

Cooling the cities with solar reflective materials: technological advances, policies and incentives

Dr. Afroditi Synnefa

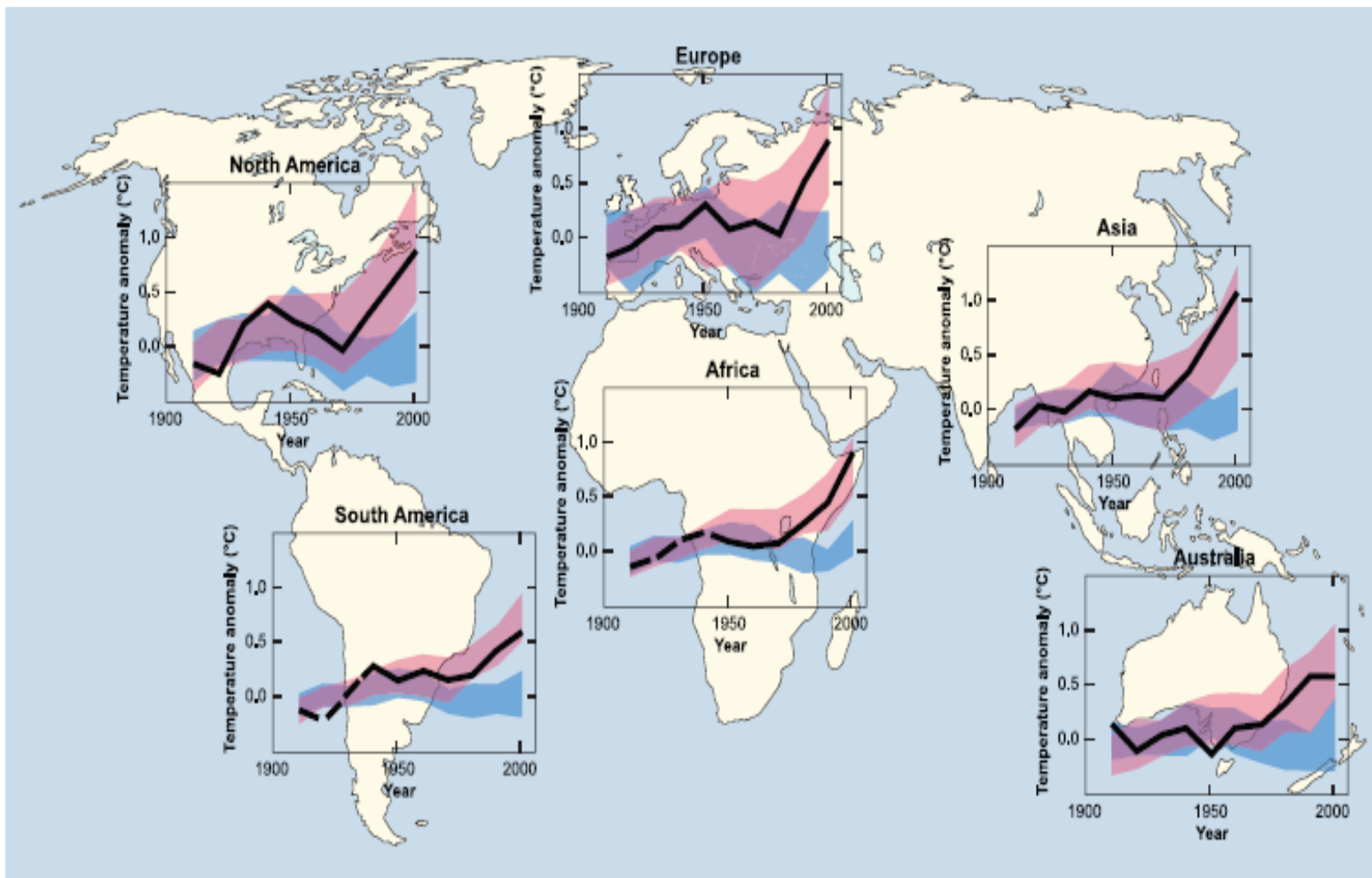
Group Buildings and Environmental Studies

National and Kapodistrian University of Athens, Greece

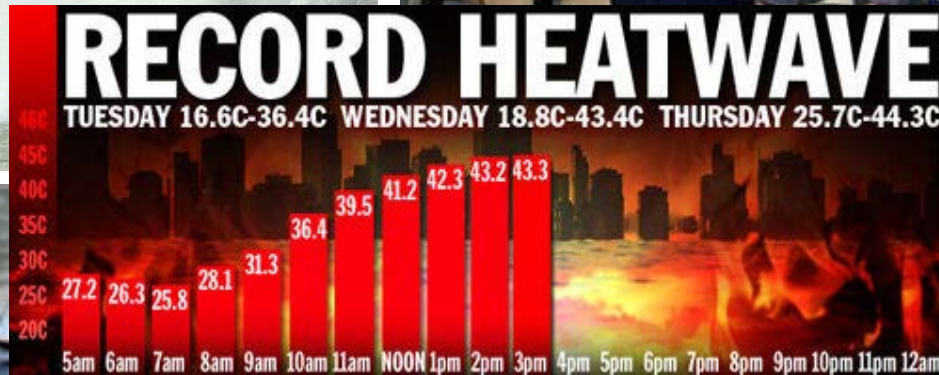


CBCS

Global temperature change



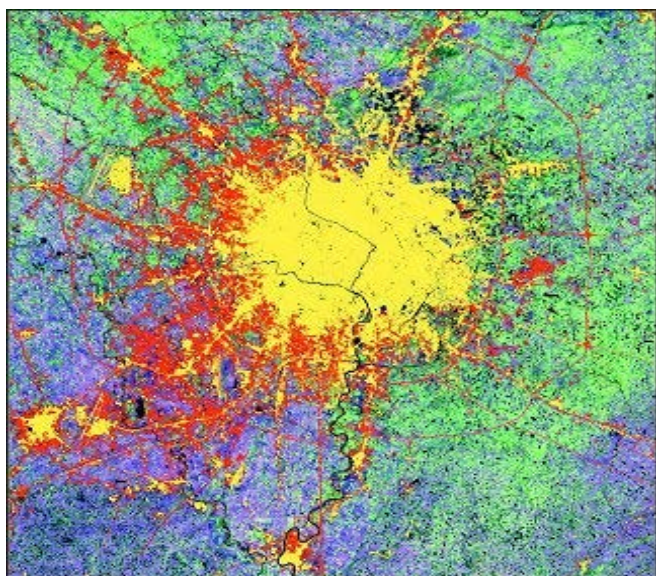
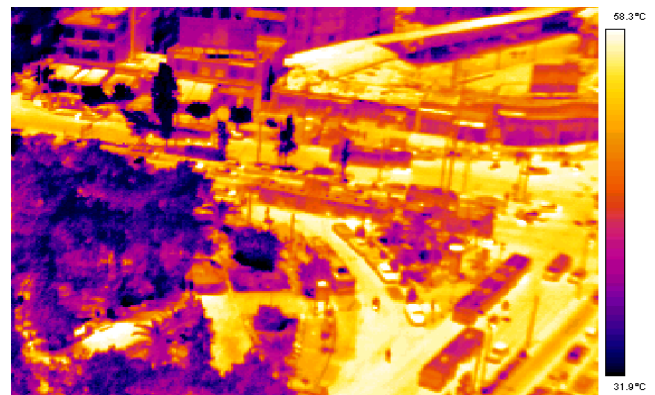
Heat waves become more frequent



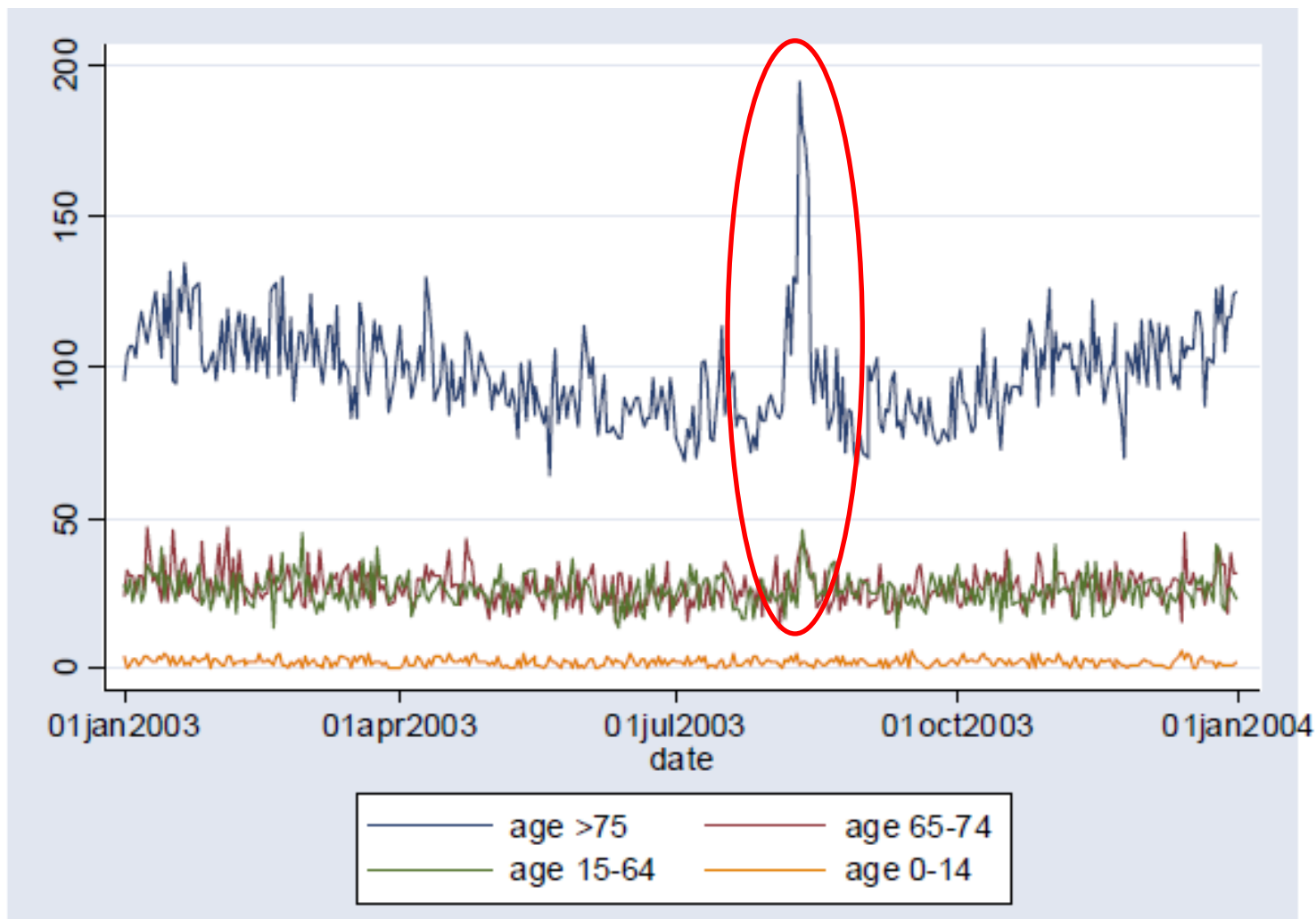
Heat island intensity increases



EPA

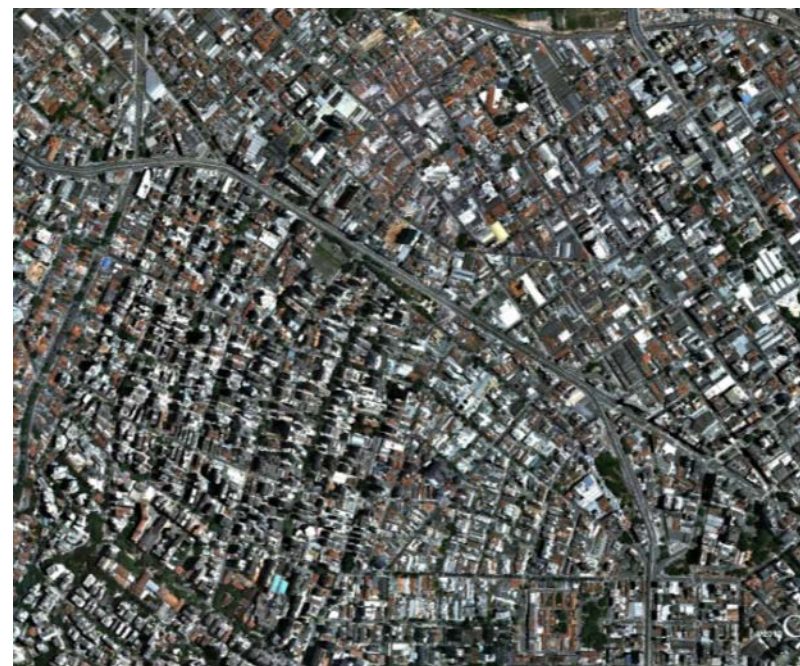


Heat related mortality



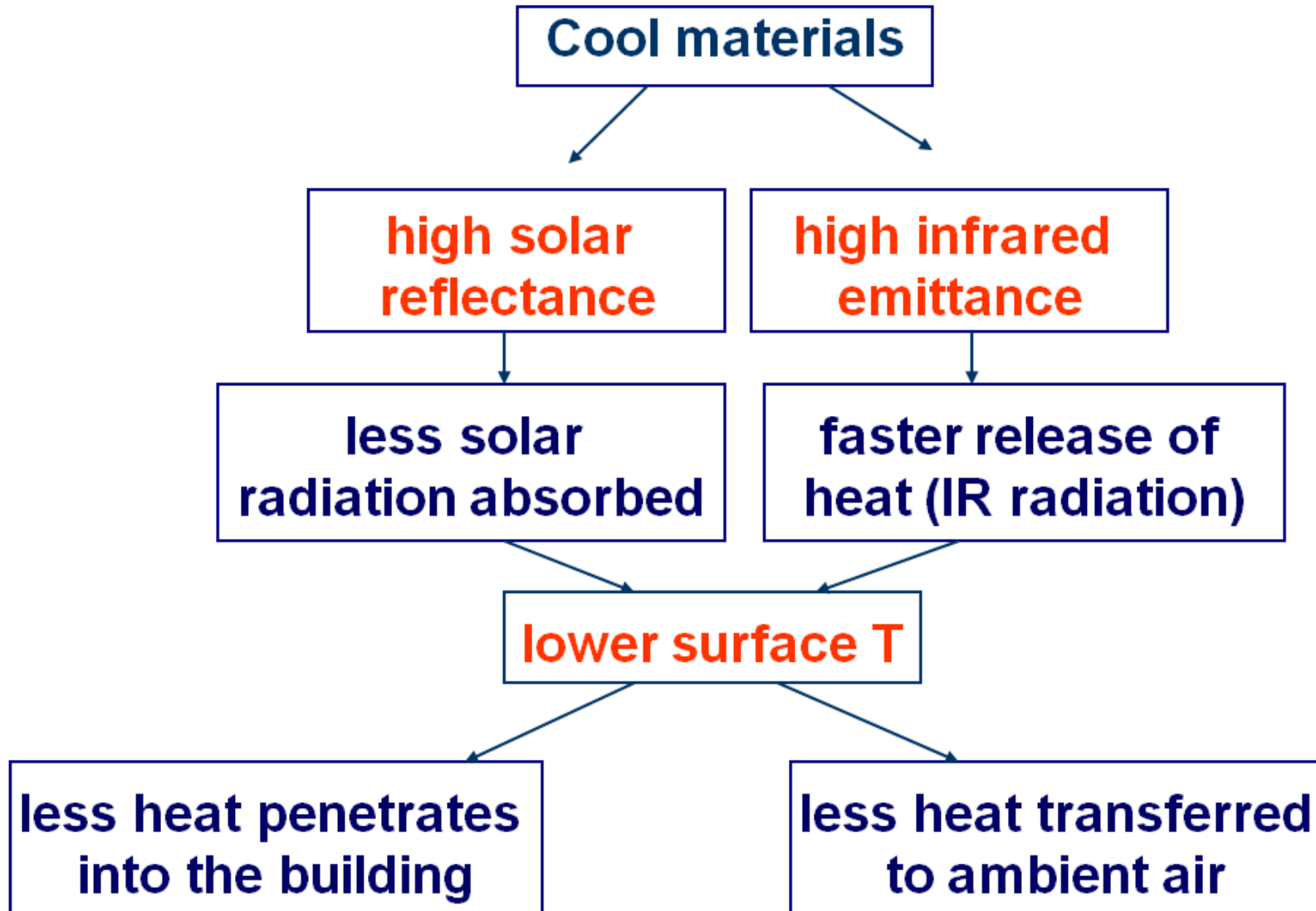
Number of deaths per day in London for 2003 (ONS)

Methods	Applications
Creation of cool surfaces	Use of appropriate materials
	Green areas
	Water surfaces
	Creation of shading area
Reduction of anthropogenic heat	Energy conservation measures
	Heat release measures
Improvement of the urban environment	City block configuration
	Building configuration

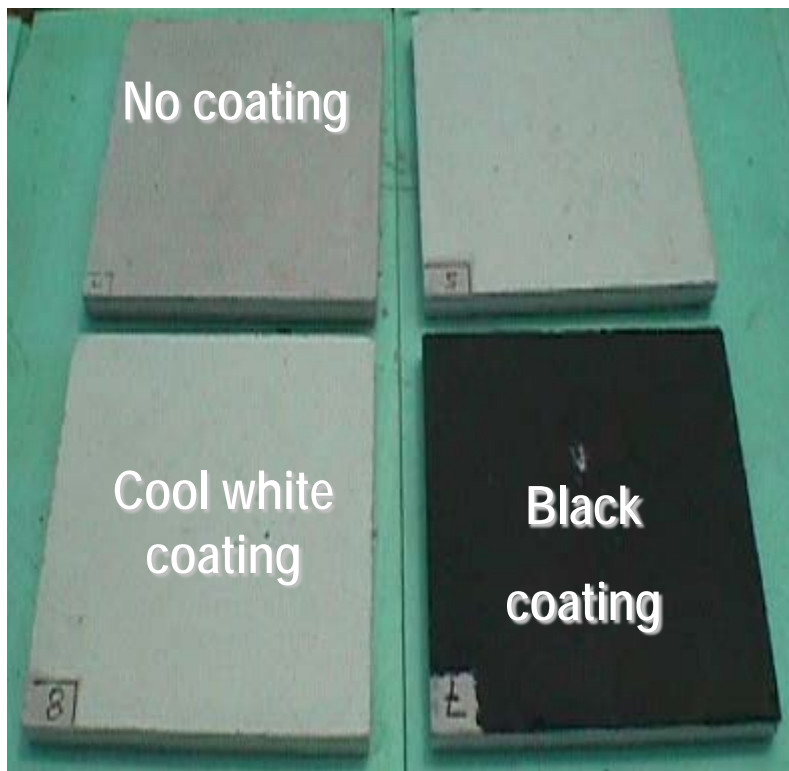


Google Earth

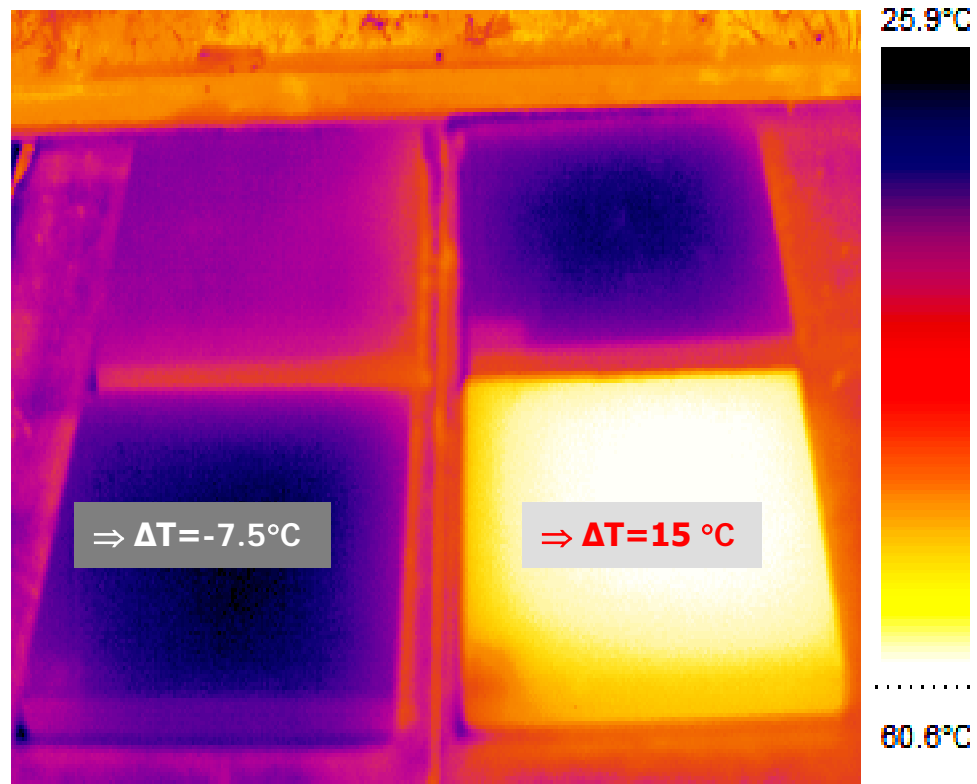
► Pavements and roofs comprise over 60% of urban surfaces



Visible



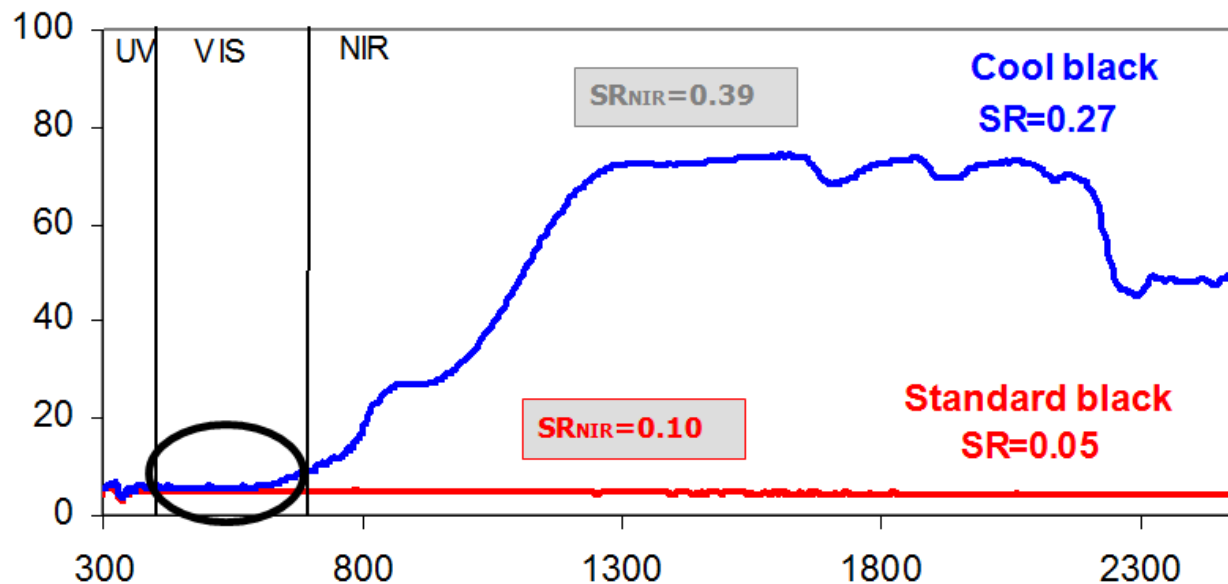
Infrared



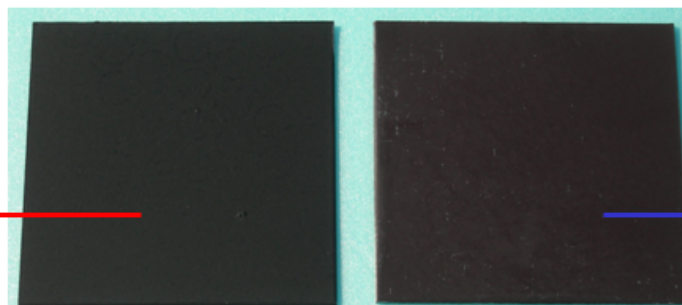




Cool colored materials




**Standard
black**



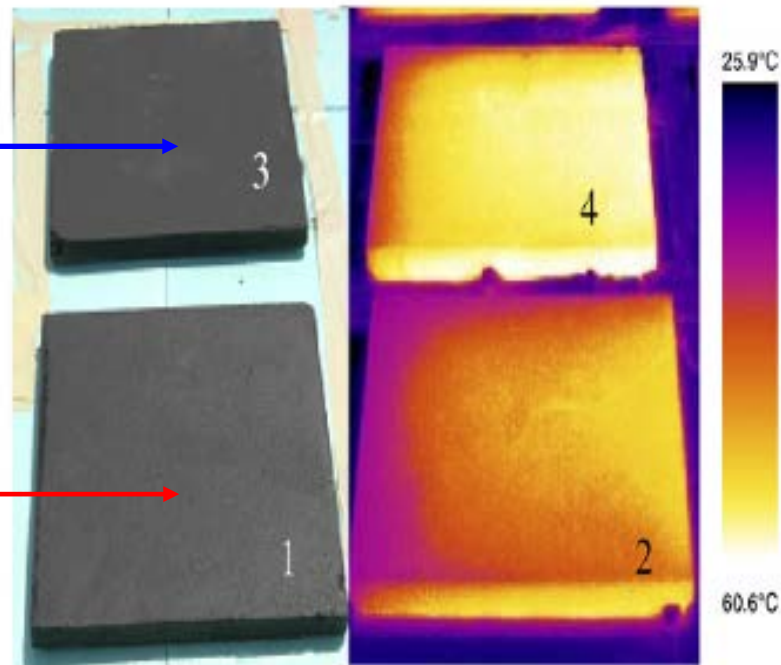
Cool black

Cool colored materials

Standard	Cool	Standard	Cool
			
Orange		Anthracite	
			
Light blue		Brown	
			
Blue		Chocolate brown	
			
Green		Light brown	
			
Black (1)		Black (2)	

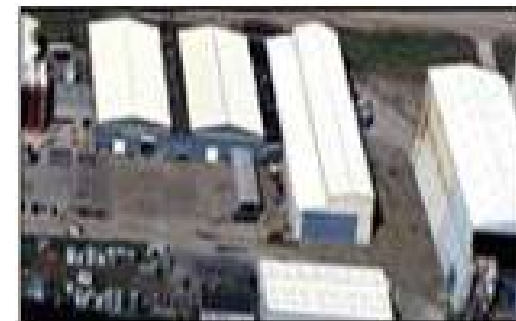
cool black

Standard black



$\Delta T_{max} = 10 \text{ }^\circ\text{C}$

Cool materials for roofs



EPA

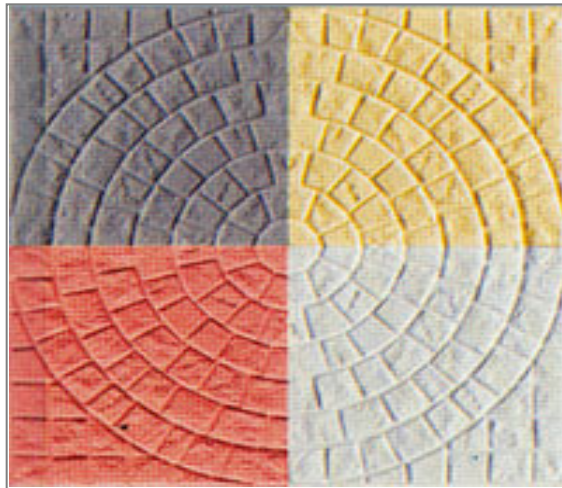


M.A. Miller/JORNI

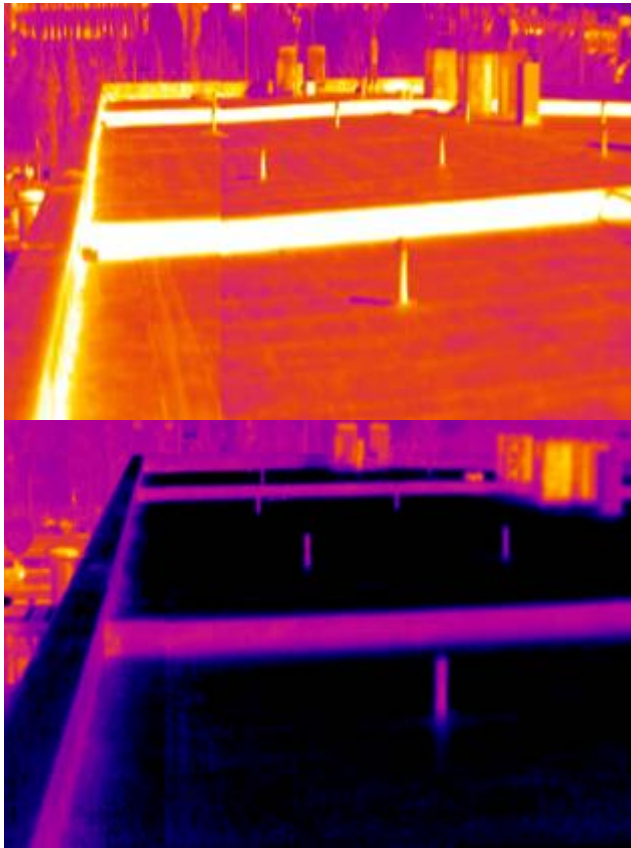


CRRC/Custom-Bit Metals

Cool materials for pavements



Benefits for building users



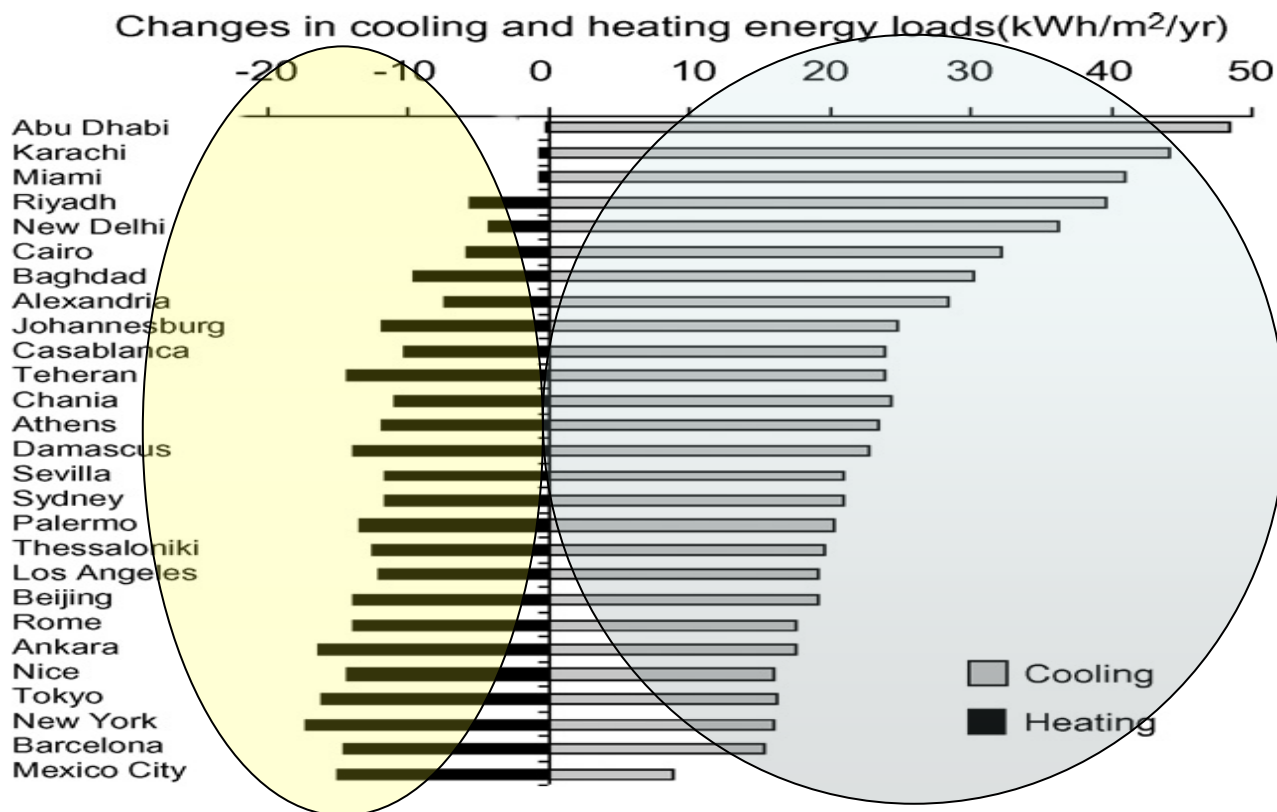
Conventional roof system: asphalt membrane with siliceous aggregates



Cool Roof: Cool White Coating

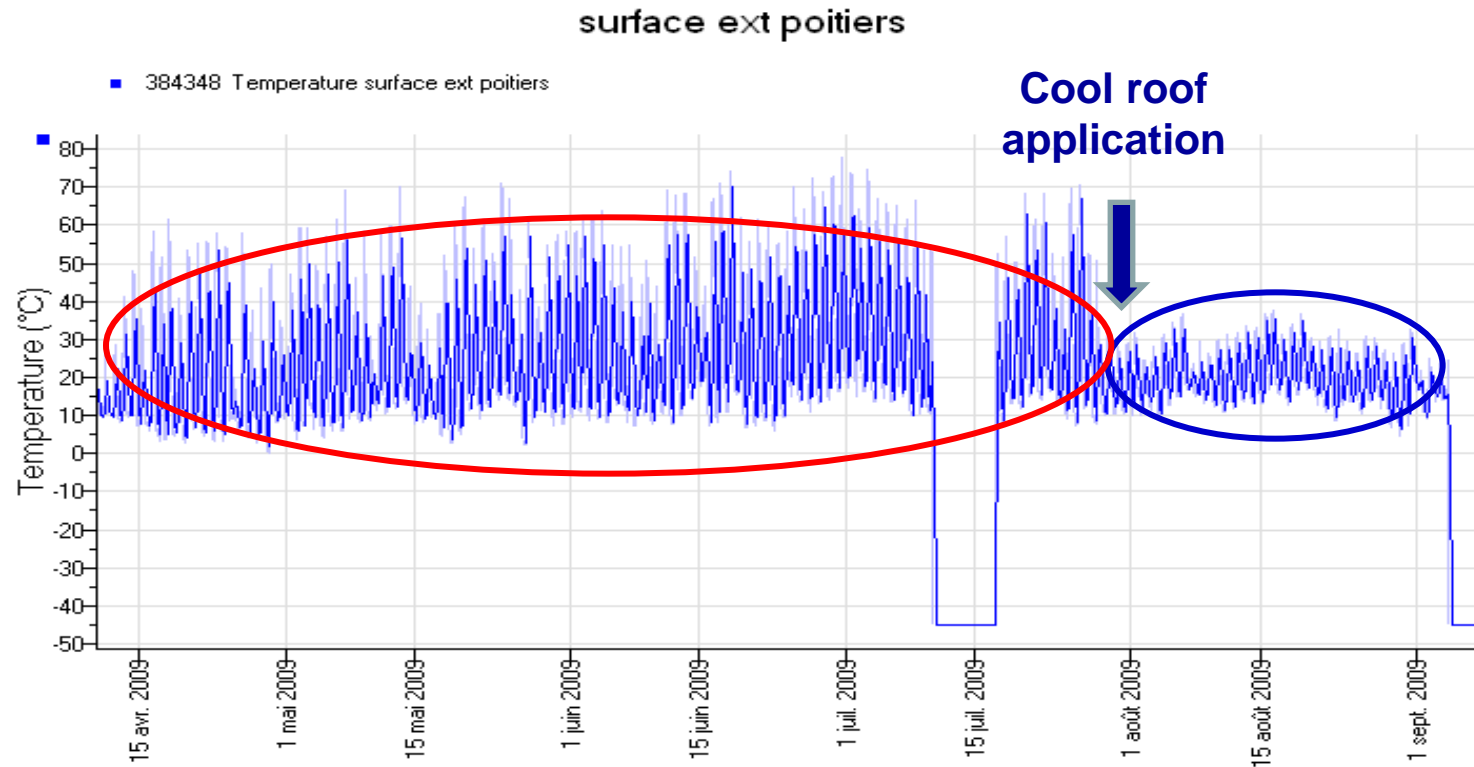
- **Improve thermal comfort conditions**
 - Reduction of discomfort hours
 - Reduction of indoor air temperature by 1 – 3°C

Benefits for building users



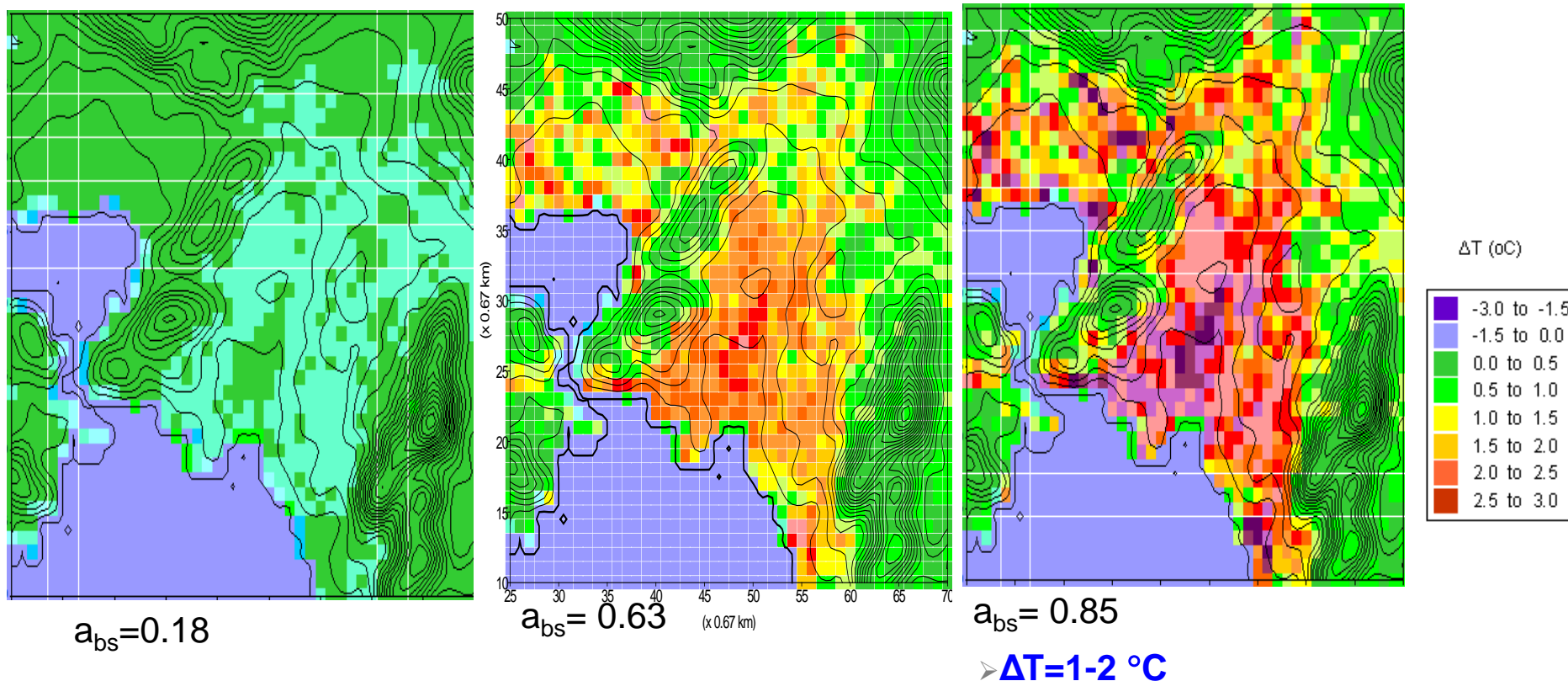
- Create savings on summertime air conditioning expenditures, in conditioned buildings. (AC savings averagely 10-40%)
- Reduce peak electricity demand and related financial savings

Benefits for building users



- Enhance the life expectancy of the roof system reducing expenses for maintenance (less thermal fatigue)

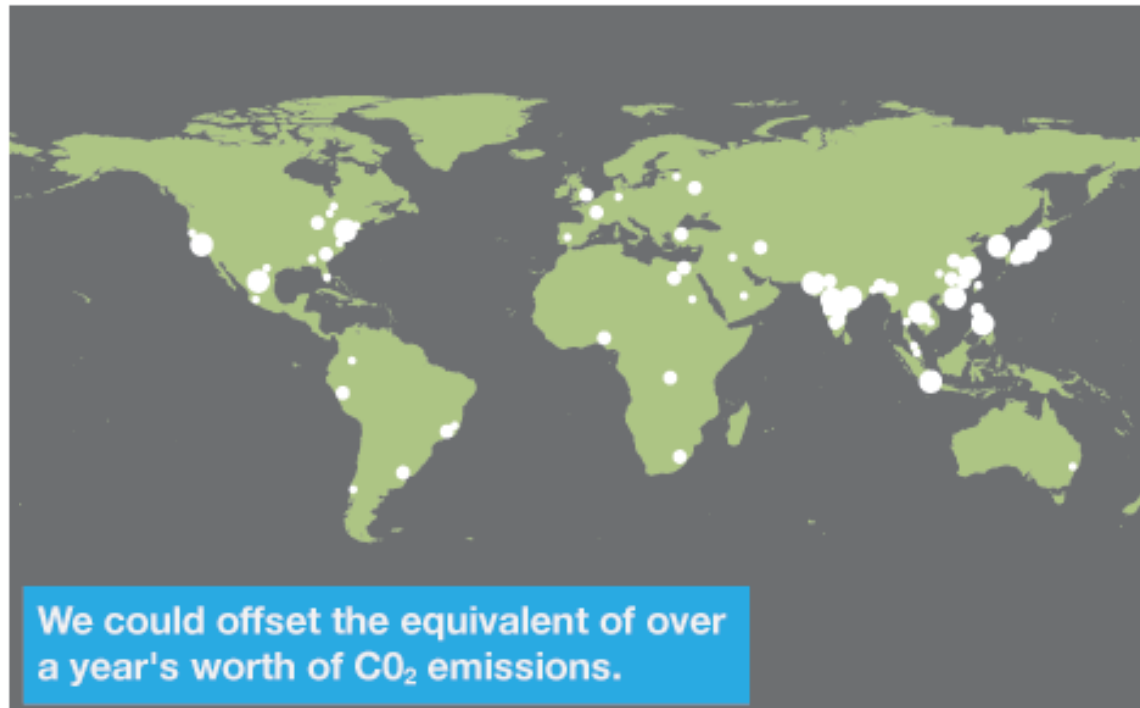
Environmental benefits



■ Reduction of heat island effect

- Lower ambient air temperature
- Improved local air quality and reduction of heat and smog-related health issues

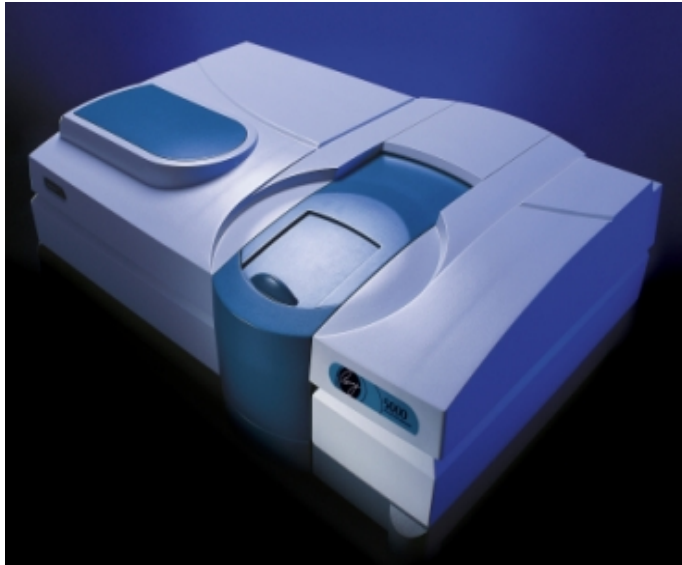
Environmental benefits



Global Cool Cities alliance

- Reduction of air pollution and CO₂ emissions
- Mitigation of global warming

Assesment of cool materials



Spectrophotometer (ASTM E903)



Solar Spectrum Reflectometer (ASTM C1549)

■ Solar reflectance



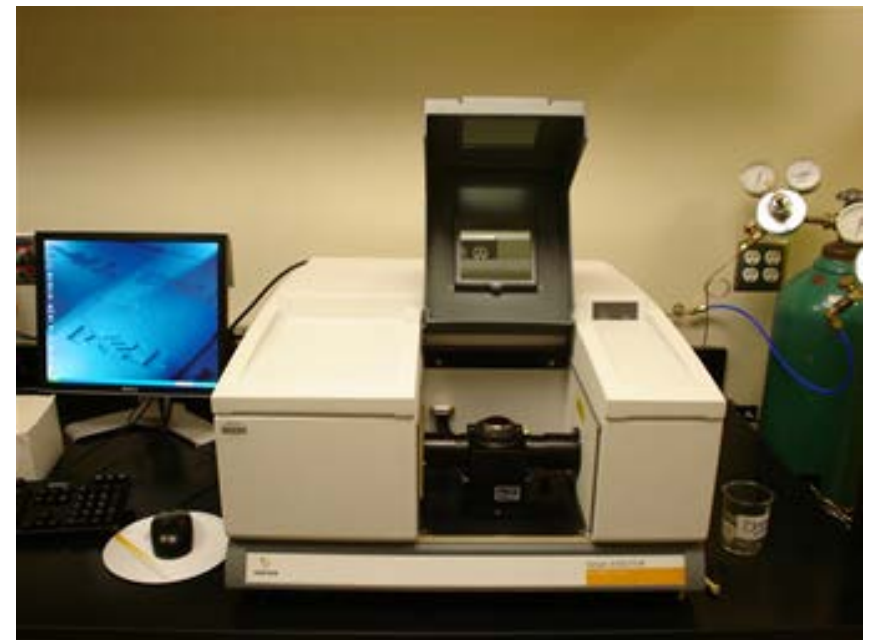
Pyranometer (ASTM E1918, LBNL E1918A)

Assesment of cool materials

■ Thermal emittance

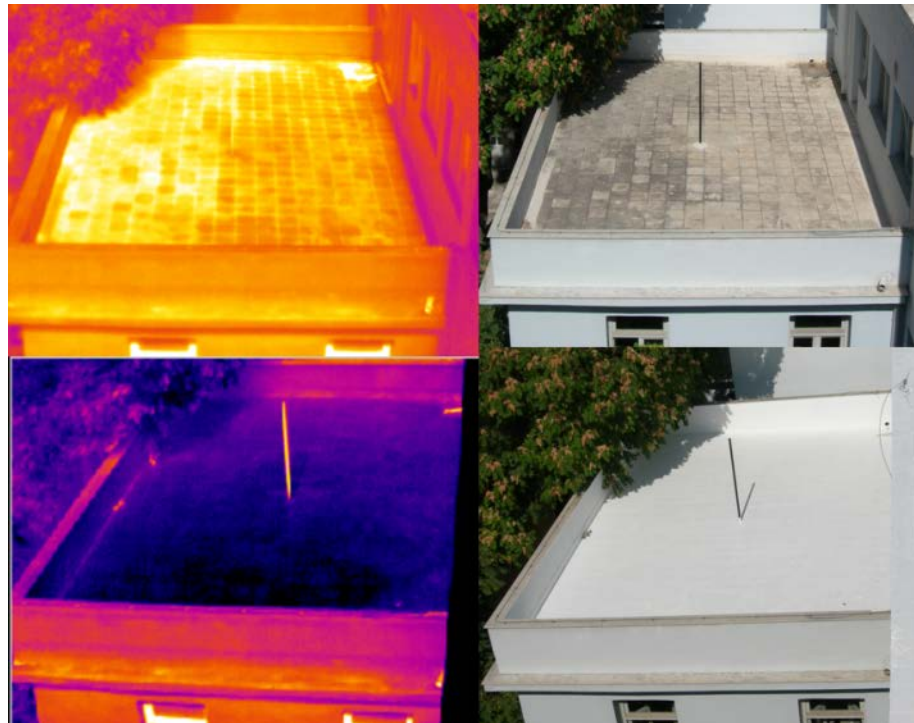


Emissometer (ASTM 1371)



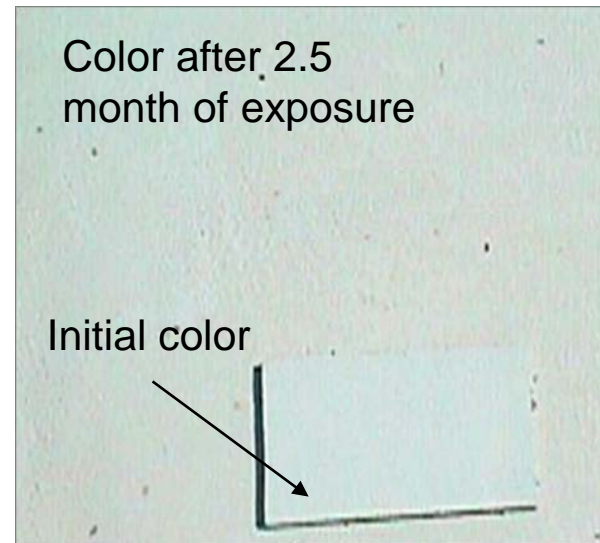
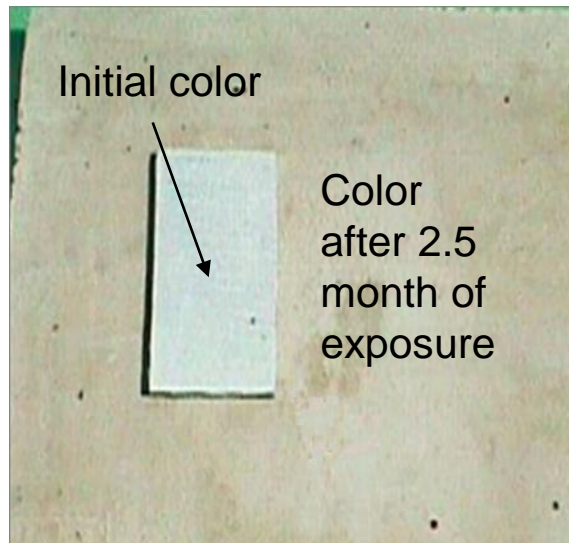
FTIR

Deterioration of cool materials



- Aging and weathering affects the performance of cool materials

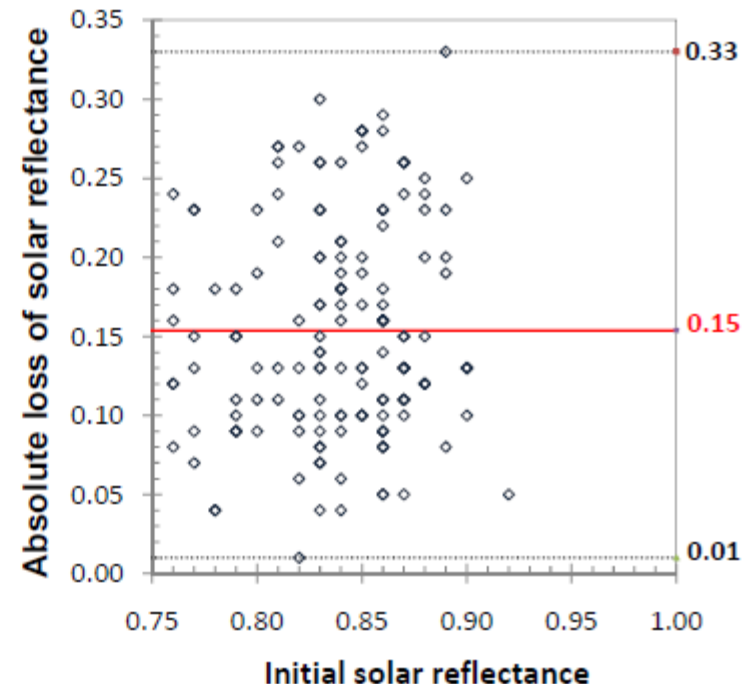
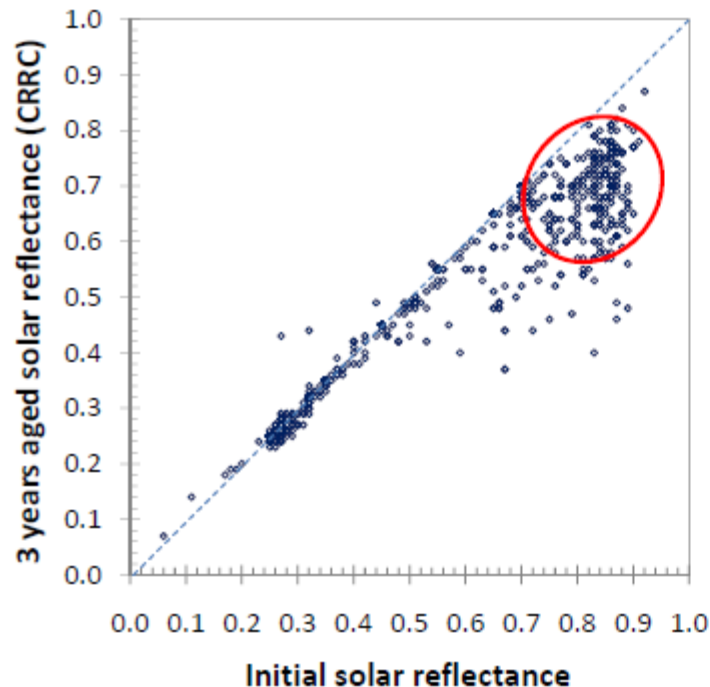
Deterioration of cool materials



- Aging and weathering can reduce the solar reflectance of cool roofing materials.
- Aged (weathered) rating performance is critical and there are also large variations in soiling among different products

Deterioration of cool materials

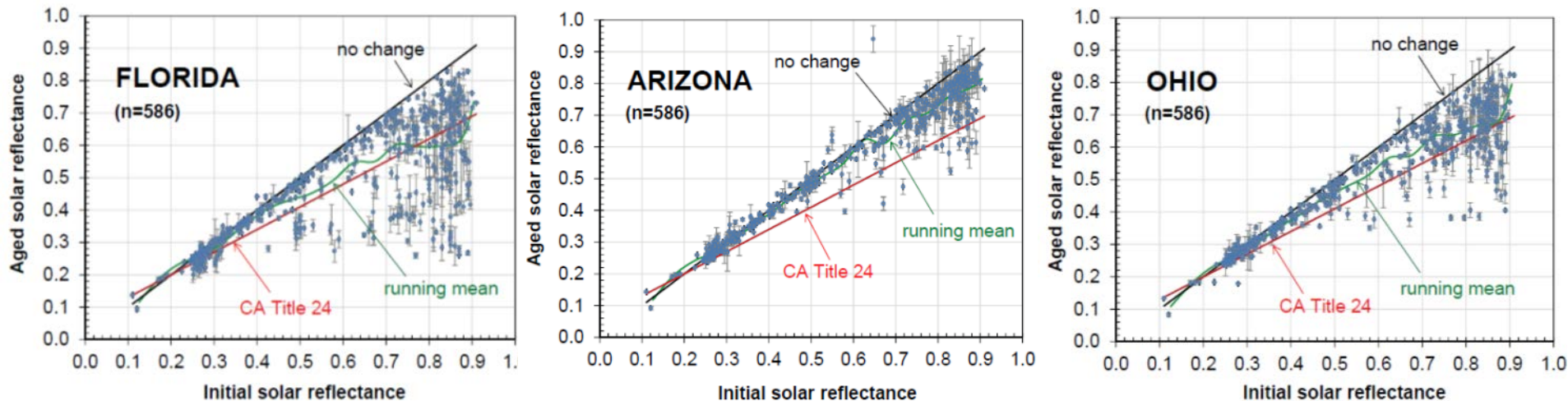
Data from products directory of Cool Roof Rating Council (CRRC): <http://coolroofs.org/products>



(Sleiman et al. 2011, *Solar Energy Materials & Solar Cells*)

- Highly reflective “cool” roofs can lose up to 40% of initial solar reflectance
- White roof coatings/ membranes soil rapidly, losing solar reflectance (SR) initial SR ~ 0.80 aged SR ~ 0.55

Deterioration of cool materials

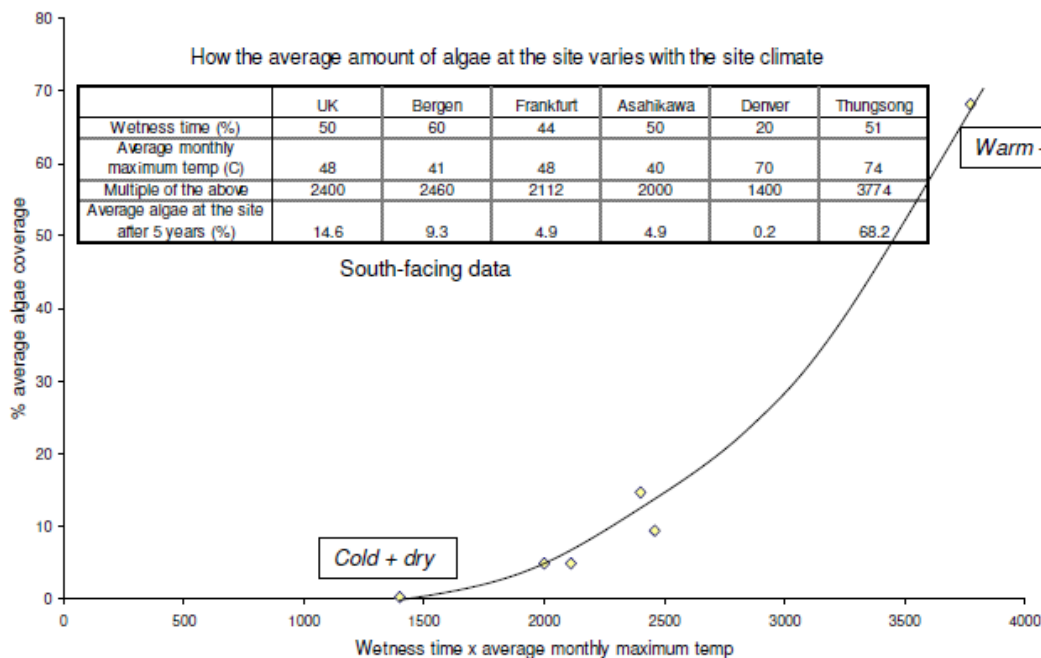


(Sleiman et al. 2011, *Solar Energy Materials & Solar Cells*)

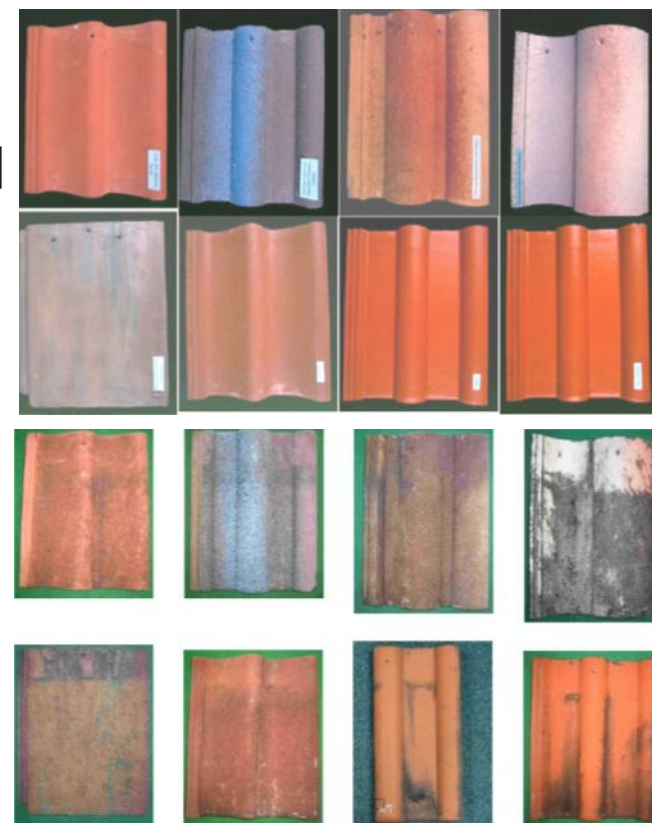
- **SR losses for samples with $SR_{in} > 0.4$ were 2 - 3 times greater in Florida (hot & humid) than in Arizona (hot & dry); losses in Ohio (temperate & polluted) were intermediate**

Deterioration of cool materials

How the average amount of algae at the site varies with the site climate

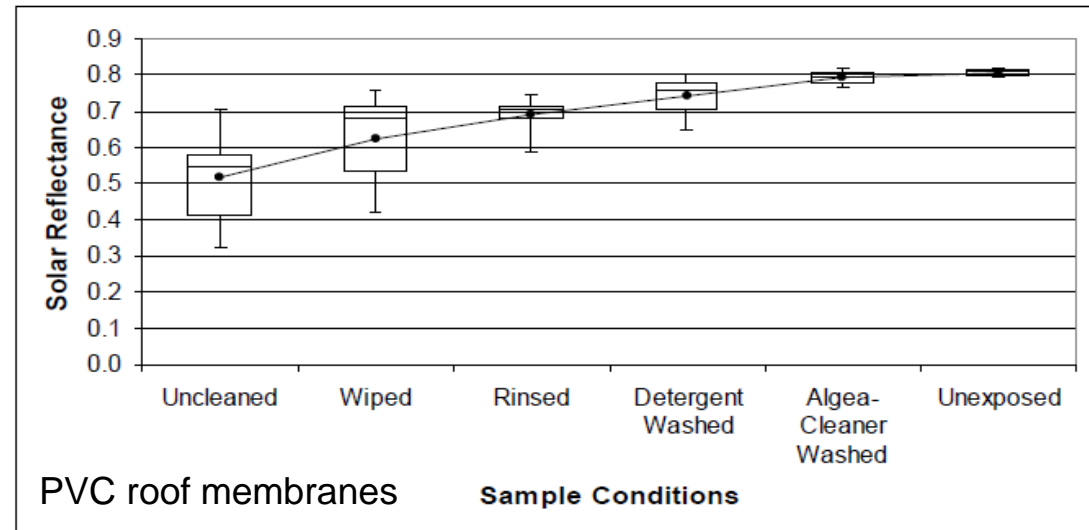
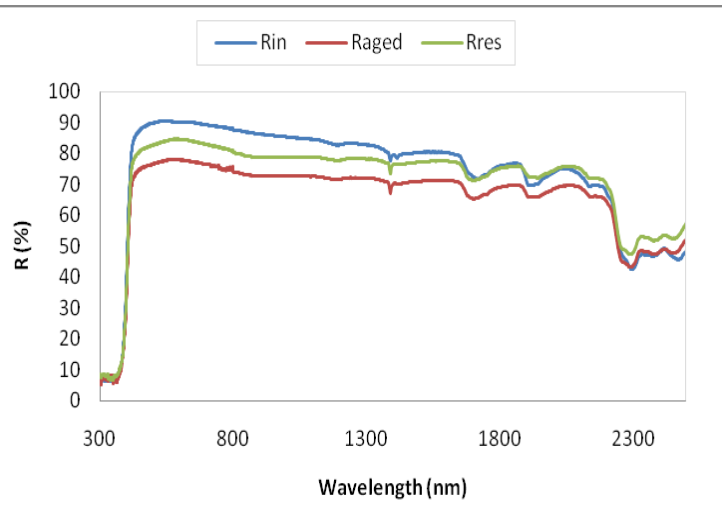


(Dr. Nigel Cherry, Monier Technical Center)



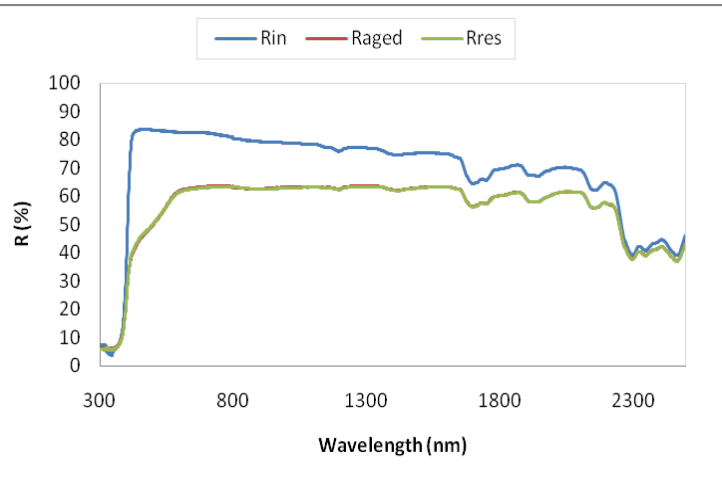
- moisture and temperature increase biological growth. Surface roughness and contact angle are also key parameters.
- materials resistant to biological growth should be used

Deterioration of cool materials



(Akbari et al, 2005, LBNL report LBNL-58055,

- **Appropriate cleaning of the roof can potentially restore SR values to some percentage**



White coatings

Cool Roofs in the US

USGBC's LEED® www.usgbc.org

U.S. Green Building Council

Green Globes®

www.thegbi.com/greenglobes



ENERGY STAR® www.energystar.gov



<http://www.globalcoolcities.org/>

International Energy Conservation Code
(IECC®) www.iccsafe.org



American Society of Heating, Refrigerating and Air-
Conditioning:

ASHRAE



New York City Building Code

www.nyc.gov



<http://www.coolroofs.org/>

American Society for Testing and Materials
<http://www.astm.org/>



Cool Roofs worldwide



GREEN BUILDING COUNCIL
BRASIL
CONSTRUINDO UM
FUTURO SUSTENTÁVEL



- Japan working aggressively to put a rating process in place
- Numerous countries are aware of cool roof benefits and some have building code requirements, but general testing and rating infrastructure does not exist

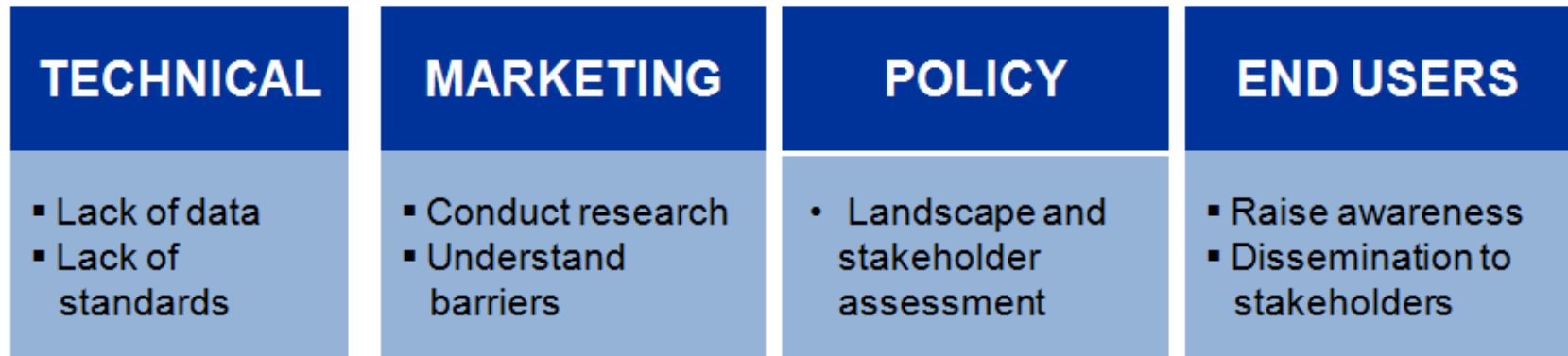
Cool Roofs in Europe

■ **Main objective: the implementation of an Action Plan for the promotion, market transformation and changing behavior towards cool materials technology in the European Union.**



Cool Roofs project : <http://www.coolroofs-eu.eu/>

The Cool Roofs project



Management – University of Athens

EU COOL ROOFS COUNCIL

- gather all interested target groups
- exchange of knowledge in technological developments and market penetration
- understand existing market, trends, dynamics to transform it
- promote EU technical standards
- explore policy & legislation in view of integrating cool roofs
- disseminate information to stakeholders

The European Cool Roofs Council



- The ECRC foundation meeting has been held in London, on Feb. 2009 with 29 participants, 4 more meetings took place until March 2011.
- Contacts with the U.S. Cool Roof rating council and other related institutions have been made and their experience is being transferred.
- The important participation and support from the European industry underlines the great interest in Cool Roofs technology and has led to the legal establishment of the ECRC as an international non profit organisation based in Brussels with 17 founding members.
- The main aim of the ECRC is to develop scientific knowledge and research in relation to cool roof technology and to promote the use of cool roof products in Europe, including developing a product rating program.

European Cool Roofs Council network

Research/ Education:

■ NKUA

■ ENEA

■ TUC

■ UBRUN

■ ULR

■ ITC-CNR

■ UPC Barcelona

■ LBNL

■ Concordia Un.

■ Cyprus Institute

■ Sonnergy

■ Perkin Elmer

■ Sapienza
University

■ INIVE

■ BRE

■ BBRI

End users:

■ Municipality of
Kessariani

■ Provincia di Trapani

■ Greater London
Authority

Policy:

■ ACG

Market:

■ ABOLIN

■ ECOBIOS

■ DAIKIN Industries

■ Daikin Chemical
Europe

■ HUNTSMAN

■ BASF

■ Akzo Nobel

■ SOPREMA

■ Bioni CS GmbH

■ ECCA

■ Hambleside Danelaw Ltd

■ Superior Products Europe

■ Monier

■ Beckers Industrial
Coatings

■ ArKema Fluorochemicals

■ Druckfarben

■ Materis paints

■ Zolpan

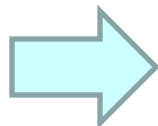
■ Arcelormittal

■ IMPERBEL/ DERBIGUM

■ DOW

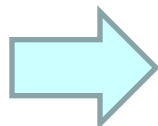
European Cool Roofs Council committees

Legal &
organizational
Committee



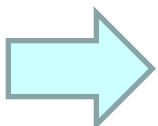
**Establish ECRC as a legal entity,
administrative issues**

Technical &
Documentation
Committee



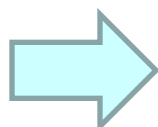
**Compile information on cool roofs
technology to demonstrate benefits
Define cool roofing material (testing
procedures and standards)**

Marketing &
policy
Committee



**Outline a plan to promote CR to markets
and decision makers**

Membership &
Outreach
Committee



**Dissemination to stakeholders, boost
memberships**

The EU Cool Roofs database

Name of the product	Manufacturer	Country	Type of product	Colour	Roof slope	Substrate	SR (%)	IE (-)	ST (°C)	SRI (-)
DERBIBRITE NT	DERBIGUM	Belgium	membrane	white	flat and steep slope	cement, concrete, tiles, plaster, wood, metal	81	0,81	44,6	100
R-NOVA	SOPREMA	France	paint	White	flat and steep slope	cement, concrete, tiles, plaster, wood, metal	88	0,89	40,3	111
SOPRASTAR	SOPREMA	France	Membrane	White	flat and steep slope	cement, concrete, tiles, plaster, wood, metal	78	0,89	45,8	97
SOPRASTAR S	SOPREMA	France	Membrane	White	flat and steep slope	cement, concrete, tiles, plaster, wood, metal	78	0,89	45,8	97
Revsun antioo	Zolpan	France	WB anticorrosive coating	White	Flat and steep sloped roofs	Metallio clads, metal roof panels, corrugated panels, concrete, bitumen roofing	73	0,89	48,4	90
Revsun antioo	Zolpan	France	WB anticorrosive coating	Sand RAL 1015	Flat and steep sloped roofs	Metallio clads, metal roof panels, corrugated panels, concrete, bitumen roofing	64	0,93	52,8	78
Revsun antioo	Zolpan	France	WB anticorrosive coating	Grey RAL 7035	Flat and steep sloped roofs	Metallio clads, metal roof panels, corrugated panels, concrete, bitumen roofing	51	0,92	59,6	60
Revsun mempur	Zolpan	France	SB liquid waterproofing coating	White	Flat roofs	Concrete, bitumen roofing, shingles, metal roof panels, wood composite	82	0,92	43,4	103
Revsun metal	Zolpan	France	WB antirust paint	White	Flat and steep sloped roofs	Metallio clads, metal roof panels, corrugated panels, concrete, bitumen roofing	76	0,88	46,9	94
Revsun metal	Zolpan	France	WB antirust paint	Sand RAL 1015	Flat and steep sloped roofs	Metallio clads, metal roof panels, corrugated panels, concrete, bitumen roofing	63	0,91	53,5	76
Revsun metal	Zolpan	France	WB antirust paint	Grey RAL 7035	Flat and steep sloped roofs	Metallio clads, metal roof panels, corrugated panels, concrete, bitumen roofing	50	0,9	60,4	58
Revsun roofing	Zolpan	France	WB liquid waterproofing coating	White	Flat and low sloped roofs	Concrete, bitumen roofing, shingles, metal roof panels, wood composite	70	0,91	49,9	86
Revsun roofing	Zolpan	France	WB liquid waterproofing coating	Sand RAL 1015	Flat and low sloped roofs	Concrete, bitumen roofing, shingles, metal roof panels, wood composite	62	0,92	54	75
Revsun roofing	Zolpan	France	WB liquid waterproofing coating	Grey RAL 7035	Flat and low sloped roofs	Concrete, bitumen roofing, shingles, metal roof panels, wood composite	50	0,92	60,1	59
Woryl 284 Reflect Finish	Westwood KUNSTSTOFFTECHNIK GmbH	Germany	coating	white	flat roof	cement, concrete, tiles, plaster, asphalt, PVC, FPO	90	0,89	39,2	114

- >200 products (initial version 100)
- mentioned in the US CRRC website
- List of European labs able to perform cool roof measurements

- 5 case studies: maximum geographical and building typology coverage
- 10-40% energy savings & 1.5-2°C reduction of the indoor temperatures, depending on the climatic conditions.



► Office building –London, UK



► Collective dwelling –Poitiers, France



► Public building –Trapani, Italy



► School building –Athens, Greece



► Lab building –Heraklion, Greece



The Cool Roofs toolkit

Calculator of energy savings (cooling-heating) for low-slope roofs (relative to a "black" roof)

Input data	Output data
Country <input type="text" value="Hellas"/>	<div style="border: 1px solid black; padding: 5px; display: inline-block;"> Calculate annual savings relative to black roof </div>
City <input type="text" value="Herakleion"/>	
Roof	
R-value (high=3.5; avg=1.5; low=0.5) <input type="text" value="2"/> K.m²/W	Net savings <input type="text" value="4.631"/> €/m² per year
Solar reflectance, SR (high=80; avg=50; low=10) <input type="text" value="80"/> %	Cooling savings <input type="text" value="11.3619"/> €/m² per year
Infrared emission, IE (high=90; avg=60; low=10) <input type="text" value="90"/> %	Heating savings (heating penalty if negative) <input type="text" value="-6.7306"/> €/m² per year
Energy costs and equipment efficiencies (visit Europe's Energy portal for help)	Insulation in black roof to yield same annual energy savings: Upgrade from R- <input type="text" value="2"/> to R- <input type="text" value="6.7"/> K.m²/W
Summertime cost of electricity (high=0.30; medium=0.15; low=0.08) <input type="text" value="0.1"/> €/KWh	Details of comparison
Air conditioner efficiency (cooling COP) (high=4; avg=3; low=1.5) <input type="text" value="3"/>	
Energy source for heating (choose one) <input checked="" type="radio"/> Electricity <input type="radio"/> Fuel	
If electricity, wintertime cost (high=0.30; avg=0.15; low=0.08) <input type="text" value="0.1"/> €/KWh	
If fuel, cost (Natural gas: high=0.15; avg=0.09; low=0.03) <input type="text"/> €/Kwh	
Heating system efficiency (heating COP) (Furnace or boiler: high=0.8; avg=0.7; low=0.5) (Electric heat pump: high=2; avg=1.5) (Electric resistance: 1) <input type="text" value="1"/>	
	Heating degree days for location chosen <input type="text" value="1188.6"/> annual °C-day
	Cooling degree days for location chosen <input type="text" value="715.98"/> annual °C-day
	Solar load for location chosen <input type="text" value="4.21"/> annual average kWh/m² per day
	Cooling load for black roof (SR=5%; IE=90%) <input type="text" value="15.24"/> kWh/m² per year
	Heating load for black roof (SR=5%; IE=90%) <input type="text" value="13.65"/> kWh/m² per year
	Cooling load for proposed roof <input type="text" value="3.61"/> kWh/m² per year
	Heating load for proposed roof <input type="text" value="15.95"/> kWh/m² per year

- Developed in the framework of EC's "CoolRoof" project.

- The accuracy of this calculator depends on the supplied data. [CLICK HERE](#) to get *help* in figuring out the best input values.

- The model used for estimating savings is adapted from the paper of Petric et al., "Effect of solar radiation control on energy costs - A radiation control fact sheet for low slope roofs", Proceedings, *Performance of the exterior envelopes of whole buildings VIII. Integration of Building envelopes*, Atlanta, December 2001, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

The Cool Roofs handbook



COOL ROOFS

PROMOTION OF COOL ROOFS IN THE EU

Contract N°: EIE/07/475/SI2.499428

WP3: Technical aspect of cool roofs

Technical Guidelines Handbook

DRAFT 2

Edited by:

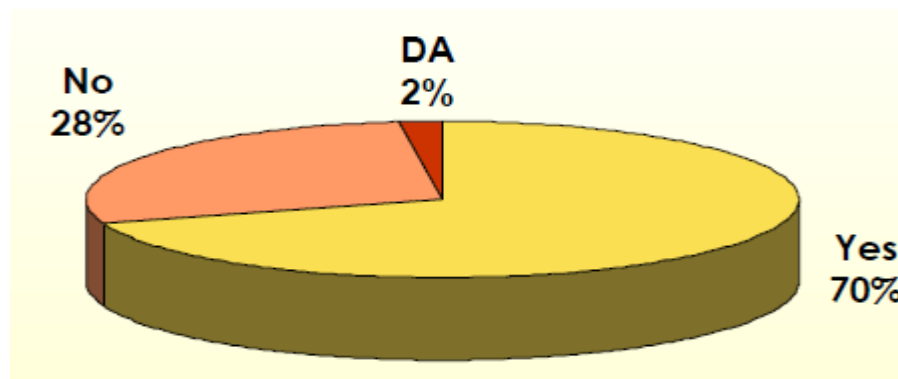
Maria Kolokotroni, Brunel University

Forward.....	4
Chapter 1: Cool Roofs characteristics	5
1.1 Introduction	5
1.2. Definition of cool roofs	10
1.3 Benefits of cool roofs or why cool roofs are important.....	14
Chapter 2: Cool roof materials.....	16
2.1 Introduction	16
2.2 Main product features	17
2.3 Cool roof materials	21
2.4 The EU cool roof materials' database	25
Chapter 3: Case-study buildings	31
3.1 Introduction	31
3.2 Building 1: School building in Kaisariani, Athens, Greece	33
3.3 Building 2: 3.2.2 Laboratory building in Iraklion, Crete, Greece	38
3.4 Building 3: Public building in Trapani, Italy	42
3.5 Building 4: Le Parvis : Collective Dwellings, Poitiers, France.....	48
3.6 Building 5: Office at Brunel University, Uxbridge, West London, UK.....	53
Chapter 4: EU COOL ROOFS TOOLKIT.....	58
4.1 Introduction	58
4.2 On-line calculators.....	59
4.3 On-line implementations.....	60
4.4 The EU-Cool Roofs toolkit.....	67
Chapter 5: Market Research and EU Policies.....	77
5. 1 Introduction.....	77
5. 3 Existing Policies in EU related to Cool Roofs.....	87
5.4 Cool Roofs Policy landscape assessment and EU.....	89
5. 5 Qualitative Survey Results on CR products perception in EU.....	94
5. 6 Quantitative Survey Results on CR products in EU.....	97
5. 7 Conclusions.....	100
List of References.....	101
Appendix 1- Glossary (electronic version only).....	105
Appendix 2: Materials Database (electronic version only)	105

Cool Roofs market survey

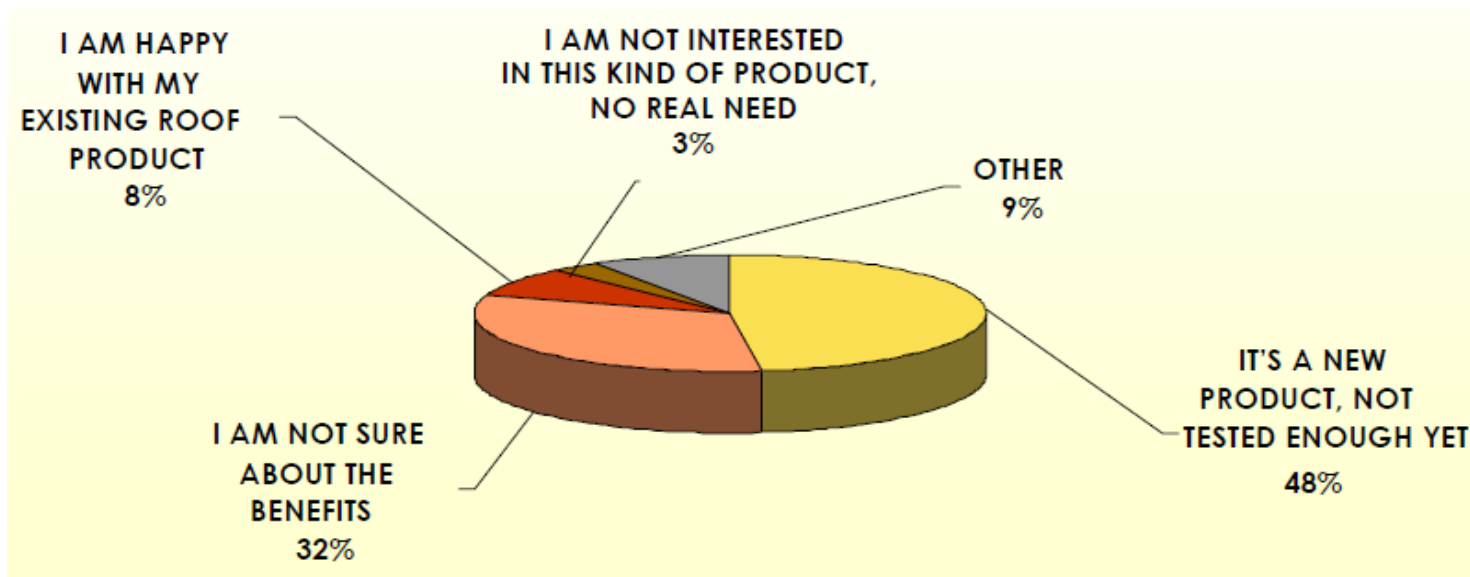
- EU Cool roofs market survey was based on interviews of major stakeholders in the field and on an on line survey – 519 questionnaires analysed
- 18 questions on a) current status, b) potential marketing c) Quality Certification, d) communication and promotion e) distribution & market channeling

The majority of the key market players claim to be aware of the cool roof technology (70%), but not all that familiar with the term “cool roofs” (57% unaware of it).

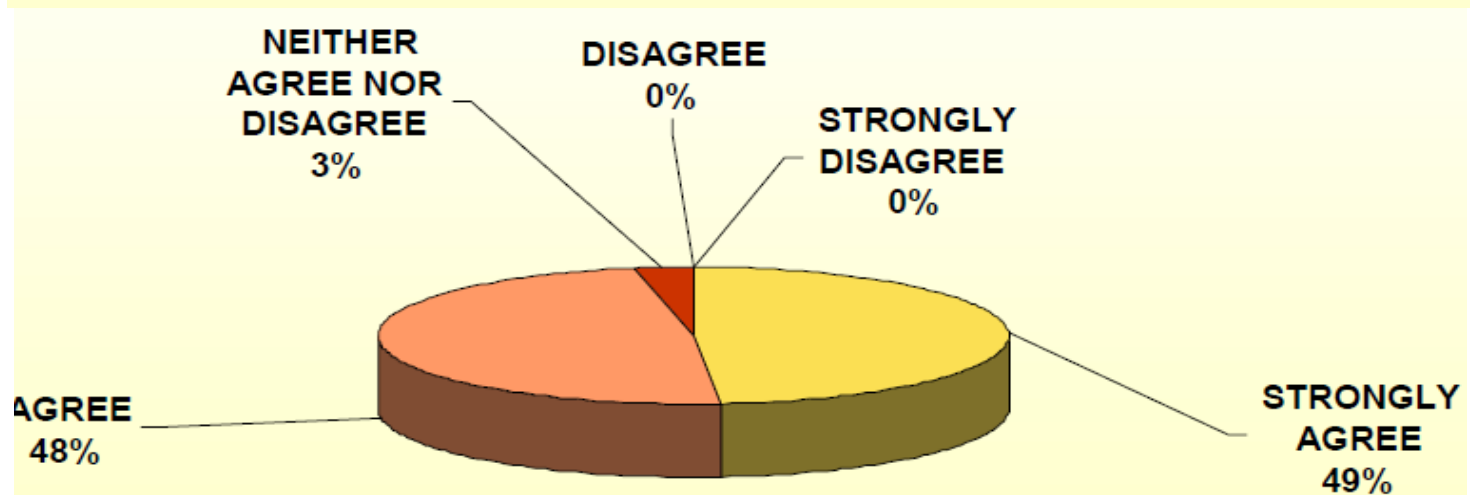


Cool Roofs market survey

Main barrier



“QUALITY CERTIFICATION” is a must



Cool Roof policies and programs

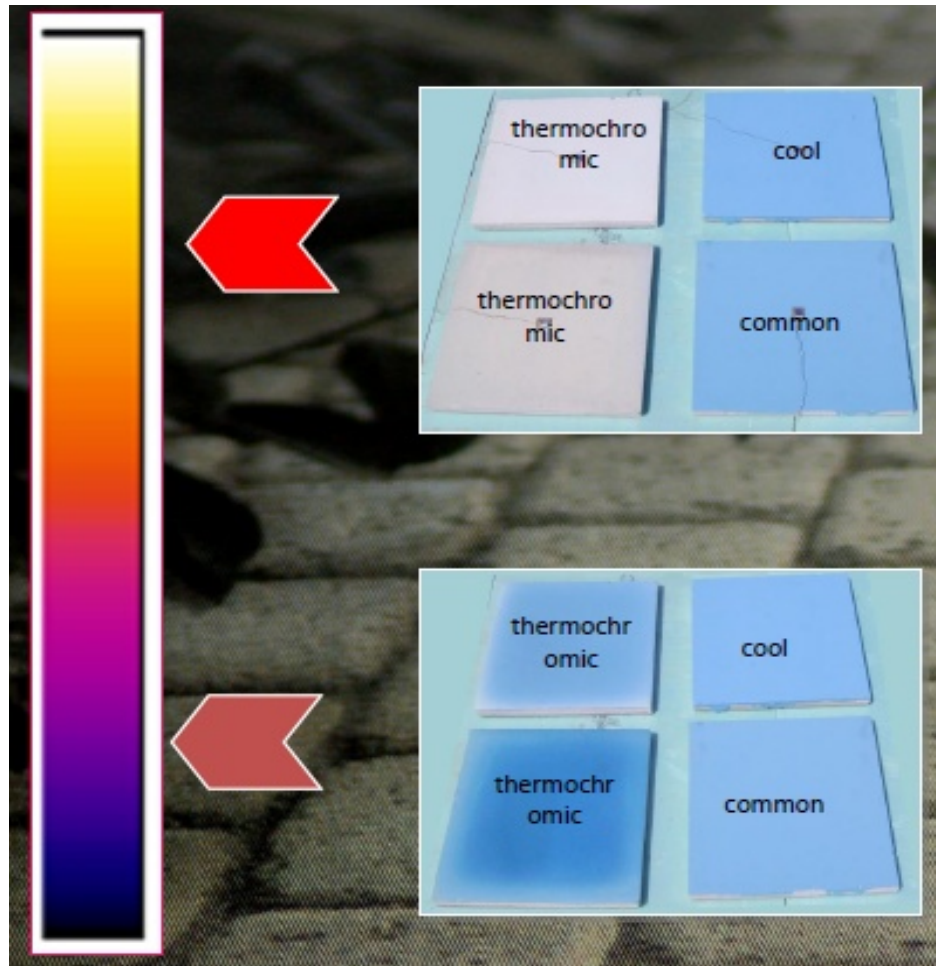
- ◆ In Italy and Greece there are directives promoting the use of cool materials as energy efficiency measures.
- ◆ In Greece a program called “Building the future” has been announced and gives incentives for the application of 20,000 cool roofs on residential buildings as a means to improve their energy performance.
- ◆ In the UK (BREEAM) and Germany (German Sustainable Building Certificate) certification standards on ecological quality and sustainability include cool materials as a heat island mitigation strategy



BREEAM®

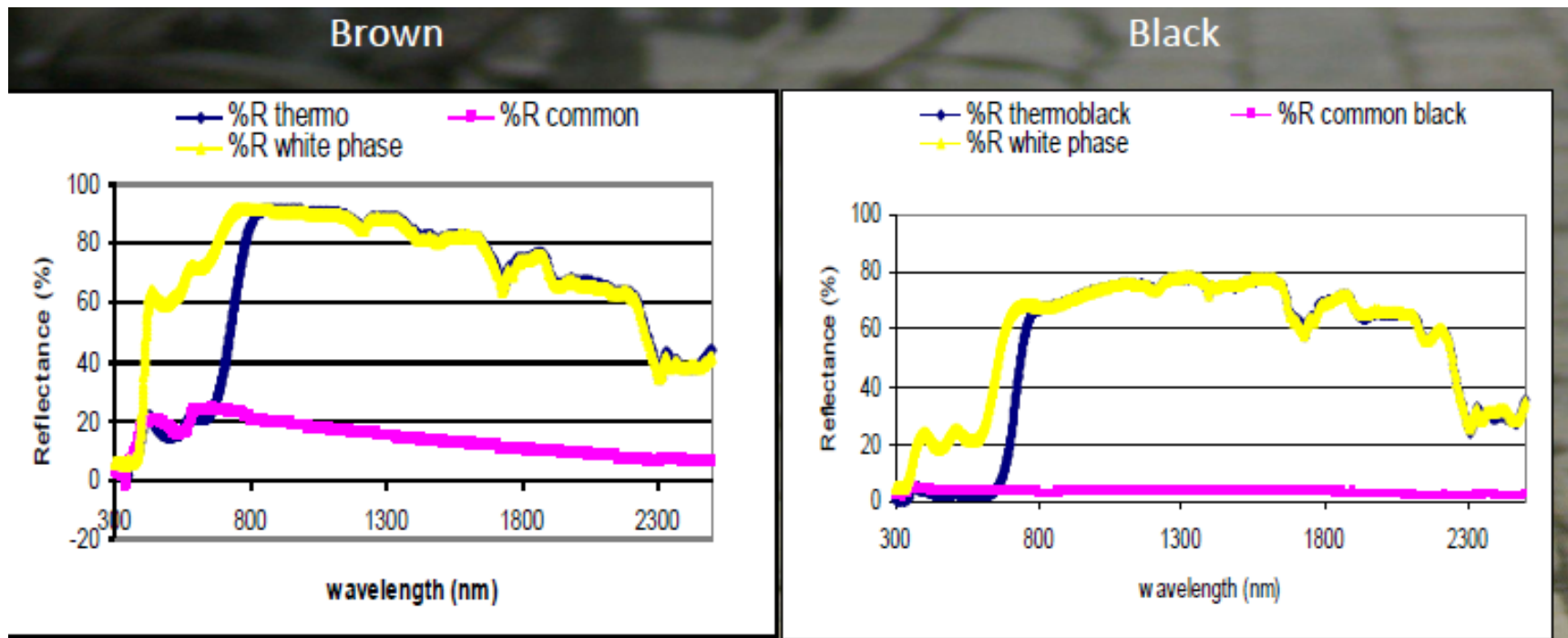


Development of thermochromic materials



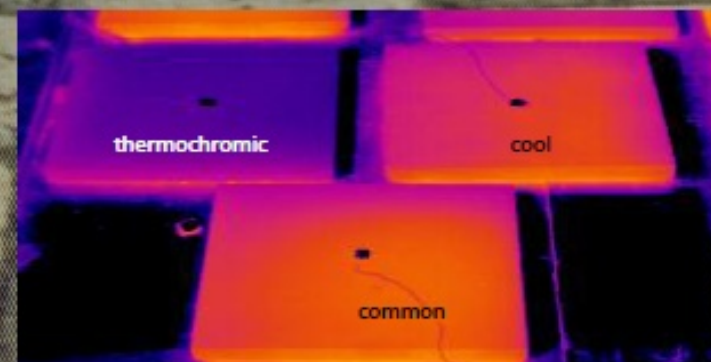
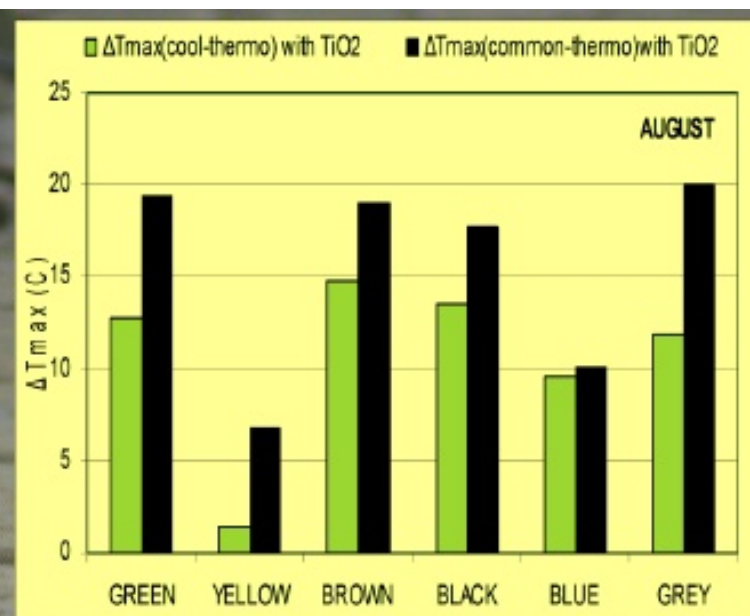
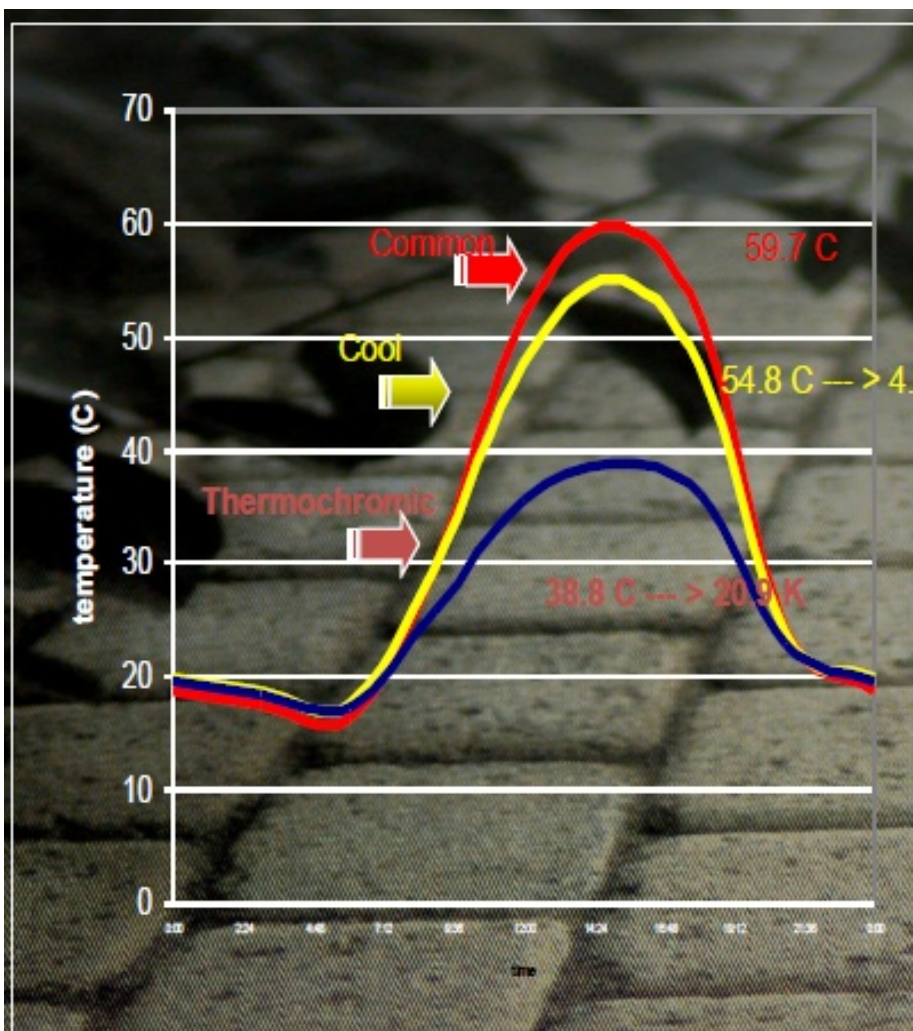
- **Thermochromic coatings change color as a function of the ambient temperature.**
- **When applied on roofs or walls it may present the best performance all year round.**

Development of thermochromic materials



- Thermochromic coatings present a high reflectivity both in the visible and infrared spectrum, while present very strong absorption in the near-ultraviolet range of the spectrum.

Development of thermochromic materials

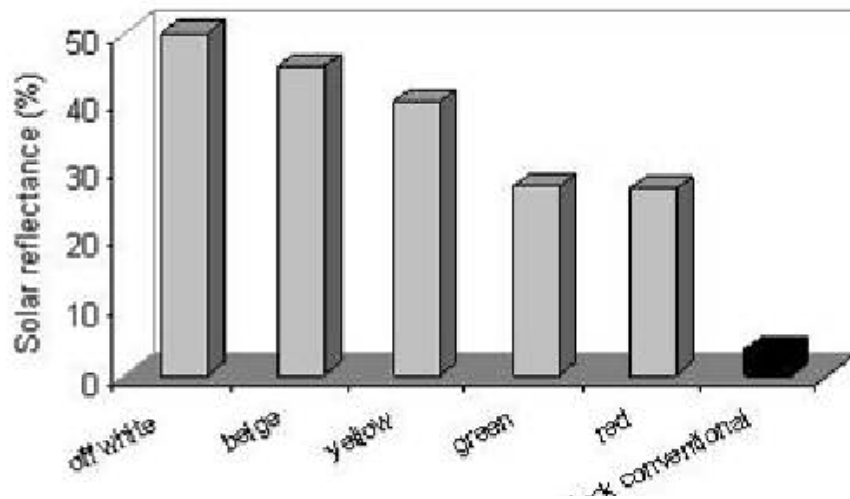


Development of cool asphalt materials

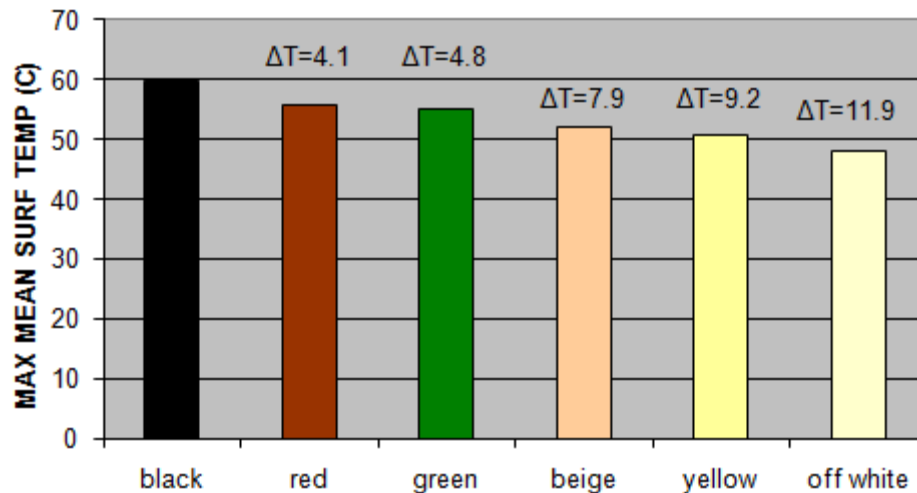


- **Cool Asphaltic materials have been developed and tested. The materials can replace conventional asphaltic materials and are available at different colors.**
- **The color thin layer asphalt samples were developed by mixing an elastomeric asphalt binder (colorless) and adding special pigments and aggregates of special sizes and colors.**

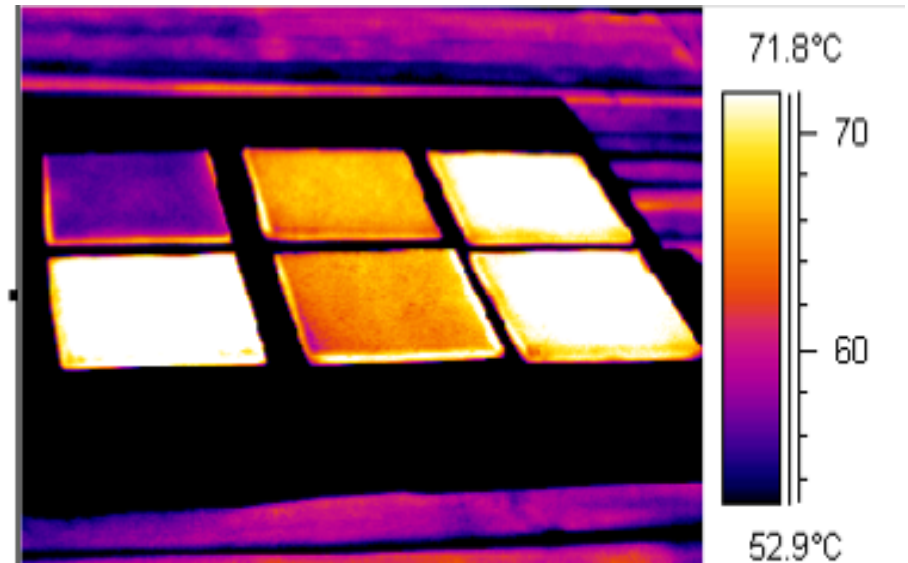
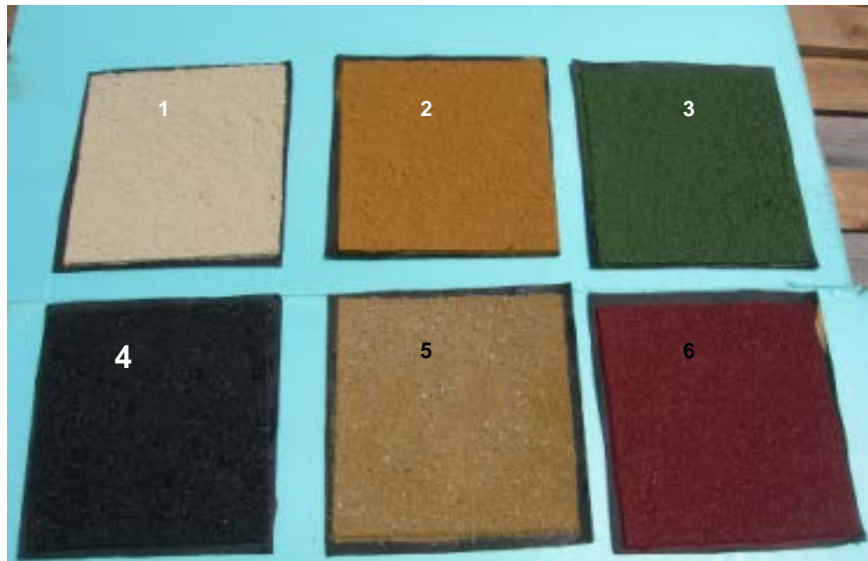
Development of cool asphalt materials



■ Cool Asphaltic materials present a much higher reflectivity and also a lower surface temperature compared to conventional asphalt materials..



Development of cool asphalt materials

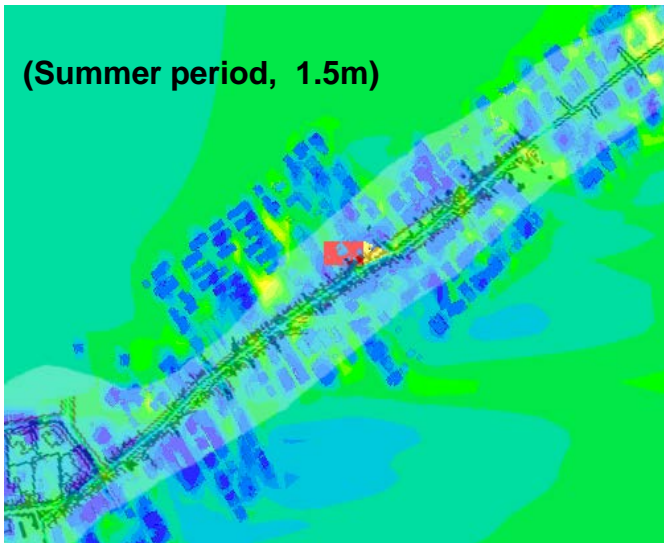


Development of cool asphalt materials

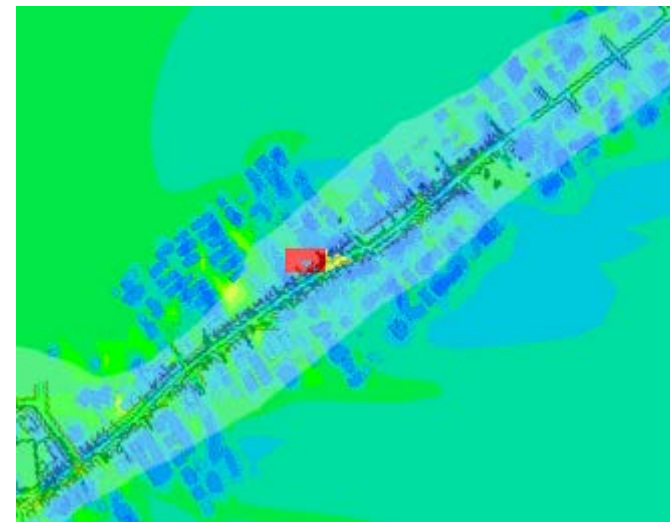


$\Delta T_{amb.} \cong 5C$

(Summer period, 1.5m)

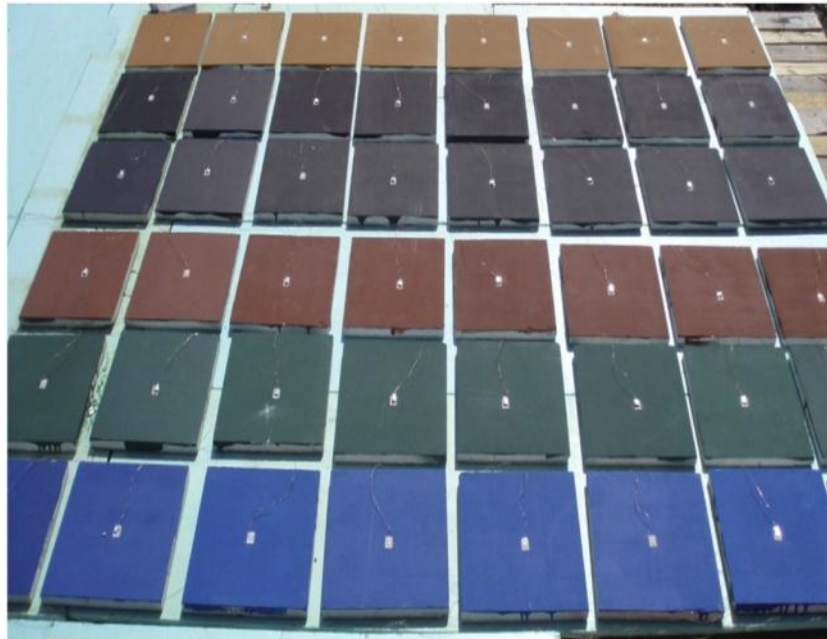


SR
=0.04



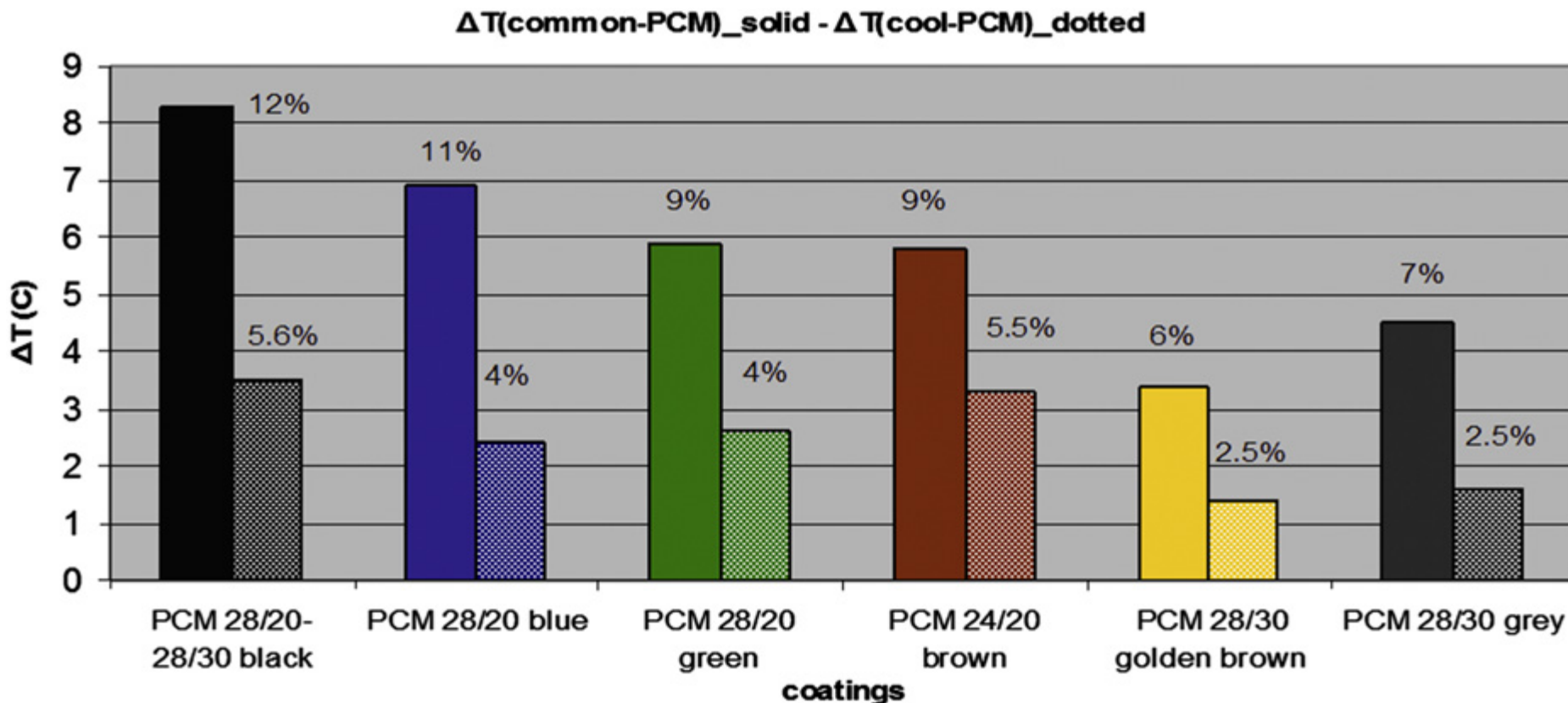
SR
=0.55

Using PCM to decrease T_s of cool colored materials



■ To further decrease the surface temperature of highly reflective colored coating phase change microcapsules containing parafins, (phase change $T = 18, 24, 28$ C), have been incorporated in the cool coatings. Microcapsules have a diameter of 17-20 μm and are protected externally by a polymeric material.

Using PCM to decrease Ts of cool colored materials



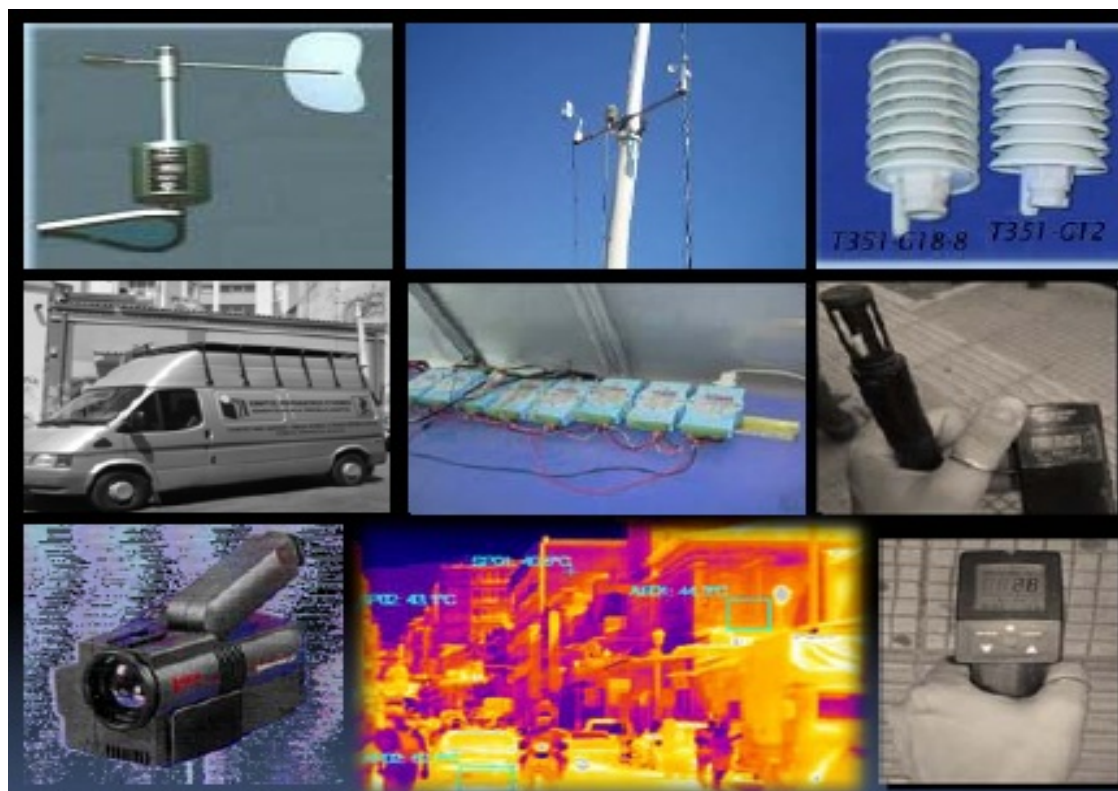
■ Compared to conventional coatings, PCM coatings present lower Ts up to 8C and to cool coatings, PCM coatings show lower Ts up to 3C

Application of CM in the urban environment



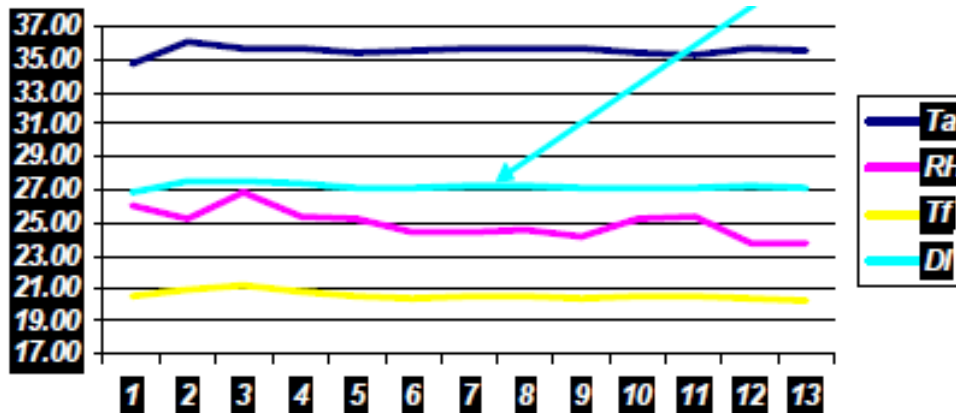
- **Improving the Microclimate in The Historical Center of Athens.**

Application of CM in the urban environment



- Ambient temperature
- Relative humidity
- Wind speed
- Surface temperature
- Infrared thermography

Application of CM in the urban environment

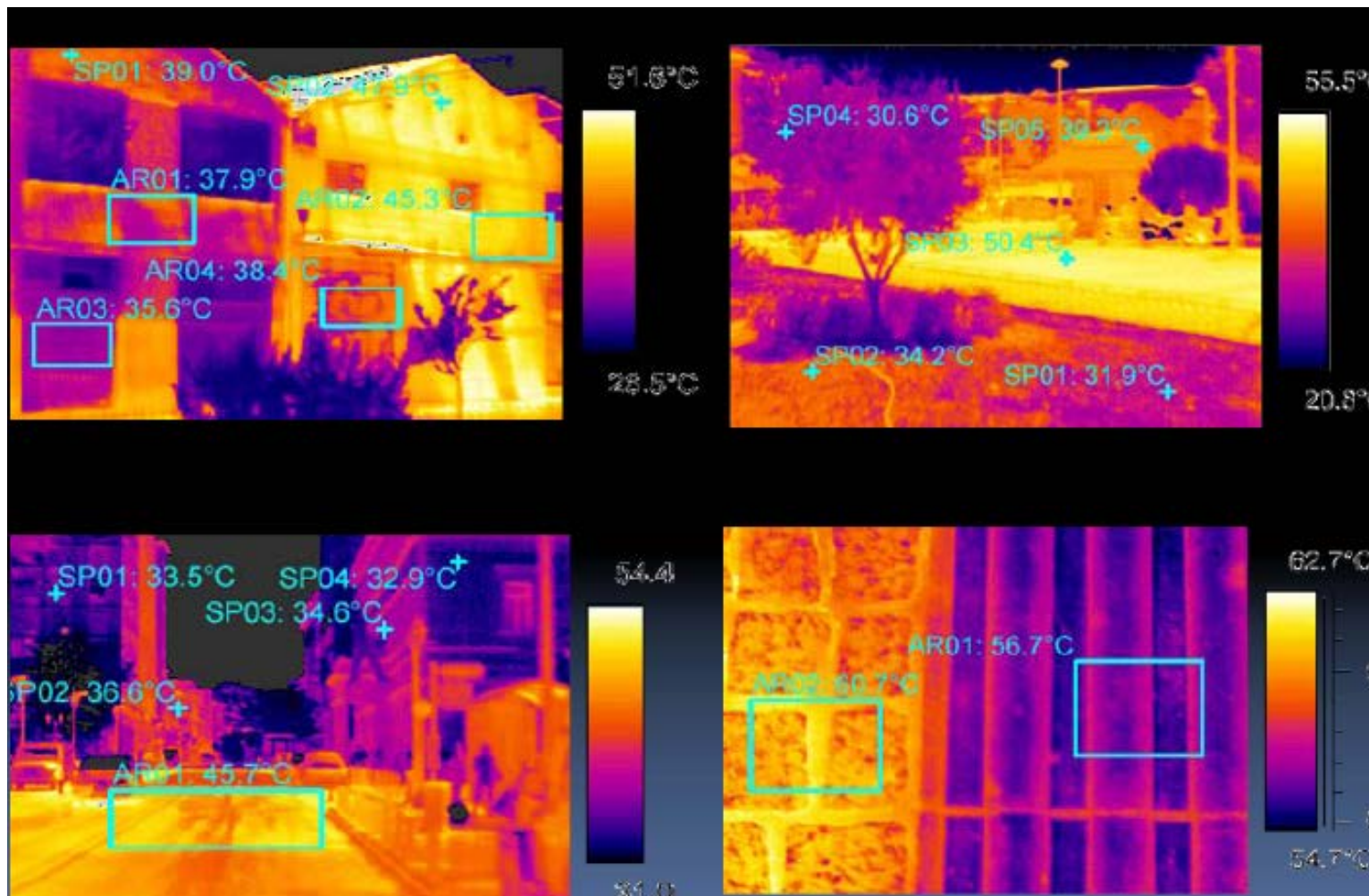


- **Microclimatic Parameters:**
 - High temperatures
 - Low wind speeds
 - Low relative humidity
- **Thermal Comfort: Thom's Discomfort index DI => more than half population feels discomfort**

Table 1. Classification of the DI values (Giles et al., 1990).

DI (°C)	Discomfort conditions
DI < 21	No discomfort
21 ≤ DI < 24	Less than 50% of the total population feels discomfort
24 ≤ DI < 27	More than 50% of the total population feels discomfort
27 ≤ DI < 29	Most of the population suffers discomfort
29 ≤ DI < 32	The discomfort is very strong and dangerous
DI ≥ 32	State of medical emergency

Application of CM in the urban environment

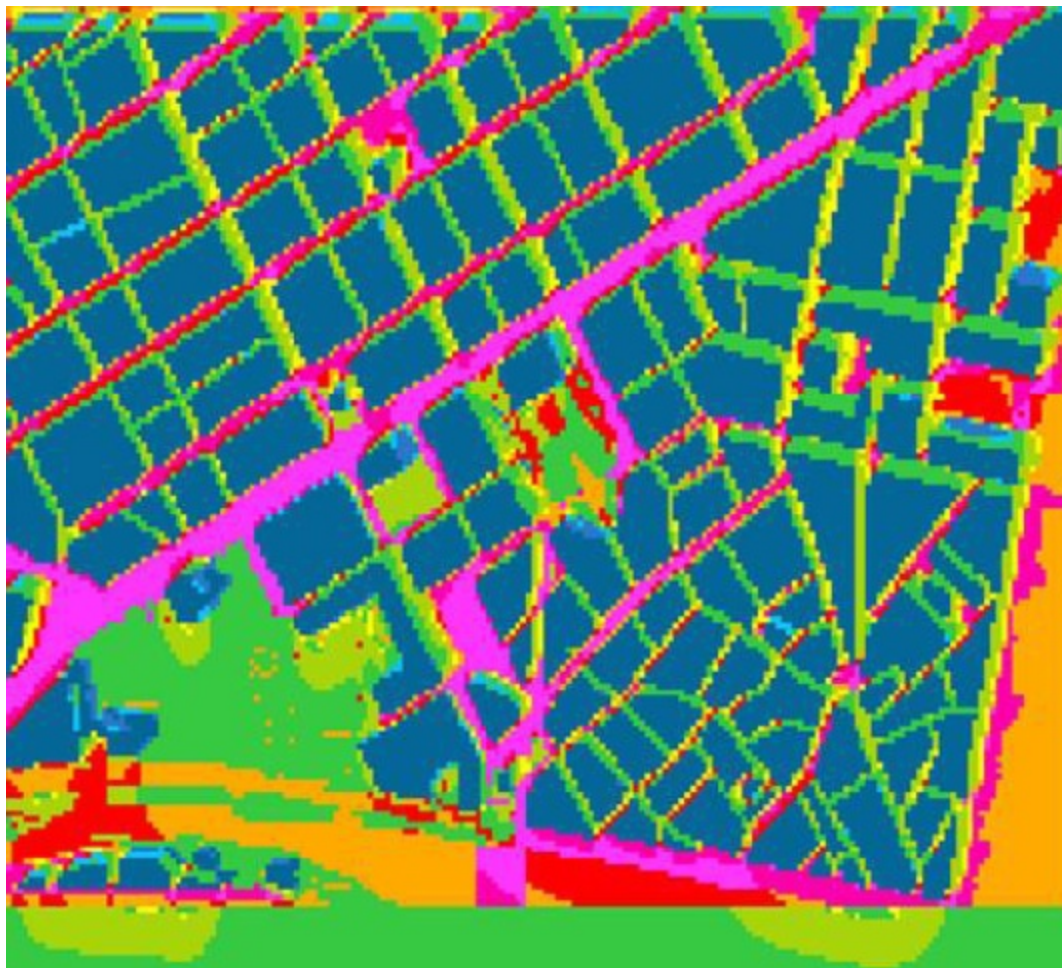


Application of CM in the urban environment



- The suggested interventions included:
 - A. Increase of vegetation, creation of green network in open spaces
 - B. Use of cool materials
 - C. Application of green roofs

Application of CM in the urban environment



- Existing situation – surface temperature

Application of CM in the urban environment



Application of CM in the urban environment



- **Air Temperature – Proposed Layout**
- T_{air} reduced by 2°C
- T_s reduced by 10°C
- Improvement in thermal comfort conditions



Obrigado pela sua atenção

Cool Roofs project: <http://www.coolroofs-eu.eu/>

EU Cool Roofs Council: <http://coolroofs-eu-crc.eu/>

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