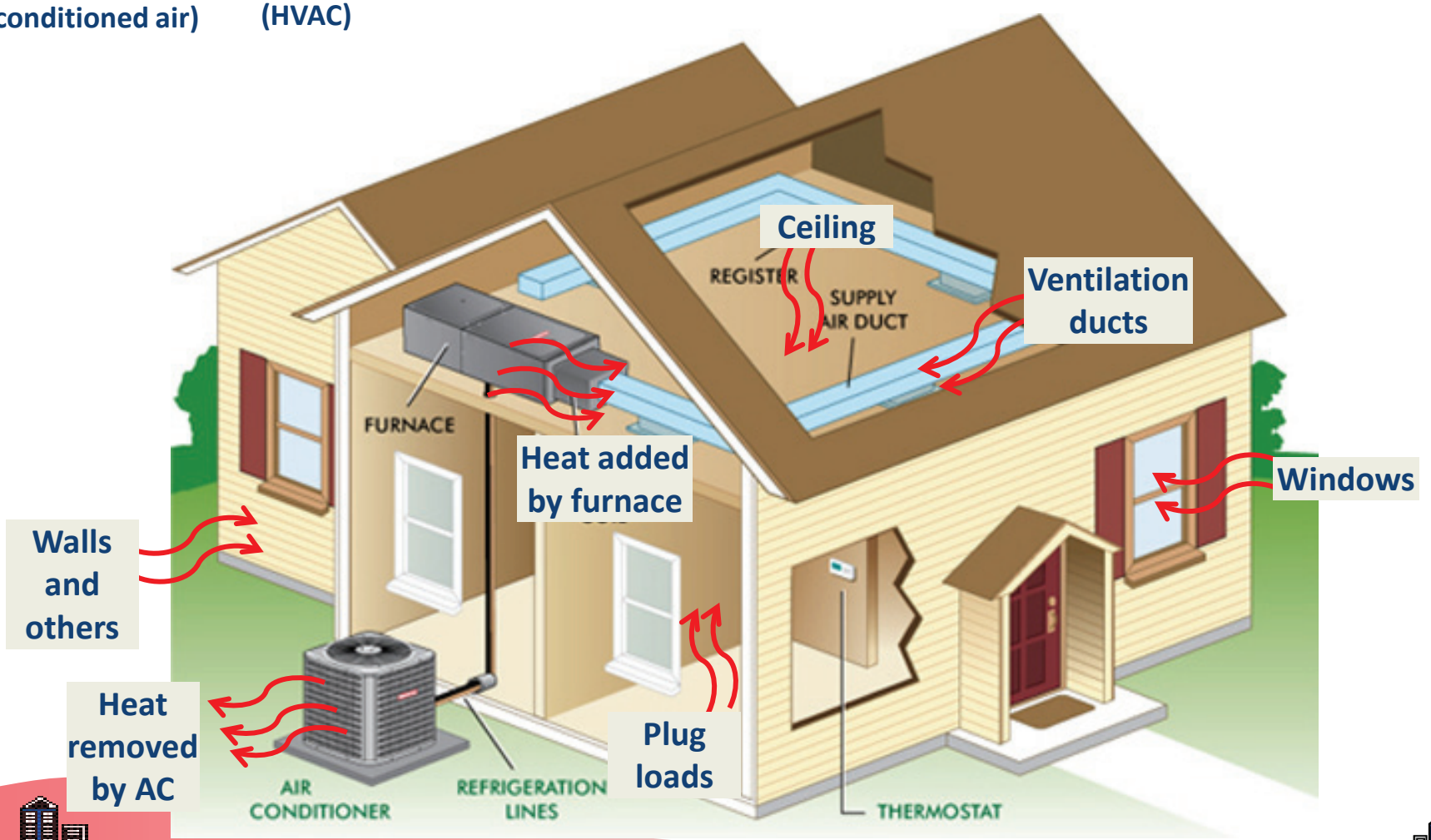
The conditioned air can gain or lose heat through the ducts and envelope, and gain heat from internal sources

$$q_{load\ (conditioned\ air)} = q_{duct\ (ventilation\ duct)} + q_{ceiling\ (ceiling)} + q_{window\ (windows)} + q_{plug\ (plug\ loads)} + q_{other\ (others)}$$



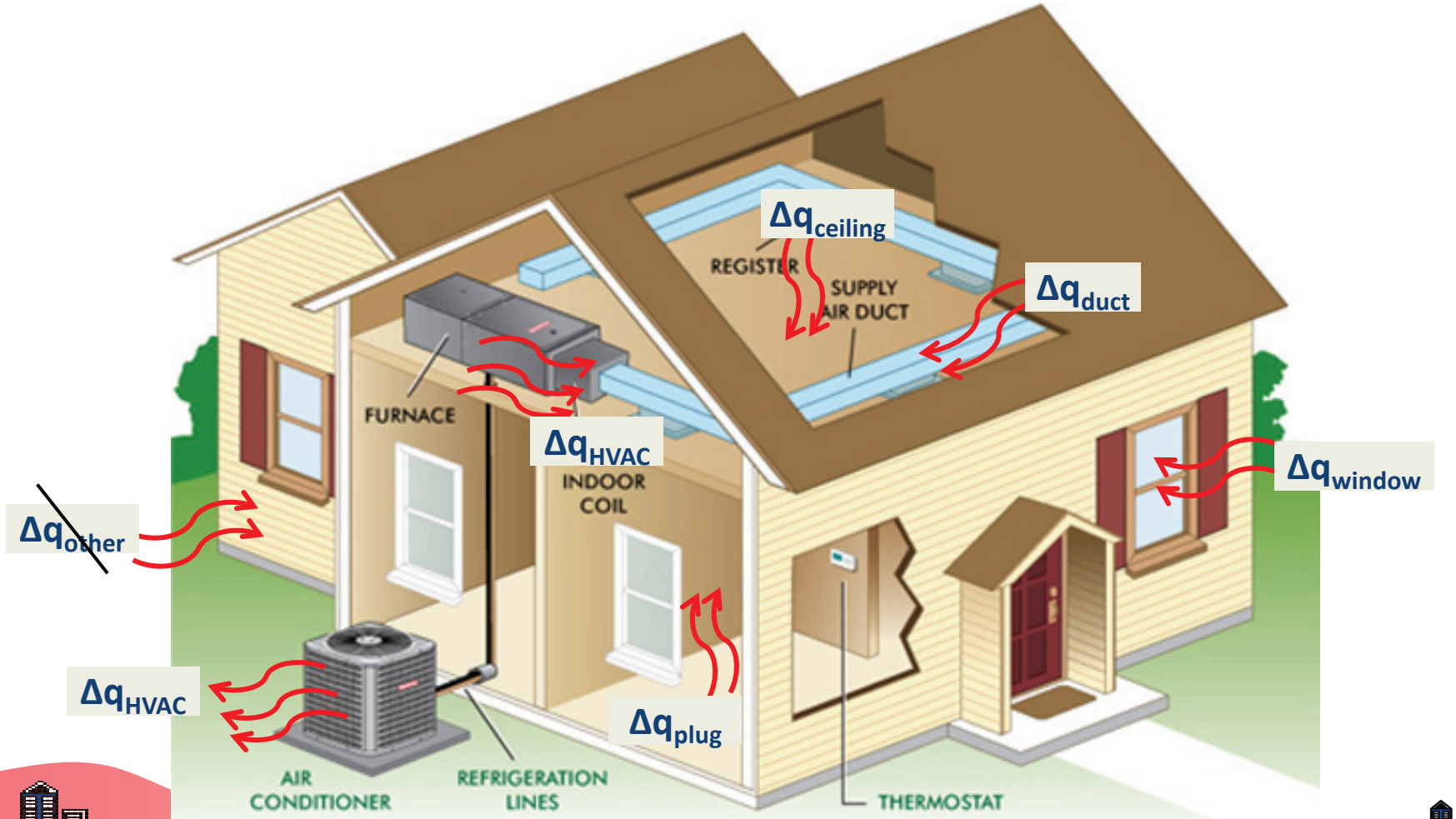
To maintain air temperature, HVAC must meet cooling or heating load

q_{load} (conditioned air) = q_{HVAC} (HVAC)



Difference in heat added or removed by HVAC = difference in building heating or cooling load

$\Delta q_{HVAC} = \Delta q_{load} = \Delta q_{ceiling} + \Delta q_{duct} + \Delta q_{window} + \Delta q_{plug} + \Delta q_{other}$



Difference in cooling power demand is proportional to difference in cooling load

$$\Delta P_{AC} \equiv \frac{\Delta q_{load}}{COP} \equiv \frac{\Delta q_{ceiling} + \Delta q_{plug} + \Delta q_{window} + \Delta q_{duct}}{COP}$$

COP = AC coefficient of performance

Cooling and heating savings must be corrected for differences in window and plug loads

The cooling power savings attributed to the cool roof is

$$\Delta P_{\text{cooling,roof}} = \Delta P_{\text{cooling}} - \frac{\Delta q_{\text{window}} + \Delta q_{\text{plug}}}{COP}$$

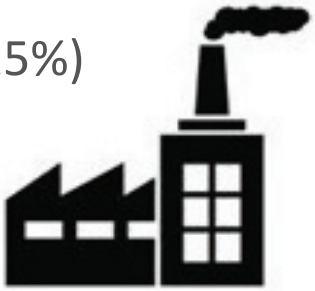
and the heating power savings attributed to the cool roof is

$$\Delta P_{\text{heating,roof}} = \Delta P_{\text{heating}} + \frac{\Delta q_{\text{window}} + \Delta q_{\text{plug}}}{\eta}$$

COP = AC coefficient of performance
η = furnace efficiency (AFUE)

The cool tile roof in Fresno, CA saved both cooling *and* heating energy in the single-family home

Annual conditioning source energy savings: 2,012 kWh (15%)
Annual energy cost savings: US$167 (20%)
Annual power-plant emission savings:
307 kg CO_2, 117 g NO_x, 8.69 g SO_2



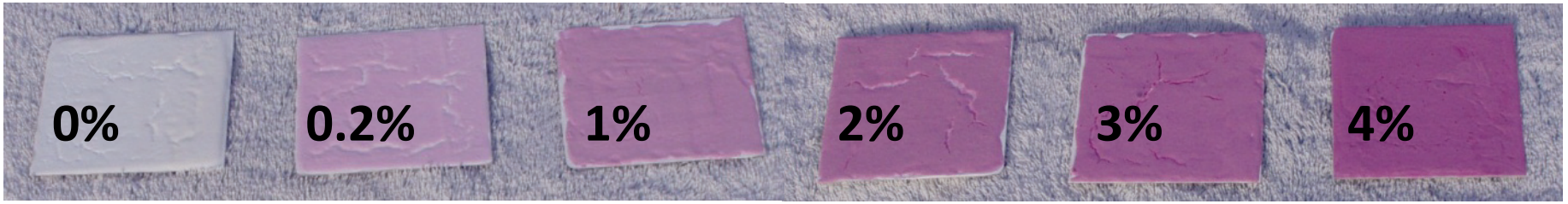
Rosado et al. 2014. *Energy & Buildings* 80, 57–71.

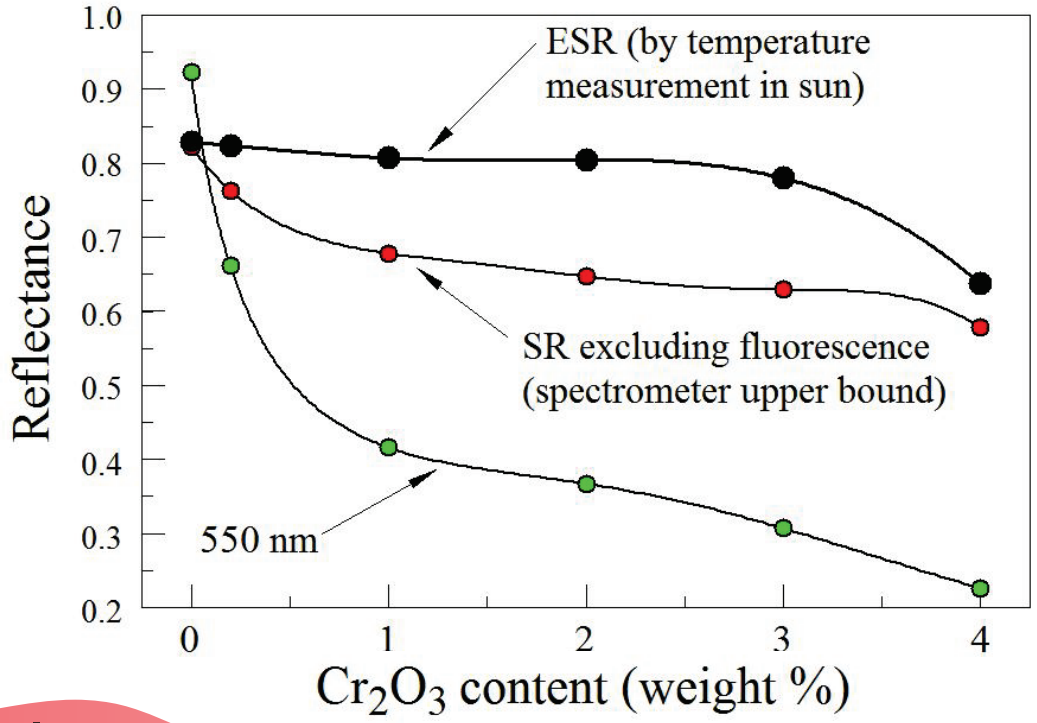
5. Cool Materials Development

Fluorescent cool dark pigments reflect NIR light and re-emit absorbed visible light as NIR

PPG (makes coatings) + LBNL

Ruby-pigmented coatings offer high Effective Solar Reflectance (ESR) in non-white colors

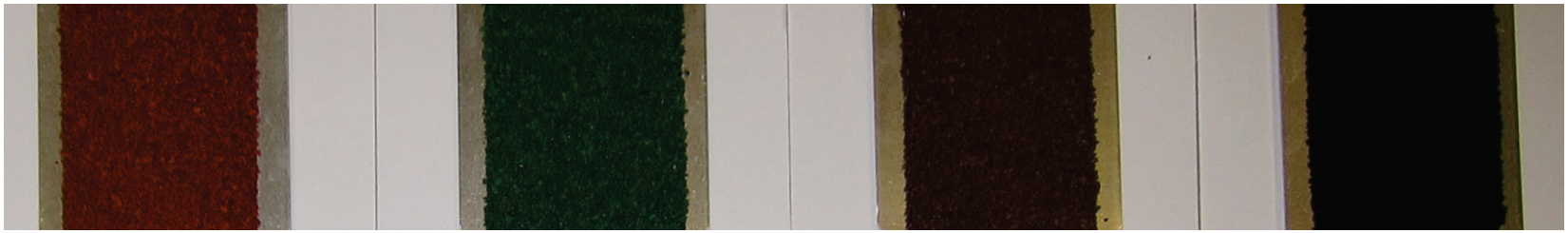




- Fluorescence (at ~700 nm) contributes up to 0.16 to ESR
- Reflectance is high up to 3% doping
- **550 nm curve** shows visual brightness
- Performance of commercial coatings will not be as high

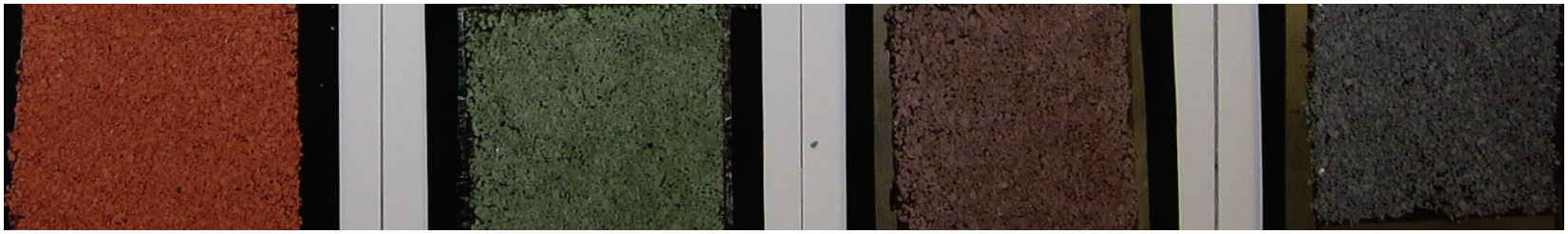
Cool colored synthetic limestone granules can capture CO_2, raise asphalt shingle albedo ρ

conventional (gray granules + non-cool pigmented coating)



ρ = 0.14 ρ = 0.07 ρ = 0.05 ρ = 0.03

cool ($CaCO_3$ granules, integrally colored w/cool pigment)

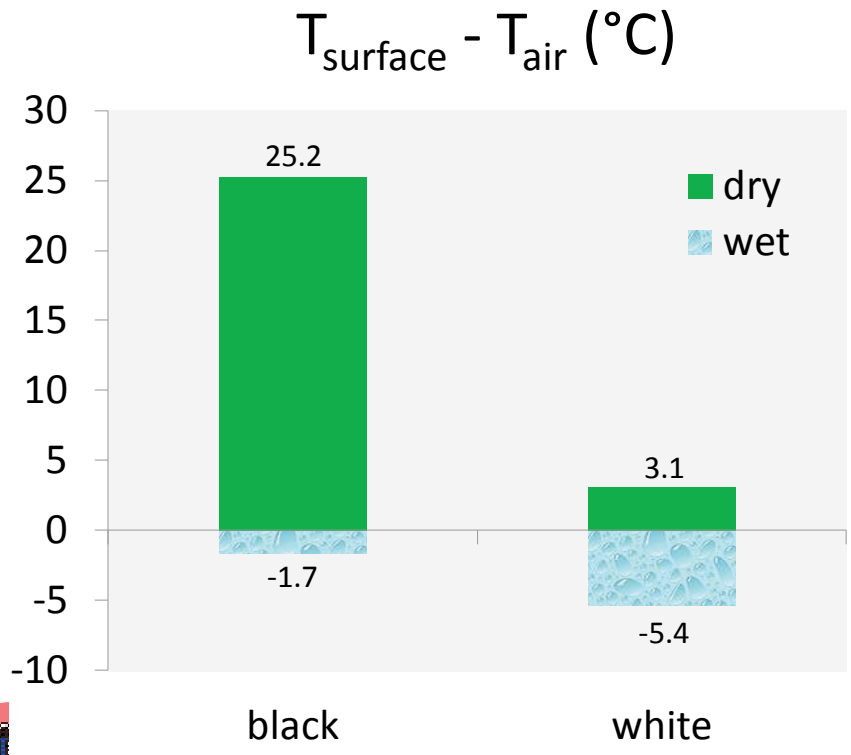


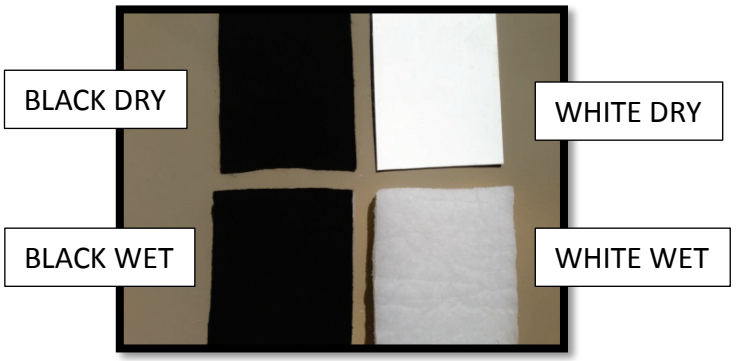
ρ = 0.39 ρ = 0.35 ρ = 0.31 ρ = 0.31

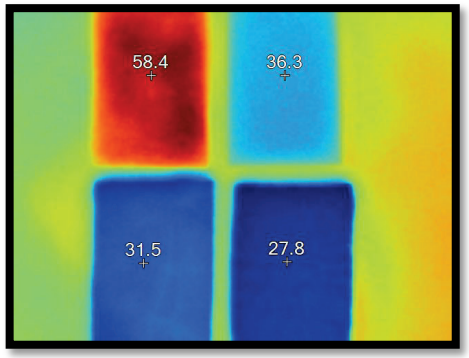
Prototype shingles by Blue Planet + CertainTeed + LBNL
$CaCO_3$ granules by Blue Planet (blueplanet-ltd.com)

White sponge roofing provides high albedo, evaporative cooling, storm water mitigation

- Reflective porous TPO over cross-linked polymer water absorber
- Provides evaporative cooling & high albedo at cost comparable to conventional TPO
- Mitigates storm water issues originating from roof surfaces, absorbing up to 3 cm water





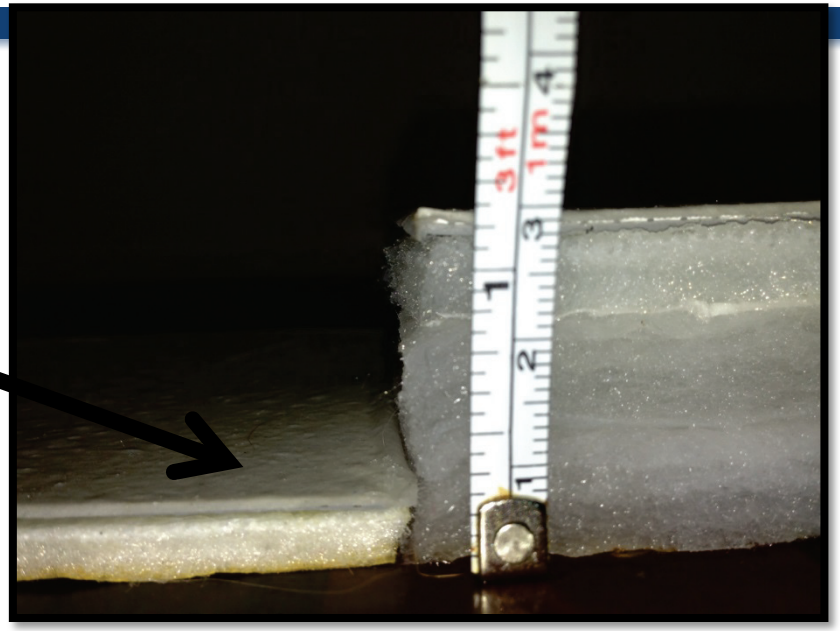


Weather

T_{air} = 33.2 °C
RH = 62%
wind = 9.4 m/s

Subsurface sponge expands by 2.5 cm when wet

CLOSE UP OF POROUS
TPO TOP SURFACE

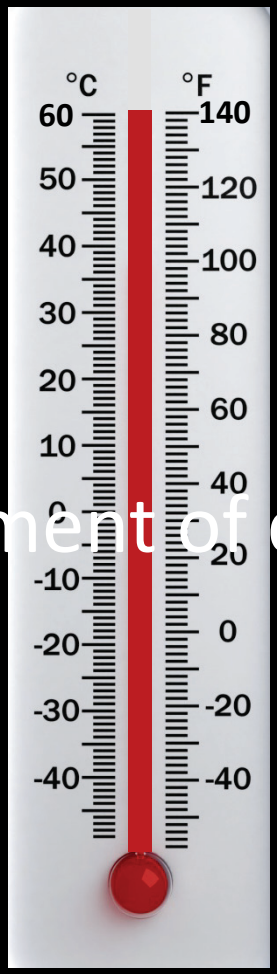


0.5 cm
(dry)

3.0 cm
(wet)

For more information:
Joe D. Byles
Turquoise Roofing Concepts
Corpus Christi, Texas
+1-830-305-2299
bylesj@msn.com

albedo ≈ 0.5



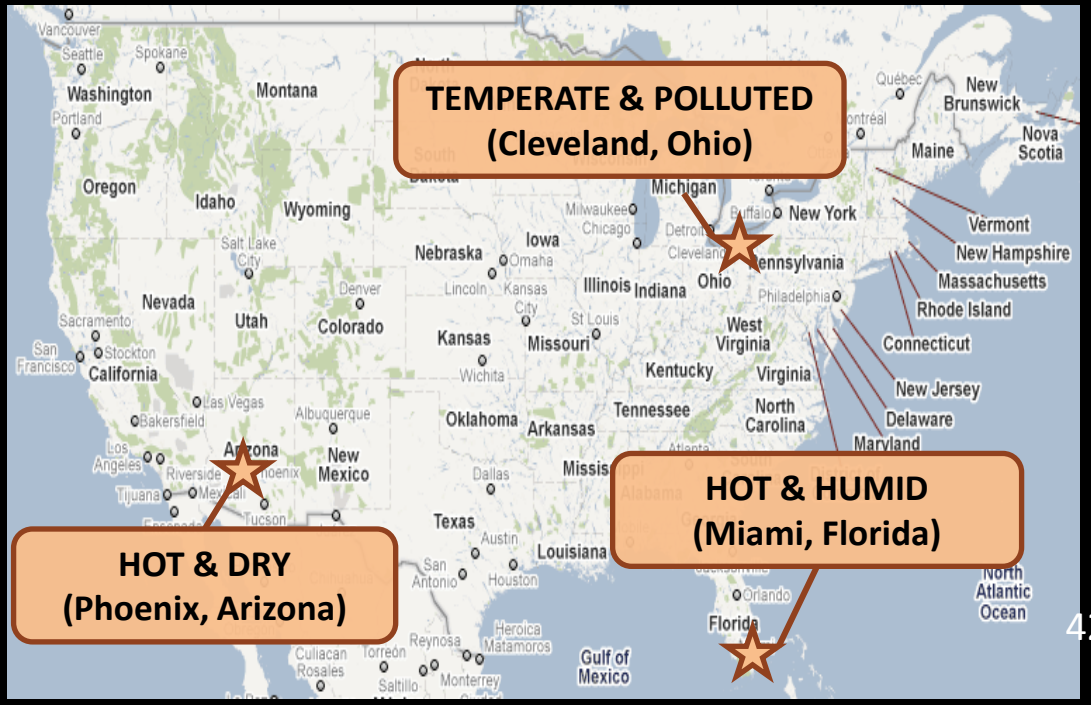
+15 °C
[+27 °F]

How can we speed the development of cool roofs?

AZ
FL
OH

3 sites

3 years!



Arizona Florida Ohio

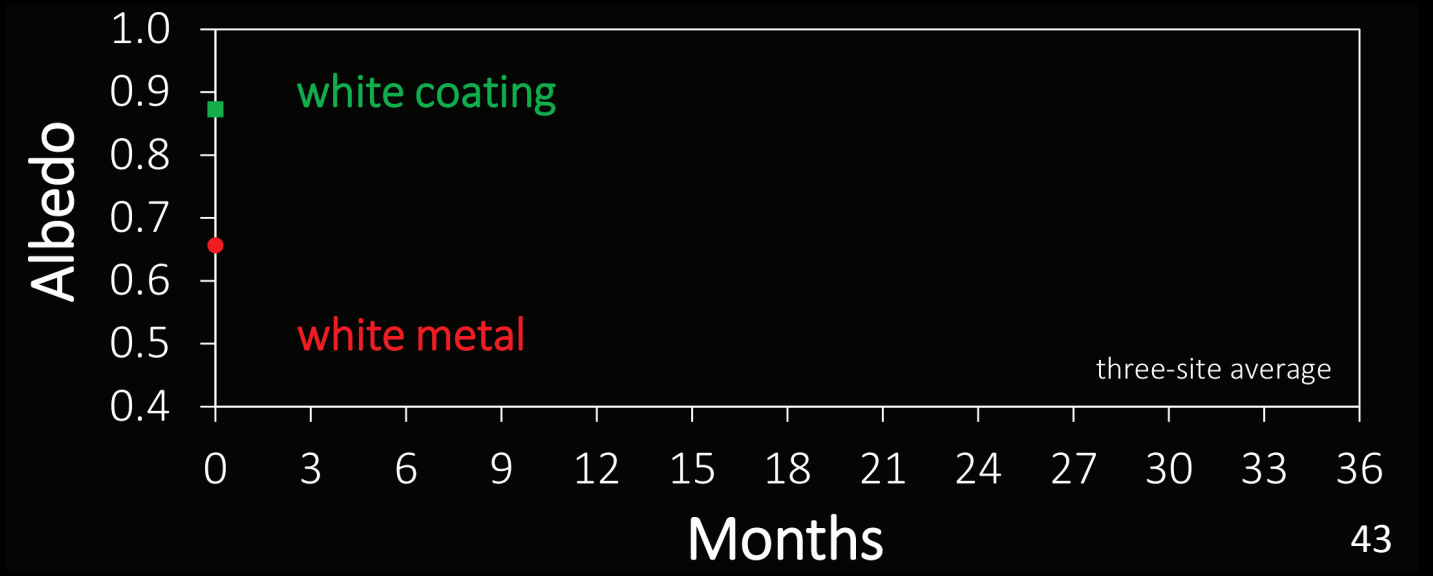
WHITE COATING

(field-applied silicone)

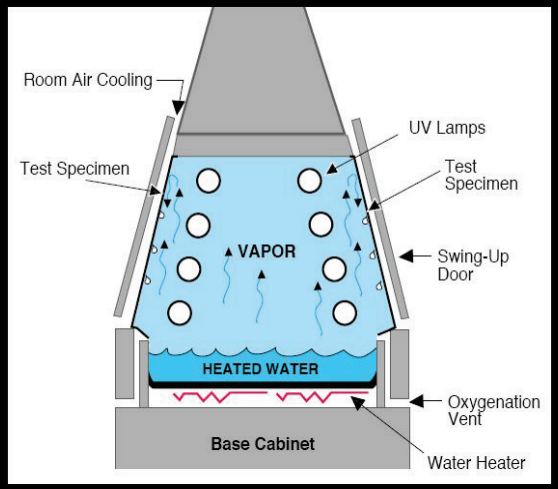
WHITE METAL

(factory-applied PVDF)

00 MONTHS



STEP 1: conditioning (24 hours)



STEP 2: soiling (10 minutes)

Pressure gauge

2-way Valve

Spraying nozzle

Compressed dry air

Aqueous Soiling mixture

Spraying vessel

Coupon of a roofing product

salts

dust

organics

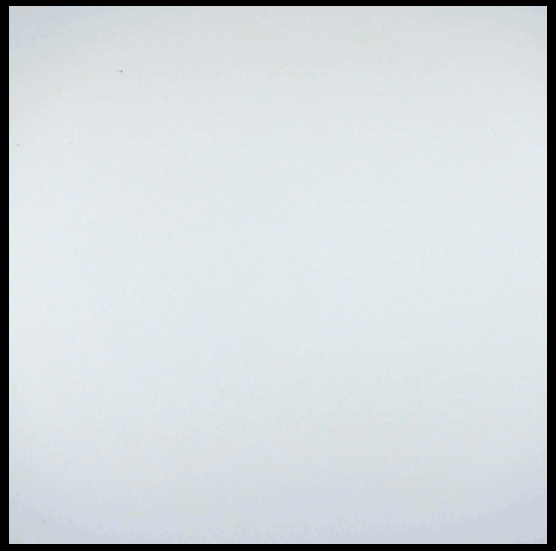
soot

STEP 3: weathering (24 hours)

Done!

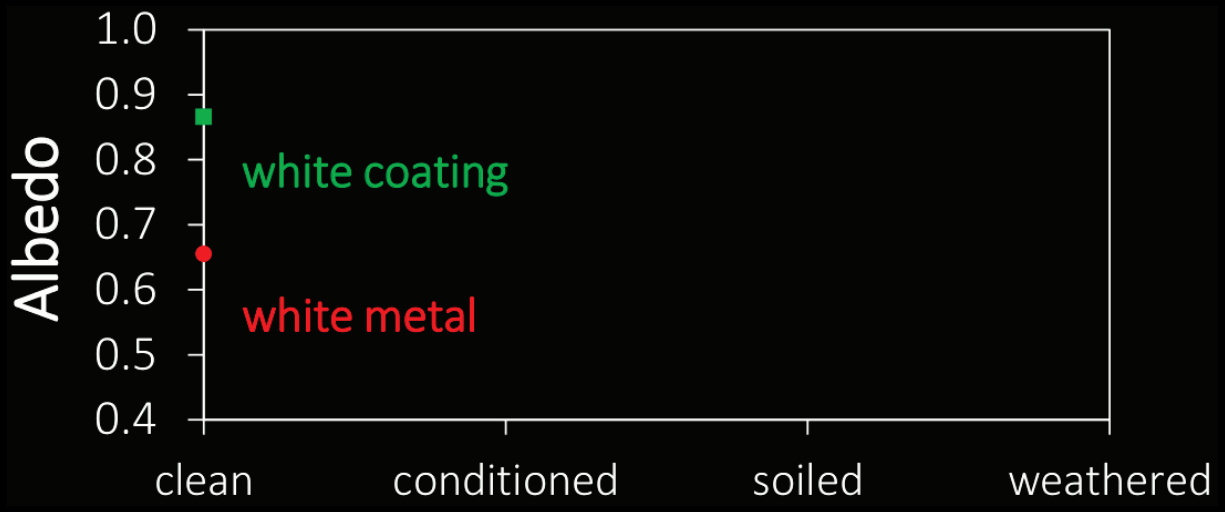
clean

WHITE COATING WHITE METAL

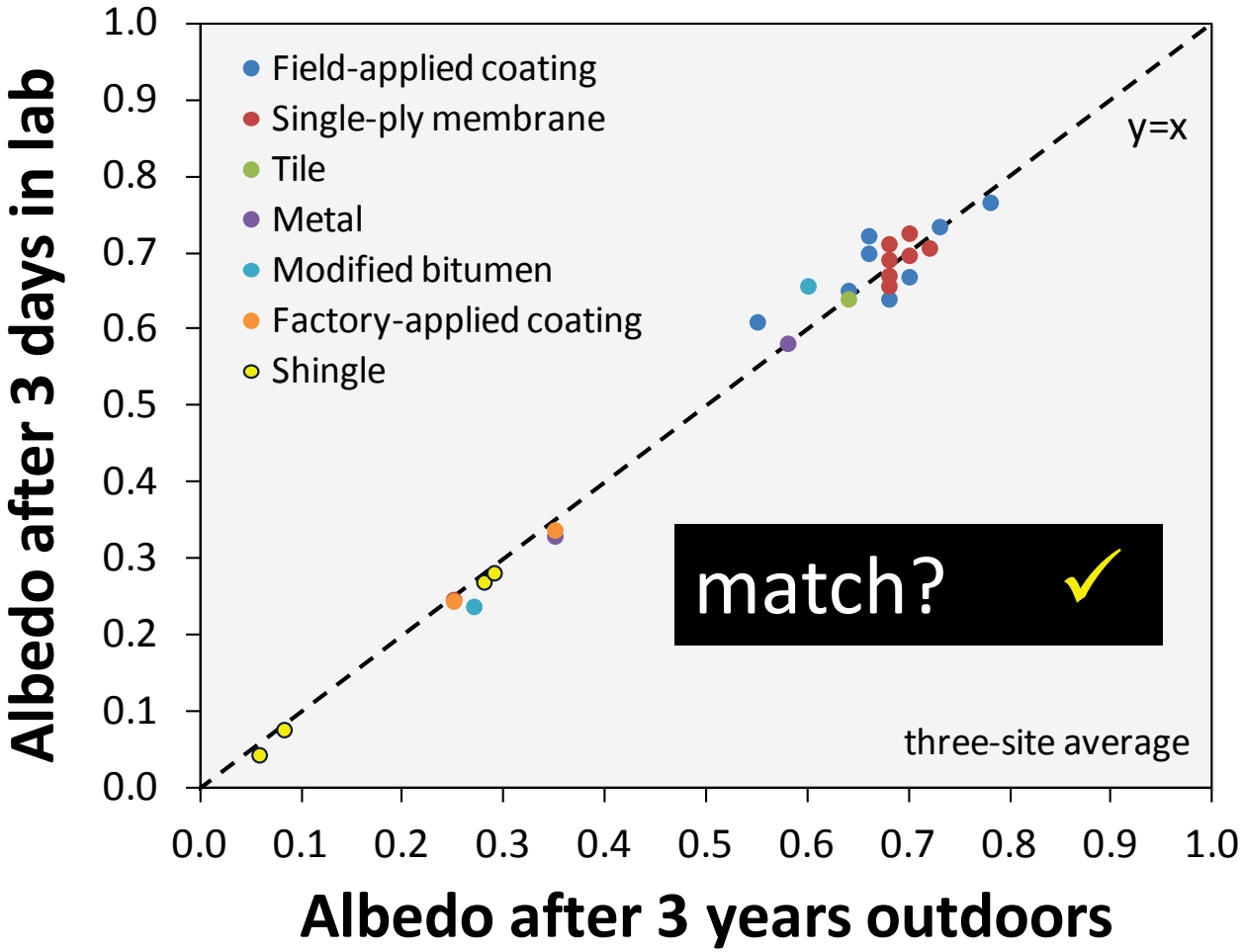


00:00

HR MIN



LBNL laboratory aging method quickly predicts 3-year-aged roof albedo, thermal emittance



- Approved by U.S. Cool Roof Rating Council in Sept. 2014
- ASTM Standard D7897-15

Sleiman et al. 2014. *Solar Energy Materials & Solar Cells* 122, 271–281.

6. A Sea of Online Resources

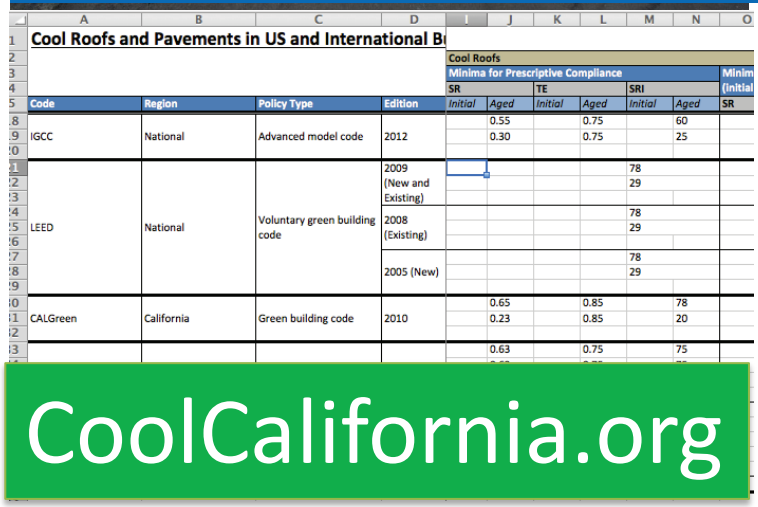
LBNL has created new cool community resources for local governments in California

Presentations & courses

Demonstrations

Online resources

Existing & model code language



Cool Roofs and Pavements in US and International B

Code	Region	Policy Type	Edition	Cool Roofs: Minima for Prescriptive Compliance — SR Initial	SR Aged	TE Initial	TE Aged	SRI Initial	SRI Aged	Minim (Initial SR
IGCC	National	Advanced model code	2012		0.55		0.75		60	
					0.30		0.75		25	
LEED	National	Voluntary green building code	2009 (New and Existing)					78	29	
			2008 (Existing)					78	29	
			2005 (New)					78	29	
CALGreen	California	Green building code	2010		0.65		0.85		78	
					0.23		0.85		20	
					0.63		0.75		75	

CoolCalifornia.org

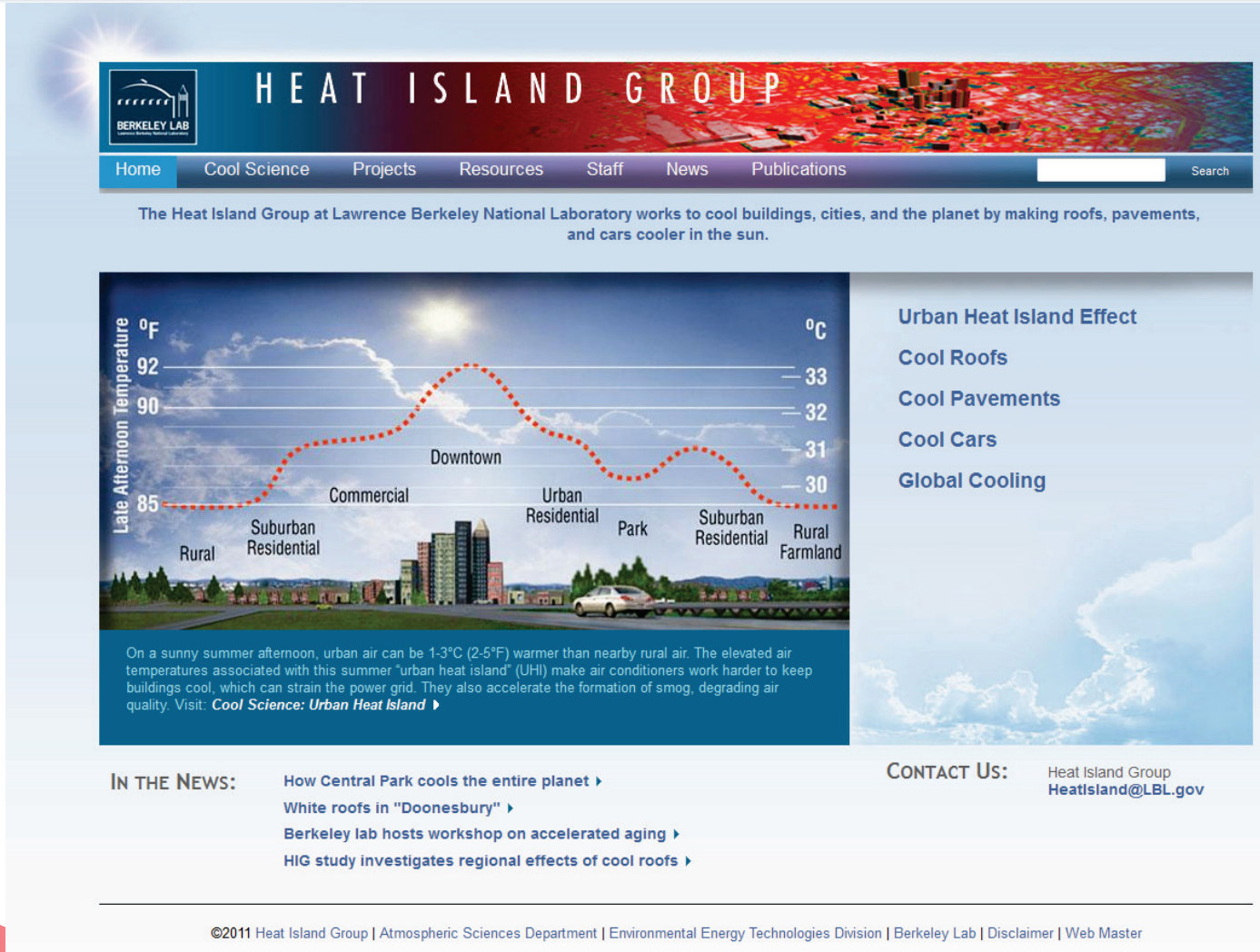
Global Cool Cities Alliance offers UHI mitigation resources for officials, experts, and the public

- Science, costs, and benefits of cool surfaces
- Global best practices for program and policy implementation
- Sample materials and relevant organizations.
- A comprehensive "knowledge base"
- Networking Forum

CoolRoofToolkit.org

Heat Island Group website

HeatIsland.LBL.gov



Thank you!