Use of TiO2 in Construction Materials to Cool Buildings, Cool Cities, Cool the World, and More

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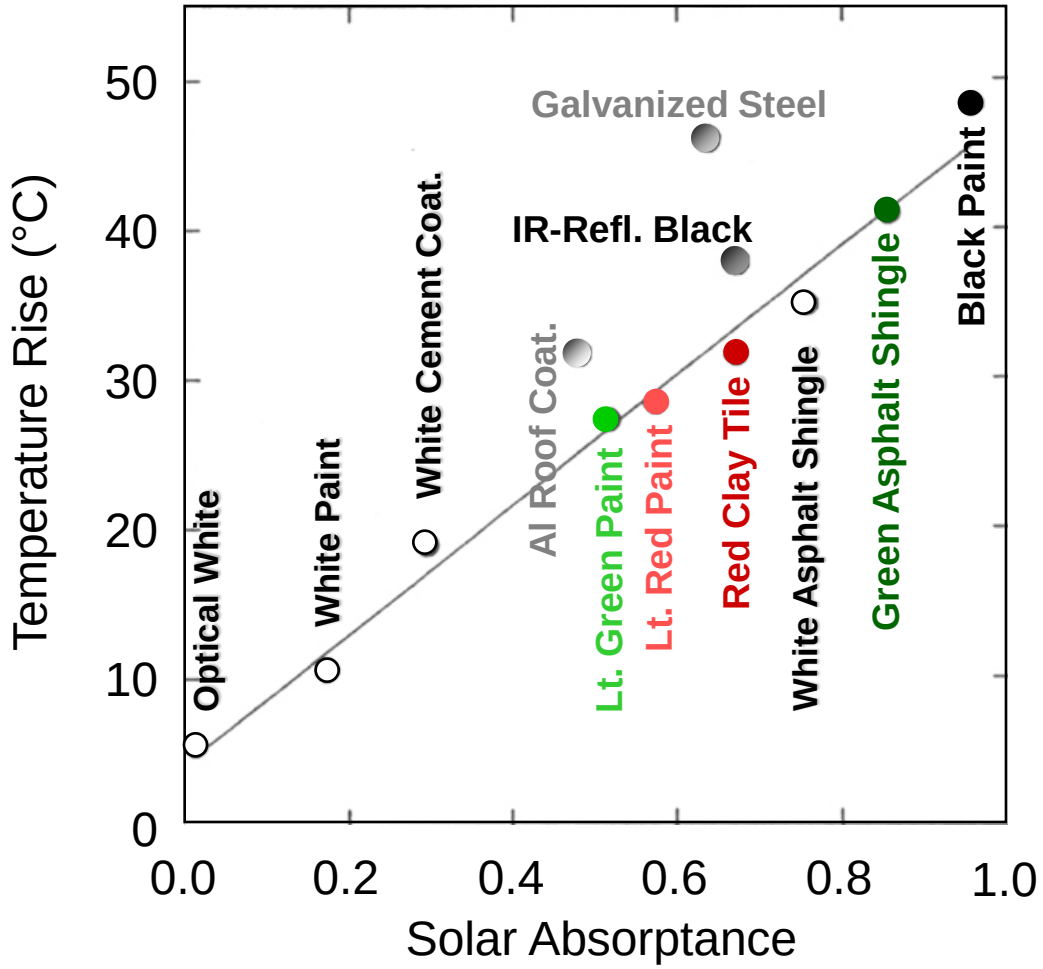
TiO2 in construction materials

- Building materials (pigments)
  - Roofs, Walls
- Pavements
- Coatings
  - Cars, Bridges, Blinds

- Air purifier
- Self cleanings
- Catalyst
- Anti-bacterial
- Superhydrophilic
  - Anti-fog mirror

Aerial images of cities: Mostly roofs and pavements

Temperature rise of various materials in sunlight



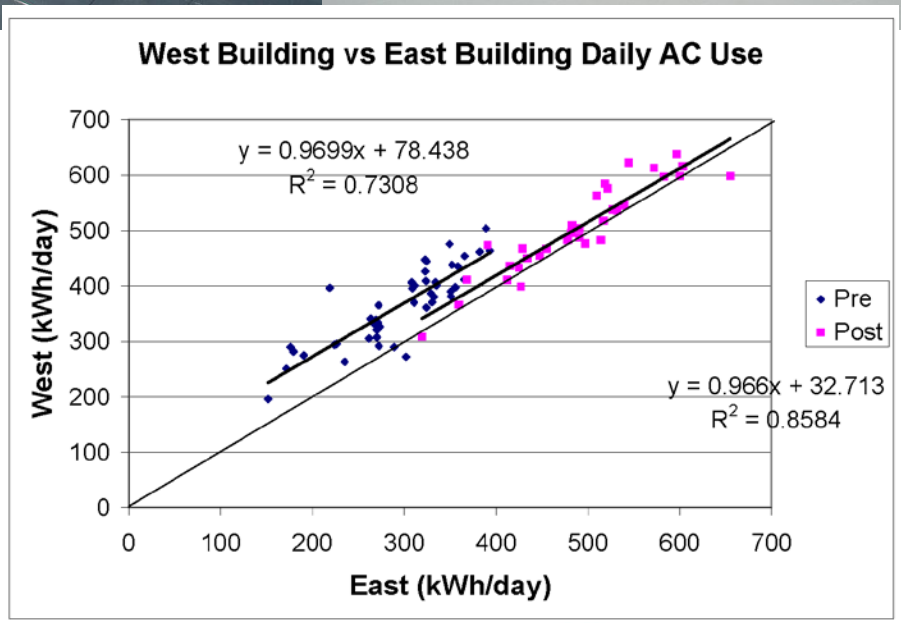
White is ‘cool’ in Bermuda

and in Santorini, Greece

and in Hyderabad, India

Cool roofs save 10%-20% air-conditioning for area under the roof

- U.S.
- Japan
- Europe
- Asia
- Middle East
- China
- India (Hyderabad demos; see graph at right)



Cool roof technologies

Old

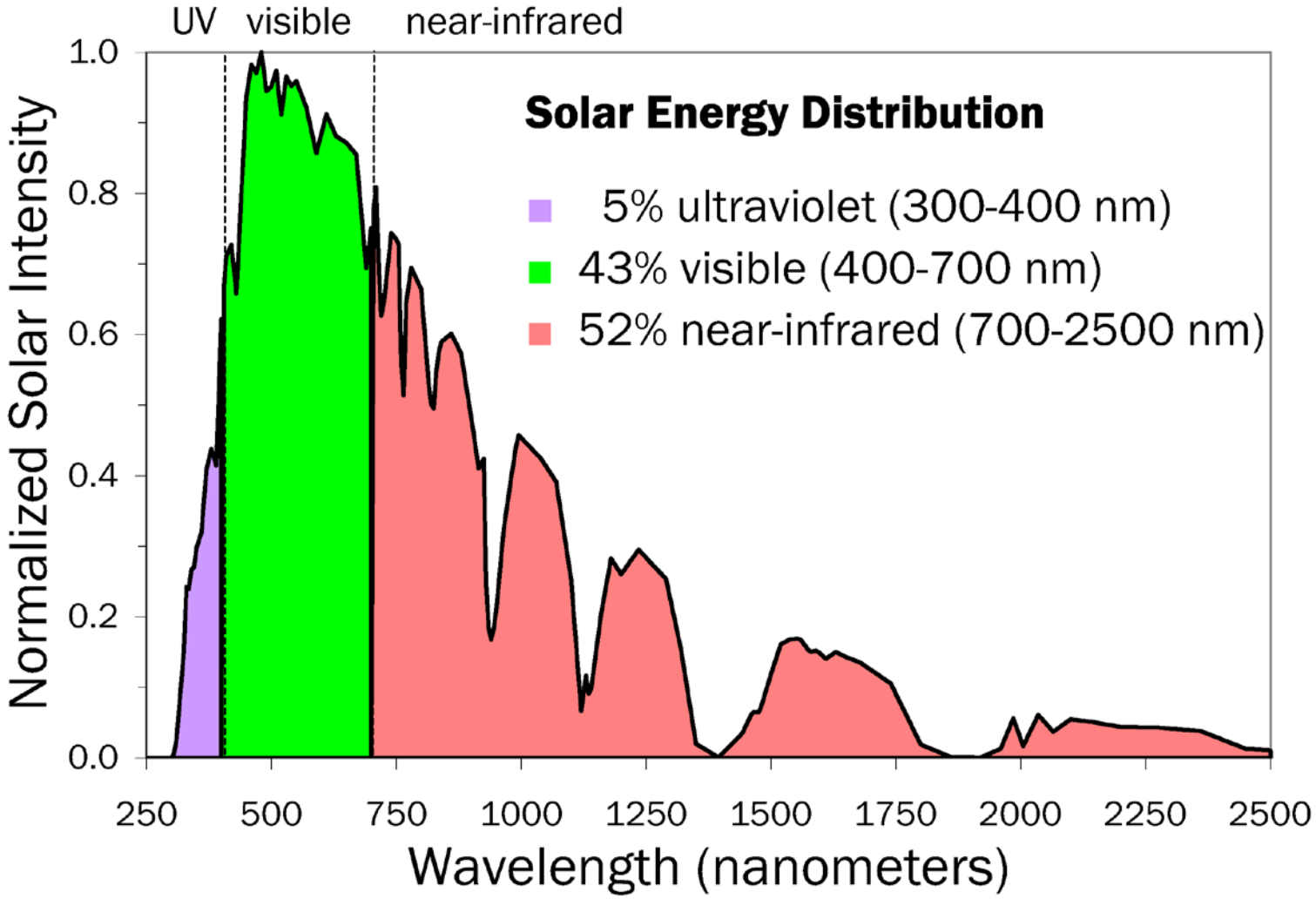
flat, white

pitched, white

New

pitched, cool & colored

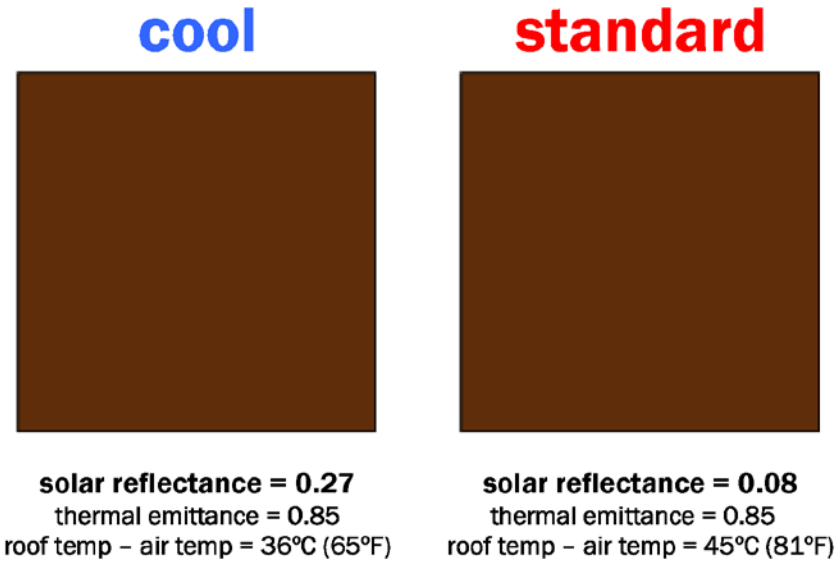
Cool colors reflect invisible near-infrared sunlight

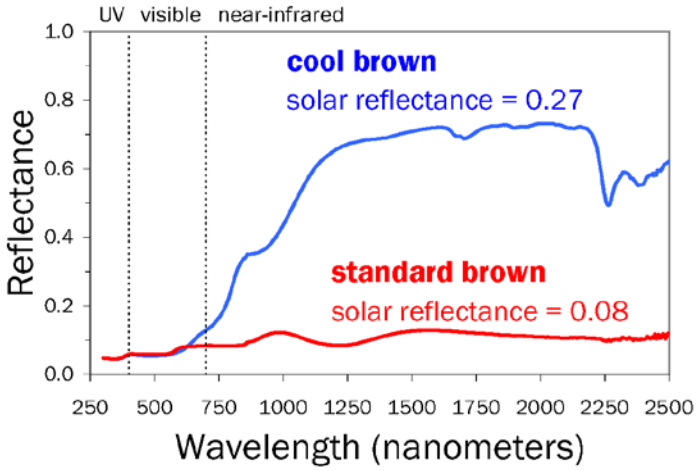


Cool and standard brown metal roofing panels

- Solar reflectance ~ 0.2 higher
- Afternoon surface temperature ~ 10ºC lower

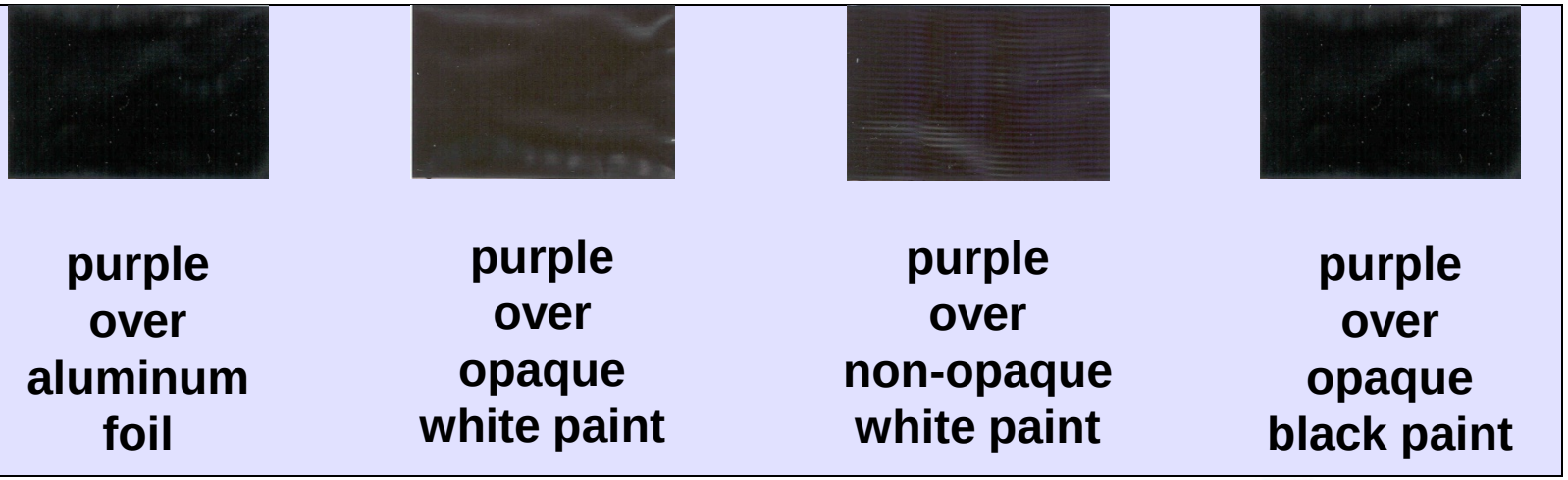
Courtesy BASF Coatings



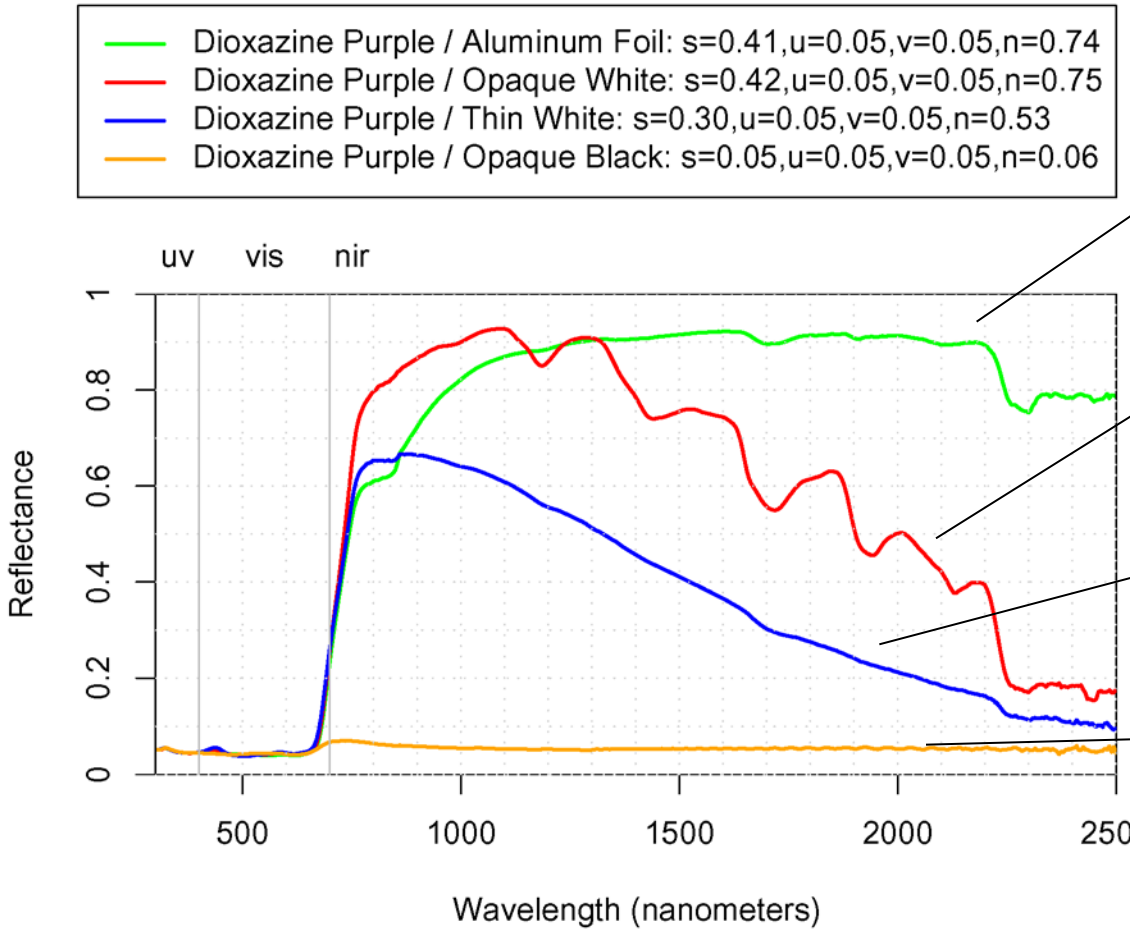


Cool black: Dioxazine purple over various undercoats

- Two-layer system
  - top coat: thin layer of dioxazine purple (14-27 μm)
  - undercoat or substrate:
    - aluminum foil (~ 25 μm)
    - opaque white paint (~1000 μm)
    - non-opaque white paint (~ 25 μm)
    - opaque black paint (~ 25 μm)



Dioxazine purple reflectances



over aluminum
R_{solar} = 0.41

over opaque white
R_{solar} = 0.42

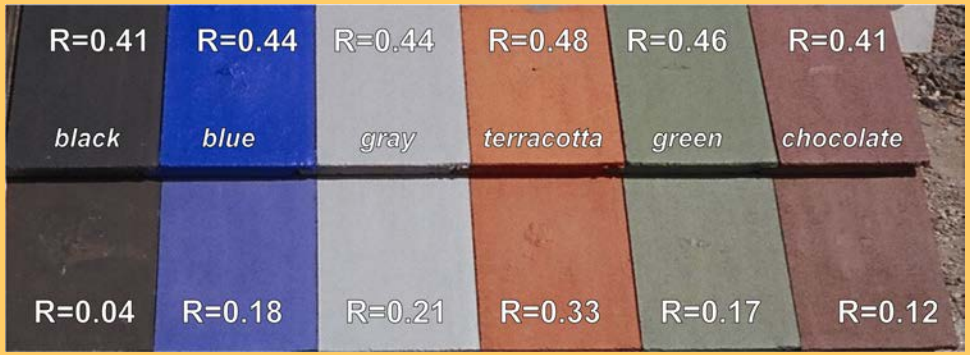
over non-opaque white
R_{solar} = 0.30

over opaque black
R_{solar} = 0.05

Cool colored roofs are in market

cool concrete tile
R ≥0.40

standard concrete tile
(same color)

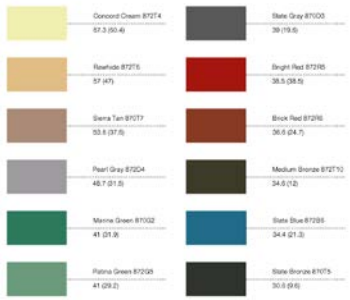


Courtesy
American
Rooftile
Coatings

solar reflectance gain =	+0.37	+0.26	+0.23	+0.15	+0.29	+0.29

cool clay tile
R ≥0.40

Courtesy
MCA Clay Tile



cool metal
R ≥0.30

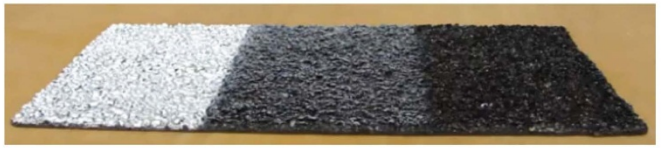
Courtesy
BASF Industrial
Coatings

cool fiberglass asphalt shingle
R ≥0.25
Courtesy
Elk Corporation

Cool angle shingles

- Cool Angle ™ Shingles

White Coating on Dark Granules



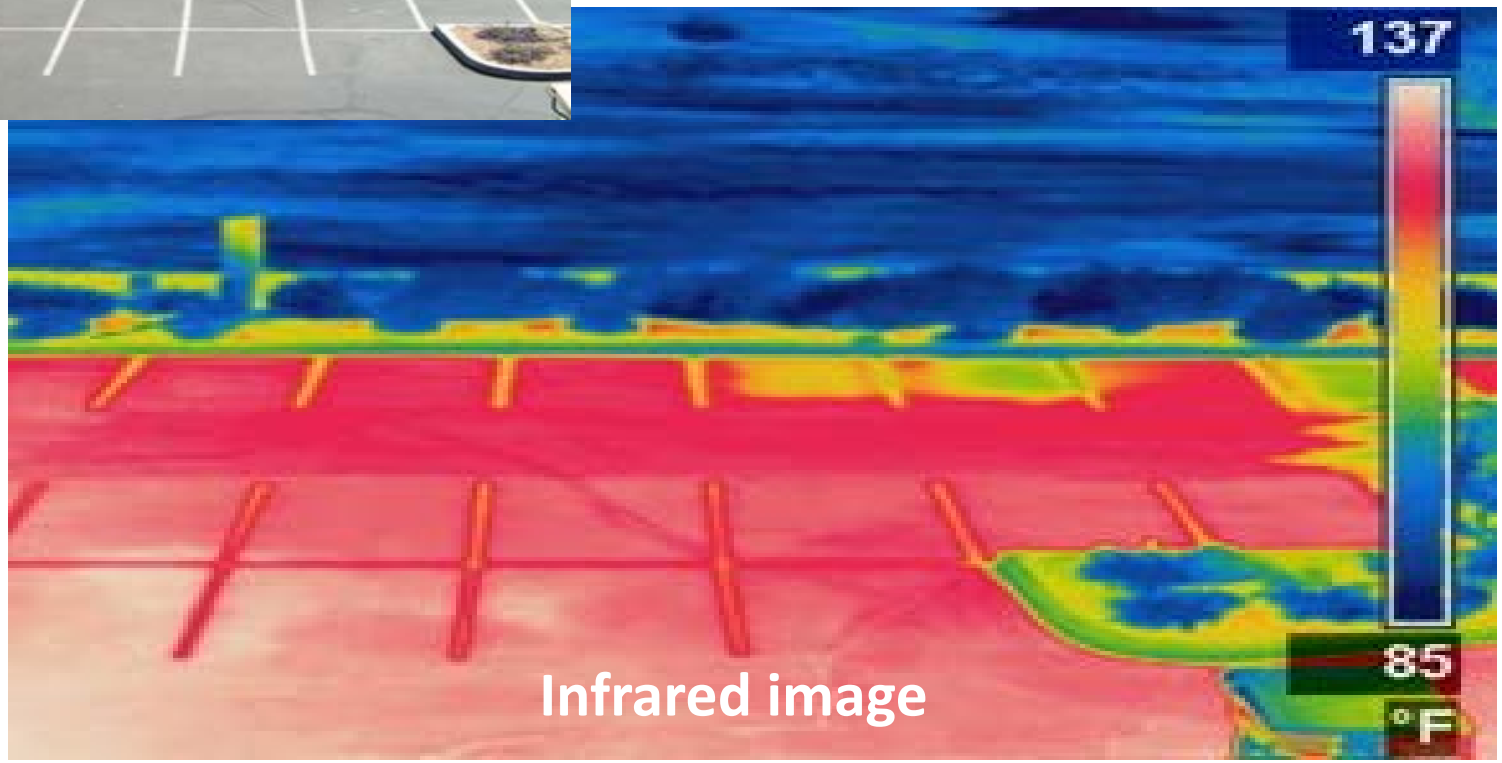
Dark Coating on White Coating

Incognito tiles

Pavements can be hot

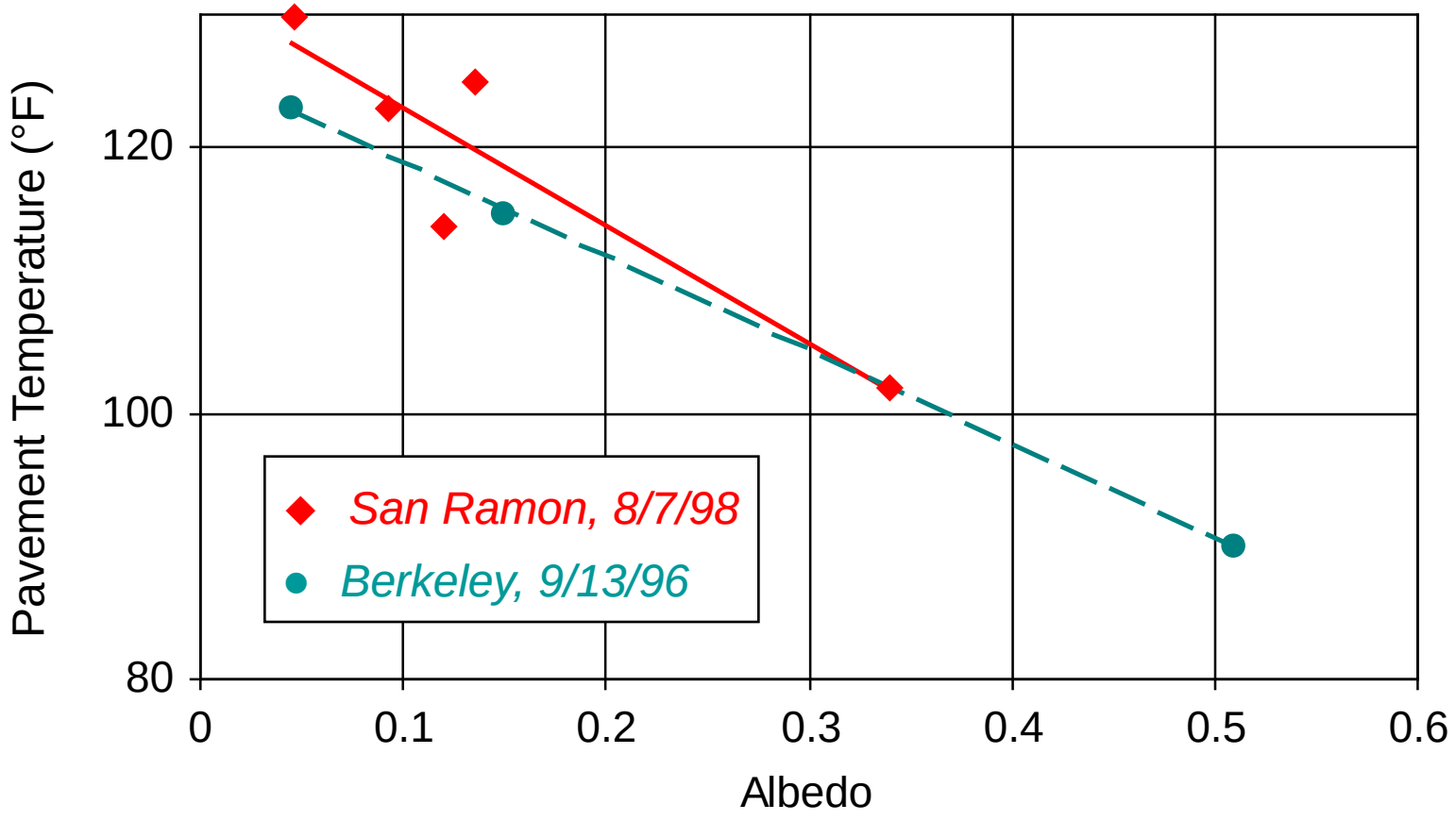
Image: Larry Scofield - APCA

Rio Verde, Arizona

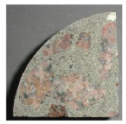
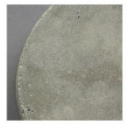


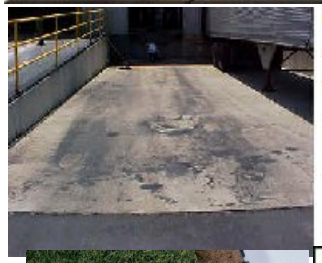
Pavement is **> 30 F** hotter than vegetation

Pavement temperature *vs.* albedo

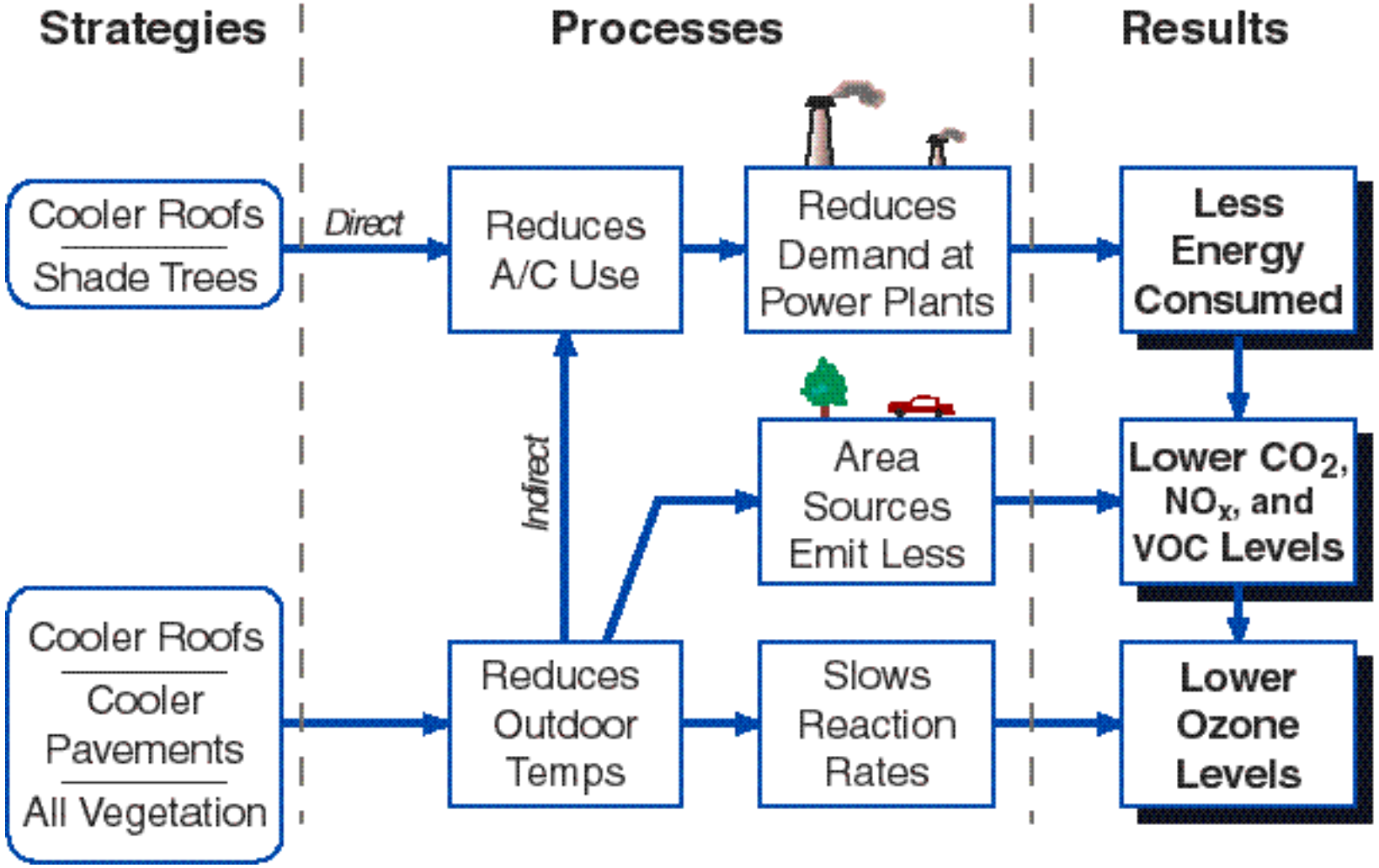


Cool paving materials: Needs more development

Concrete	**(a)** Unexposed	**(b)** Weathered	**(c)** Weathered, wetted	**(d)** Soiled	**(e)** Abraded	**(f)** Formed
C1:S1:R2 gray cement/ riverbed sand/ granite rock						
	ρ=0.44	ρ=0.34	ρ=0.14	ρ=0.43	ρ=0.24	ρ=0.25



Energy and air quality analysis



Passive PCO (Photo-Catalytic Oxidation) — the promise

- Can reduce local air pollutants by 20% to 70%, depending on sunlight levels and wind
- Marginally adds to the cost (e.g., ~20% to the cost of cement)
- Covering 15% of the exposed surfaces of a city like Milan could cut pollution in half
- As a bonus, TiO_2 helps buildings stay white by resisting the pollutants that stain building surfaces

PCO of NO

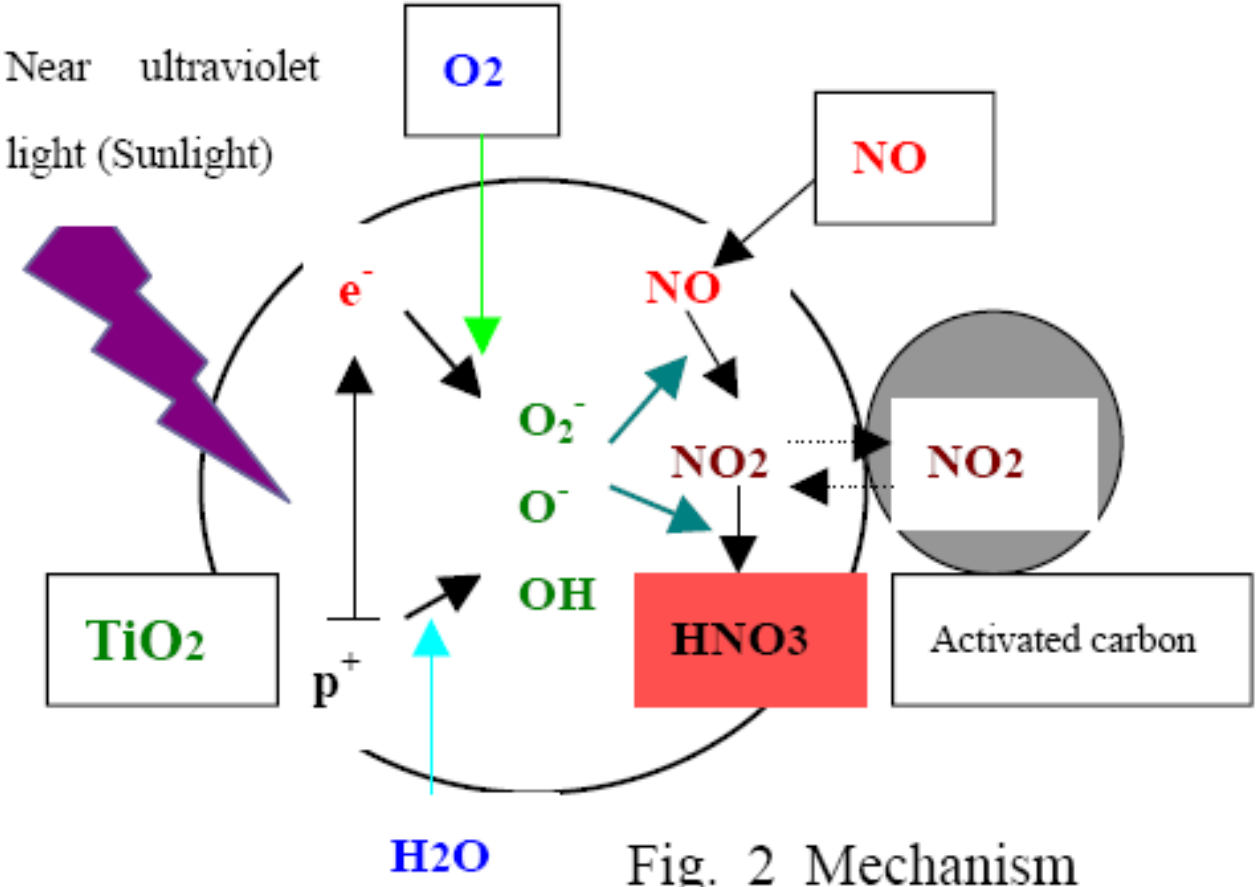


Fig. 2 Mechanism of photocatalysts

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Self-cleaning tent

Self-cleaning tent material

These small test-size tents were located on the grounds of a factory in Saitama prefecture, north of Tokyo, where they were exposed to significant air pollution. After a three-month exposure, the conventional tent material, seen on the left, had become severely stained. On the right, the photocatalytic tent material has remained clean, having been washed off periodically by rainwater.

ordinary white tent

(Courtesy of Taiyo Kogyo Corporation)

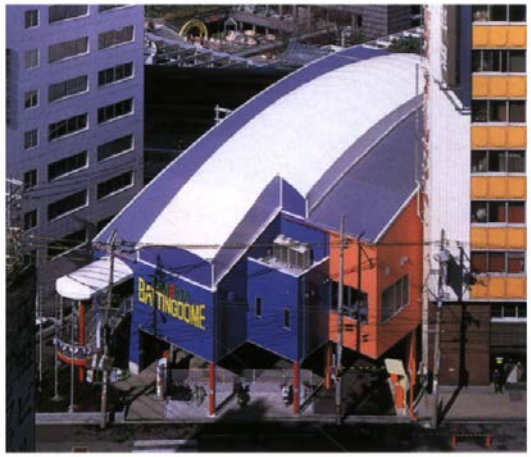
photocatalytic white tent

This tent, located in Tsukuba Science Center, is a full-size storage tent made from the photocatalytic tarpaulin material. Also having been washed by rainwater, it remains clean.

Self cleaning

Self-cleaning tent material

The tent for this batting practice center, located opposite the main railway station in Osaka, was made from tarpaulin material containing titanium dioxide.



(Courtesy of Taiyo Kogyo Corporation)

Recent Applications of Photocatalysis in Japan

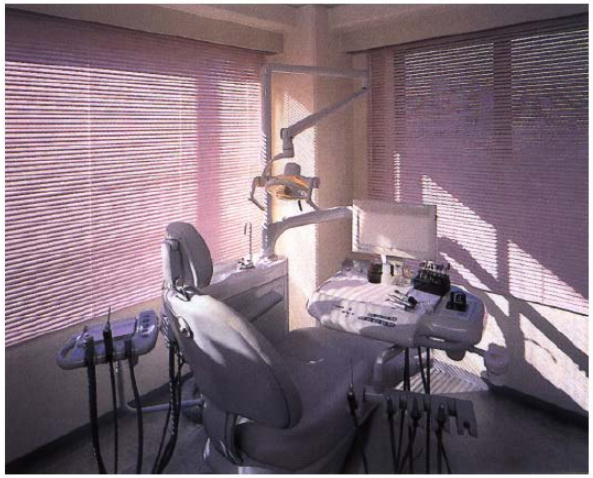
Self-cleaning aluminum siding

The aluminum siding on this building (Sendai YF Building of the YKK Corporation, in Sendai) is coated with titanium dioxide. Completed in April, 1999, it consists of 800 square meters of siding.

(Courtesy of YKK Corporation)

Self-cleaning window blind

This titanium dioxide-treated window blind, shown here in use in a dental office, has three functions: 1) it keeps itself clean, 2) it helps keep the air in the office clean, and 3) it helps to kill bacteria in the office.



(Courtesy of Nichibei Trading Co., Ltd.)

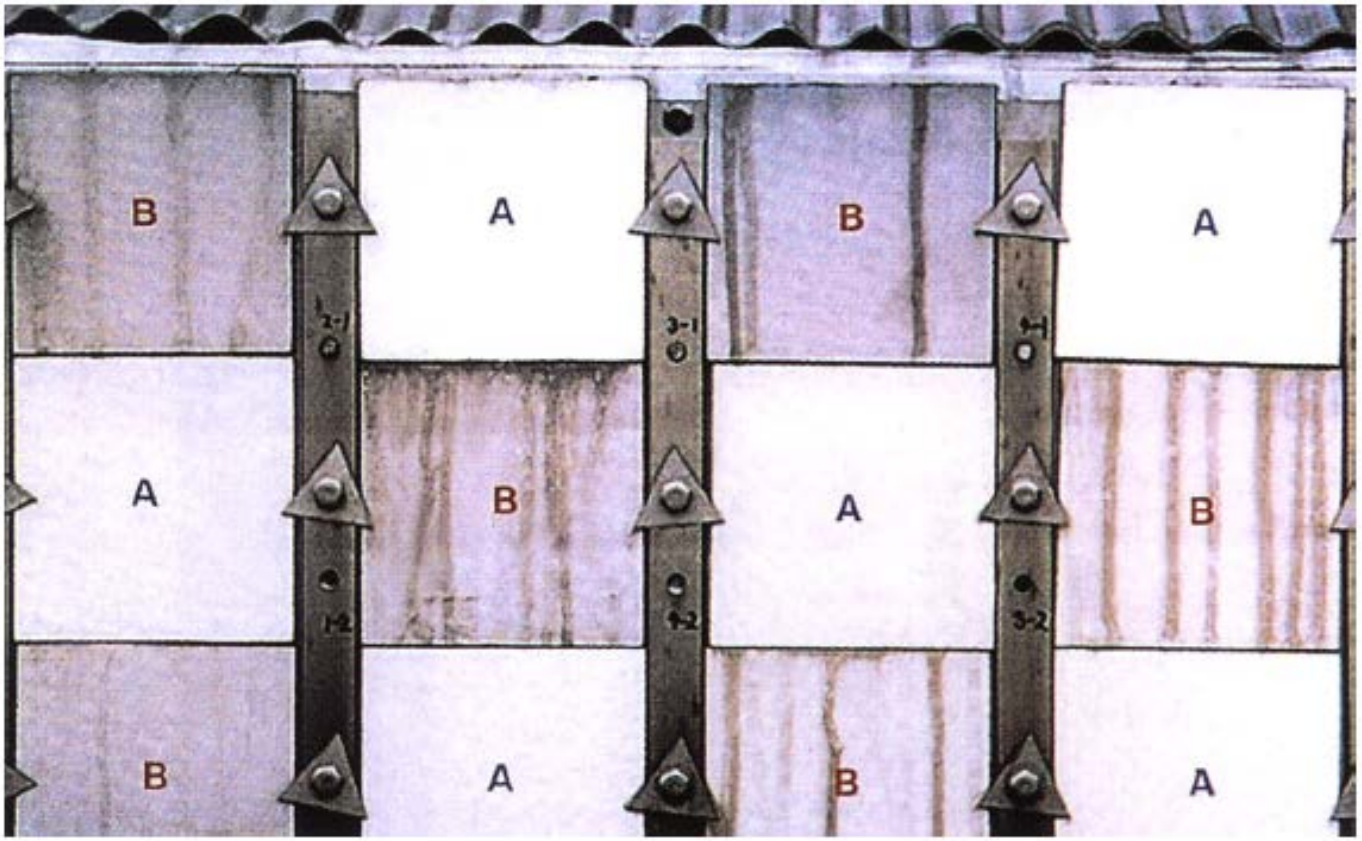
Car body spray coating

Thanks to the superhydrophilic effect of the "Hydrotect" coating, stains and grime caused by exhaust emissions, as well as rain droplets, are easily removed.

The photo shows the effectiveness of the coating, which has been applied only to the right side of the car. After one month´s exposure to polluted urban air, it remains clean while the left side has become dingy.

(Courtesy of TOTO Ltd.)

Self-cleaning tiles by TOTO, Inc.



A: Tiles with photocatalytic, superhydrophilic coating

B: ordinary painted wall tiles

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Transparent stain-proof film

Stain-proof plastic film

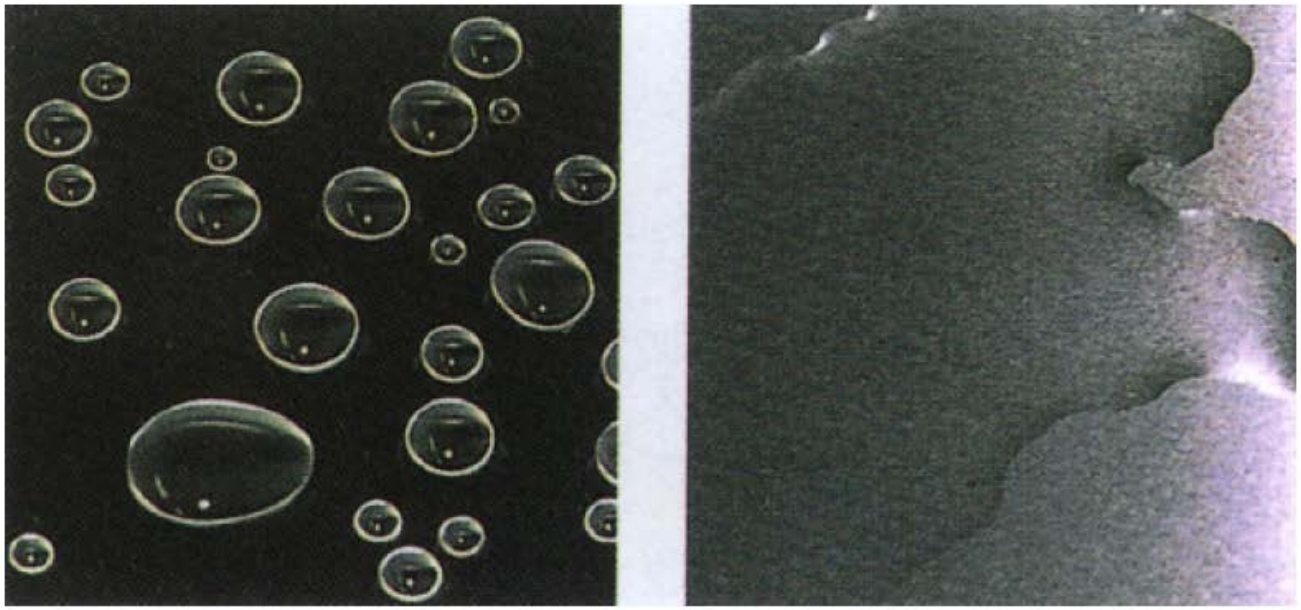
This type of titanium dioxide-treated plastic film is being used now in many applications where ease of cleaning is important. For example, the "on" button of a rice cooker would normally become stained after month of usage; however, coated with this film, it can be wiped clean with a quick swipe.

(Courtesy of Nippon Soda Co., Ltd.)

Superhydrophilic surface

Anti-fogging glass

Generally, if moist air comes in contact with glass, small water droplets form, and the glass becomes fogged. However, on titanium dioxide-coated glass, the water forms a continous flat sheet, so that there is no fogging. This is an example of what we call "superhydrophilicity"



Small water droplets are responsible for fogging.

Here the water forms a thin sheet, with no fogging effect.

Hydrophilic mirror reflects clear images

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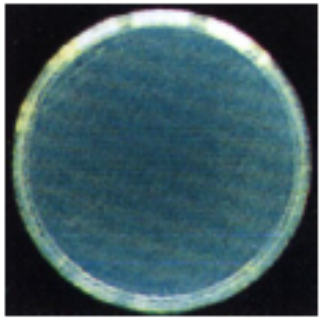
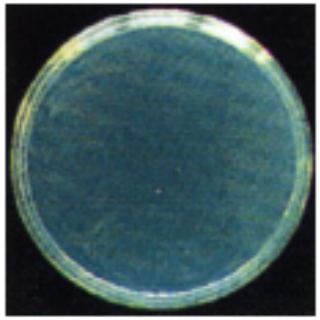
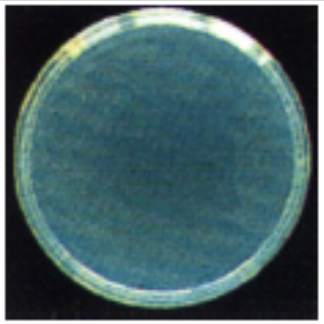
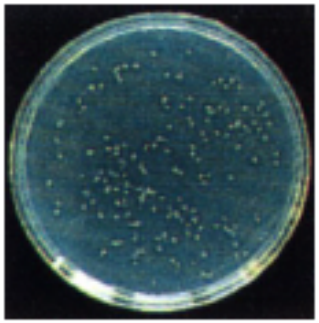
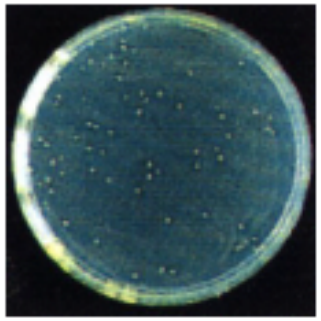
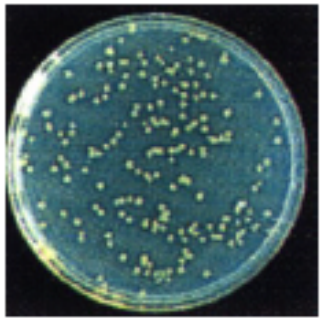
Anti-bacterial effect

		E. coli	Methicillin-resistant *Staph. aureus* (MRSA)	*Pseudomonas aeruginosa*
Photocatalytic anti-bacterial tiles	1000 lux illumination (1 hour)			
Ordinary Tile	1000 lux illumination			

Cool surfaces also cool the globe

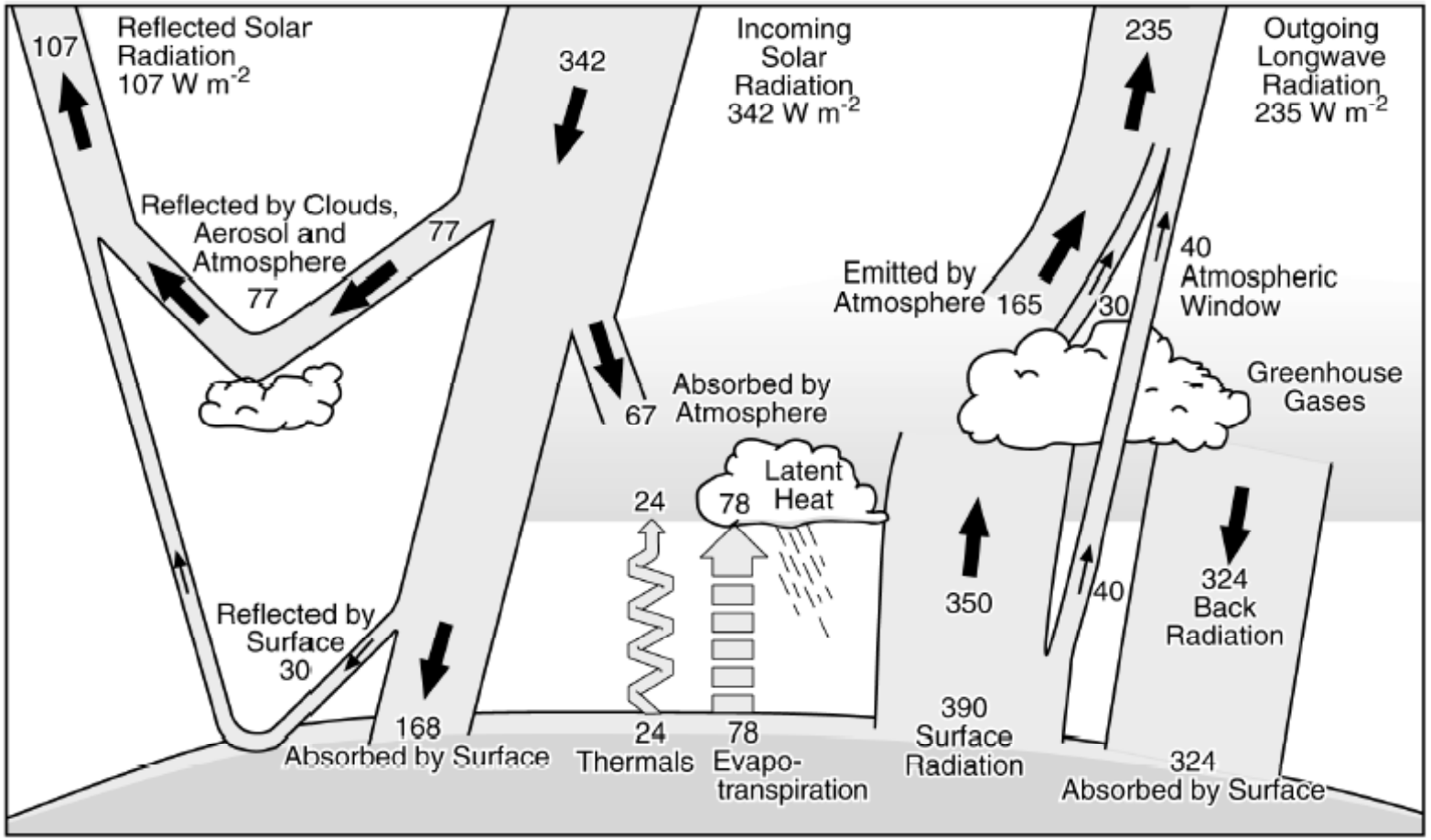
- Cool roofs, cool pavements, and shade trees save energy, improve air quality, and improve comfort; we estimate savings of > $50B/year
- Reflective roofs and pavements also directly cool the globe, independent of avoided CO_2

Geo-engineering 101

Geo-engineering technologies

- Solar radiation management
  - Atmospheric projects (Cloud seeding)
  - Terrestrial albedo modification
  - Land management / Bio-geoengineering
  - Space projects
- Greenhouse gas remediation
  - Carbon sequestration
  - Biological processes
  - Physical processes
  - Chemical techniques
  - Other greenhouse gas remediation
- Other schemes (black moon, white bubles)

CO_2 offset: The Earth's radiation budget



Source: Kiehl and Trenberth, 1997

CO_2 offset of cool roofs and pavements

- Low-sloped roofs
  - Δ albedo for aged white roofs = 0.40
  - Emitted CO_2 offset for white roofs = -280 kg CO_2/m^2
  - It takes about 4 m^2 of white roof to offset 1 T CO_2 emitted
- Sloped roofs
  - Δ albedo for typical residential and non-residential cool roofs = 0.25
  - Emitted CO_2 offset for cool roofs = -170 kg CO_2/m^2
- Pavements
  - Δ albedo for cool pavement = 0.15
  - Emitted CO_2 offset for cool pavements = -100 kg CO_2/m^2

Source: Akbari et al, 2012

World-wide CO_2 offset of cool roofs and pavements

- Typical urban area is 25% roof and 35% paved surfaces
- World-wide urban areas = 1.5×10^{12} m^2 (1.5 M km^2)
- World-wide roof area = 3.8×10^{11} m^2 (0.38 M km^2)
- World-wide paved area = 5.3×10^{11} m^2 (0.53 M km^2)
- Emitted CO_2 offset for cool roofs = 67 GT CO_2
- Emitted CO_2 offset for cool pavements = 57 GT CO_2
- Total for cool roofs and cool pavements = 124 GT CO_2

CO_2 offset of cool roofs and pavements

- 124 GT CO_2 is over 3 years of the world 2025 emission of 37 GT CO_2
- At a growth rate of 1.5% in the world's CO_2 - equivalent emission rate, 124 GT CO_2 would offset the effect of the growth in CO_2-equivalent emissions for over 20 years
- Would offset emissions from all cars for over 50 years

Value of CO_2 offset

- CO_2 emissions currently trade at ~$25/tonne
- 124 GT worth $3200 B, for changing albedo of roofs and paved surfaces
- Cooler roofs alone worth $1700B
- Cooler roofs also save air conditioning (and provide comfort) and improve air quality worth over $5000B over the next 100 years

The white-roof revolution

THE INDEPENDENT

TIMESONLINE

THE NEW REPUBLIC
A Journal of Politics and the Arts

THE HINDU

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n on the
subject.

THE VANCOUVER SUN

ate that making roofs and pavemen ht-colour global
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urban roofs and p ra ar-reflecti l offset
4 billion tonnes of carbon dioxide.

ANSA.it

CBS

abc

Le Monde.fr

entis aking buildings more comfortable and
mitigate the on of concrete surfaces in cities.

METEO ITALIA

THE WALL STREET JOURNAL

zeroEmission.TV

San Francisco Chronicle

guardian.co.uk

BBC

THE CHRISTIAN SCIENCE MONITOR

The New York Times

Los Angeles Times

www.jamejamonline.ir

UNIVERSITÉ Concordia UNIVERSITY

A global action plan: The big picture

- Develop an international program to install cool roof/pavement in world's100 largest cities
- This is a simple measure that we hope to organize the world to implement **AND**
- **WE'D BETTER BE SUCCESSFUL**
- We can gain practical experience in design of global measures to combat climate change

100 Cool Cities

Global Cool Cities Alliance (GCCA)

- Non-profit international cooperation launched in 2009
- Mission: Advance policies and actions to increase solar reflectance of urban surfaces to
  - Cool buildings
  - Cool cities
  - Cool the world
- Membership: Open to all cities in the world

"100 Cool Cities" initiative needs your help

- Initial list of cities
  - NYC, Taipei, Tokyo, Osaka, Tallahassee, Rome, Milano, Athens, Sao Palo, Hyderabad, Delhi, Los Angeles, Toronto, Montreal, Philadelphia, Chicago, Singapore
- Where are other cities (?)
- Join me to contact city officials and recruit more cities
- Industry needs to co-lead



?

Cool roofs in action

- ASHRAE Standards 90.1 and 90.2
- States' energy efficiency codes (commercial and residential)
- U.S. EPA ENERGY STAR™ Label
- LEED Green Building Rating System
- International Energy Conservation Code
- Cool Roof Rating Council
- European Union Cool Roof Council
- India energy code for offices
- White roofs in several other countries

White low-sloped roofs for AC buildings

- Annual AC savings of ~ 0.5 - 1.0 $/m^2; 5 -10 kWh/m^2
- Annual CO_2 savings of 3.8 - 7.5 kg/m^2
- CO_2 savings over 20 years life of roof 75-150 kg/m^2
- NPV of 20 years AC savings of ~ 7.5-15 $/m^2
- Maximum incremental cost for most roofs 2.5 $/m^2

A no brainer

Cool-colored steep-sloped roofs for AC buildings

- Annual AC savings of ~ 0.3-0.5 $/m^2; 3-5 kWh/m^2
- Annual CO_2 savings of 2.3 - 3.8 kg/m^2
- CO_2 savings over 20 years life of roof 45-75 kg/m^2
- NPV of 20 years AC savings of ~ 4.5-7.5 $/m^2
- Maximum incremental cost for most roofs 2.5 $/m^2

Go for it

White low-sloped roofs for non-AC buildings

- Global cooling offset: 100 kg/m^2
- Current value of CO_2 offset: 25 $/tonne
- Global cooling value of white roofs: 2.5 $/$m^2$
- Incremental cost for most roofs: 0 - 2.5 $/$m^2$
- Give 1 $/$m^2$ rebate every 10 years
- Save the remainder 1.5 $/$m^2$; see it grow to 2.5 $/$m^2$ in 10 years

Does it work?

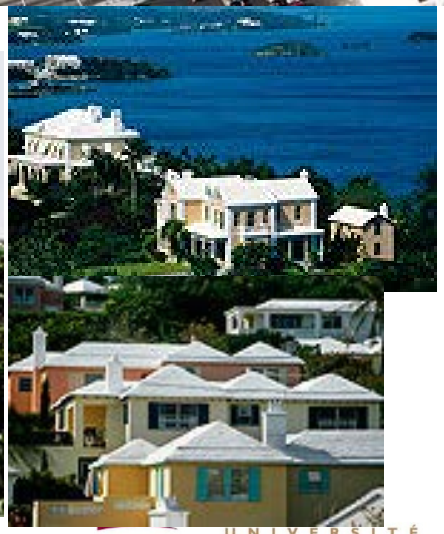
Cool pavements

- Global cooling offset: 40 kg/m^2
- Current value of CO_2 offset: 25 $/tonne
- Global cooling value of cool pavements: 1 $/m^2
- Incremental cost of cool pavements: 0 - 2 $/m^2

How can we make it work?

Cool pavements last longer?

100m^2 of a white roof, replacing a dark roof, offset 25 tonnes of CO_2 emissions



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