SOLAR PROPERTIES OF SURFACES

performance parameters and their measurement, when new and after aging

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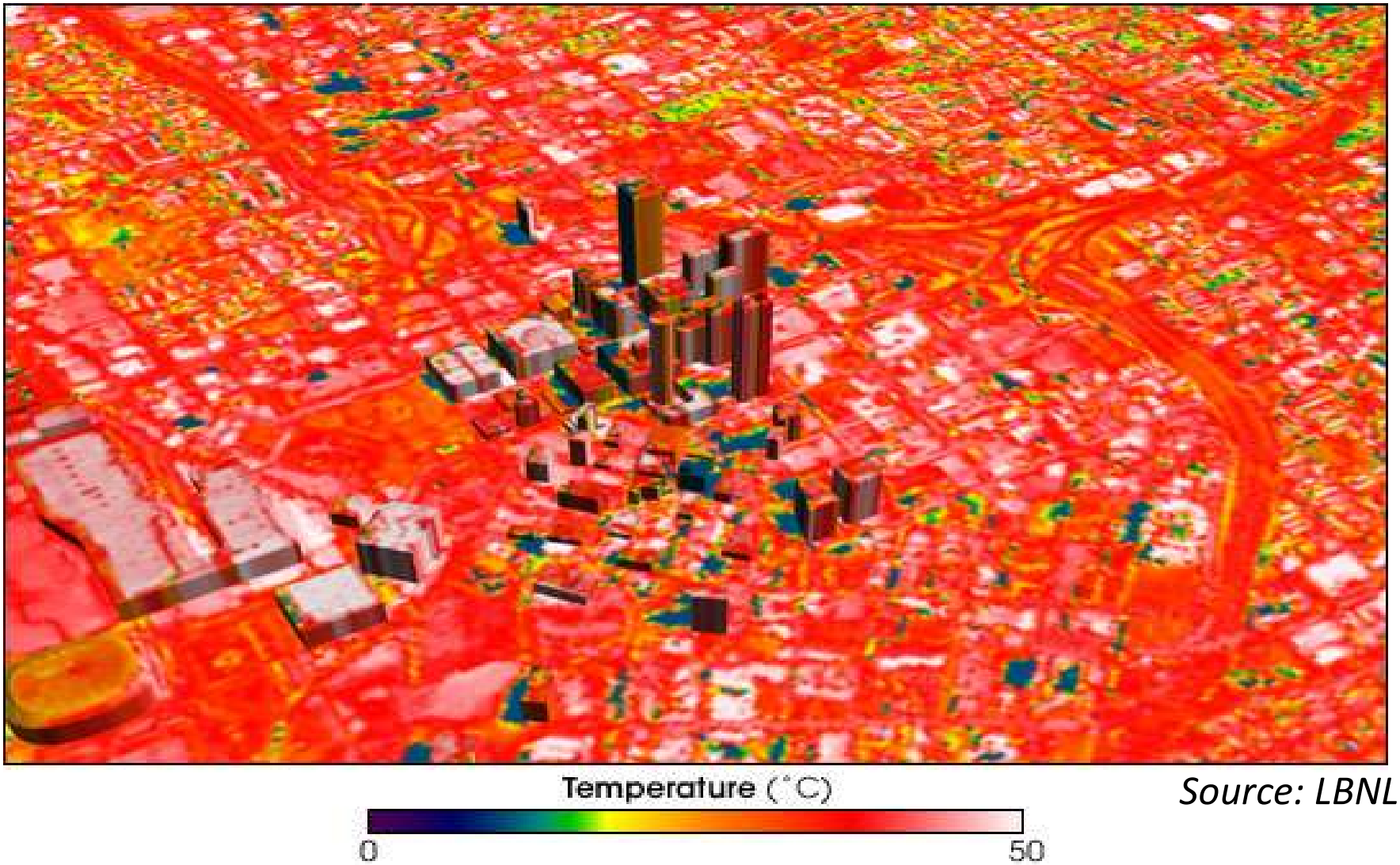
In collaborazione con INSTM – Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali (www.instm.it/)

Urbanization + Urban Heat Island + Global Warming



Source: LBNL

Humanity is gathering in cities that are a lot warmer than the surrounding world, which is itself warming up!

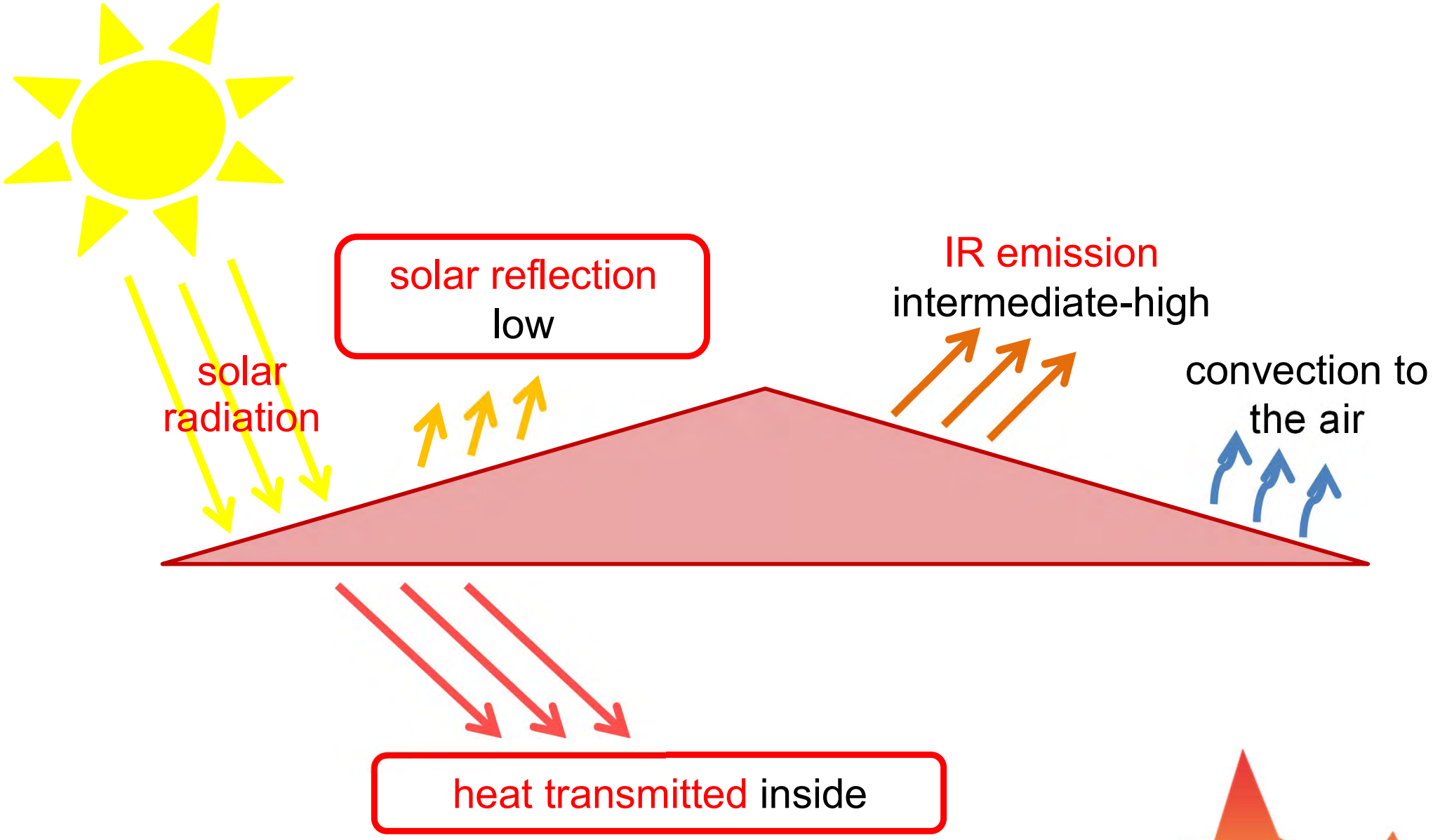
"Cool" solar-reflective materials: a clear countermeasure

"Cool" solar-reflective materials: definition

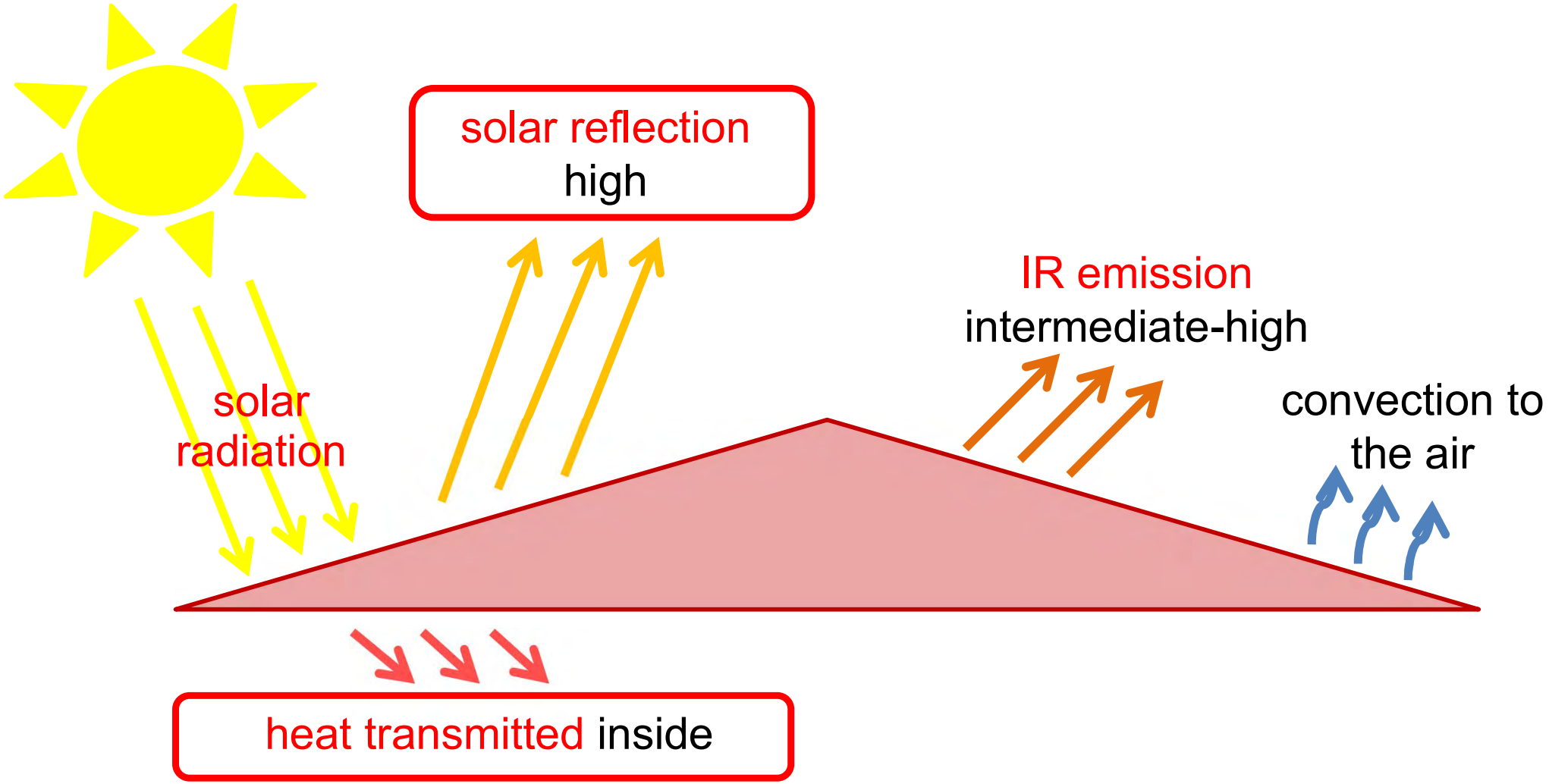
The technical terms "cool roof", "cool pavements", "cool materials" identify solutions that prevent either single buildings or whole urban areas to overheat thanks to:

- High capacity to reflect incident solar radiation ⇒ high solar reflectance, or albedo
- High capacity to return to the environment the (however) absorbed fraction of solar radiation thanks to infrared radiation ⇒ high thermal emittance or IR emittance
- Stability of such surface properties
- Low tendency to soiling because of pollution

Thermal balance of a roof



Thermal balance of a roof



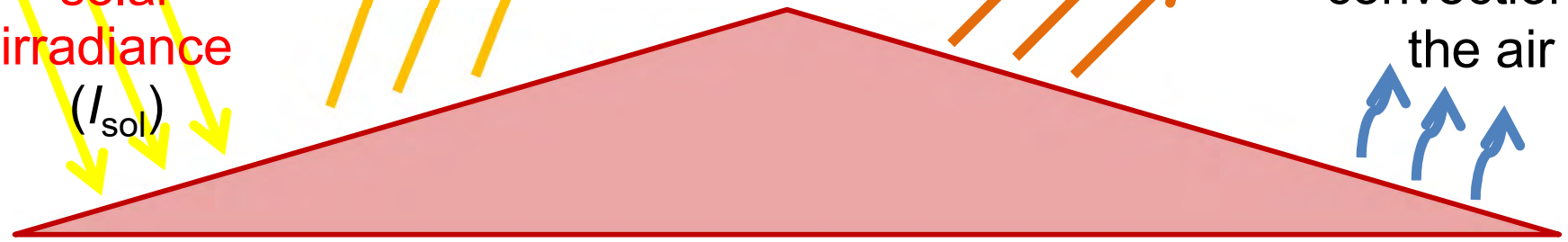
Thermal balance of a roof and surface properties

Solar Reflectance (albedo):
fraction of solar radiation
reflected by the surface

IR (thermal) Emittance:
capability of the surface to re-radiate
in the IR the absorbed heat

solar
irradiance
(I_{sol})

convection to
the air

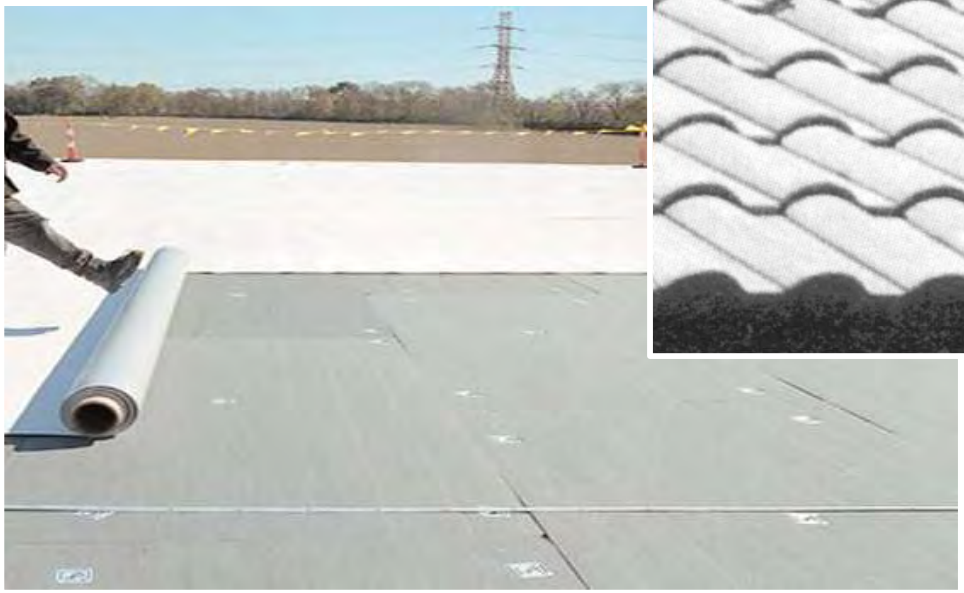


heat transmitted inside

(*with low-wind conditions,*
convection to the air is weak
and re-emission by IR radiation
may even be dominant)

History has taught something

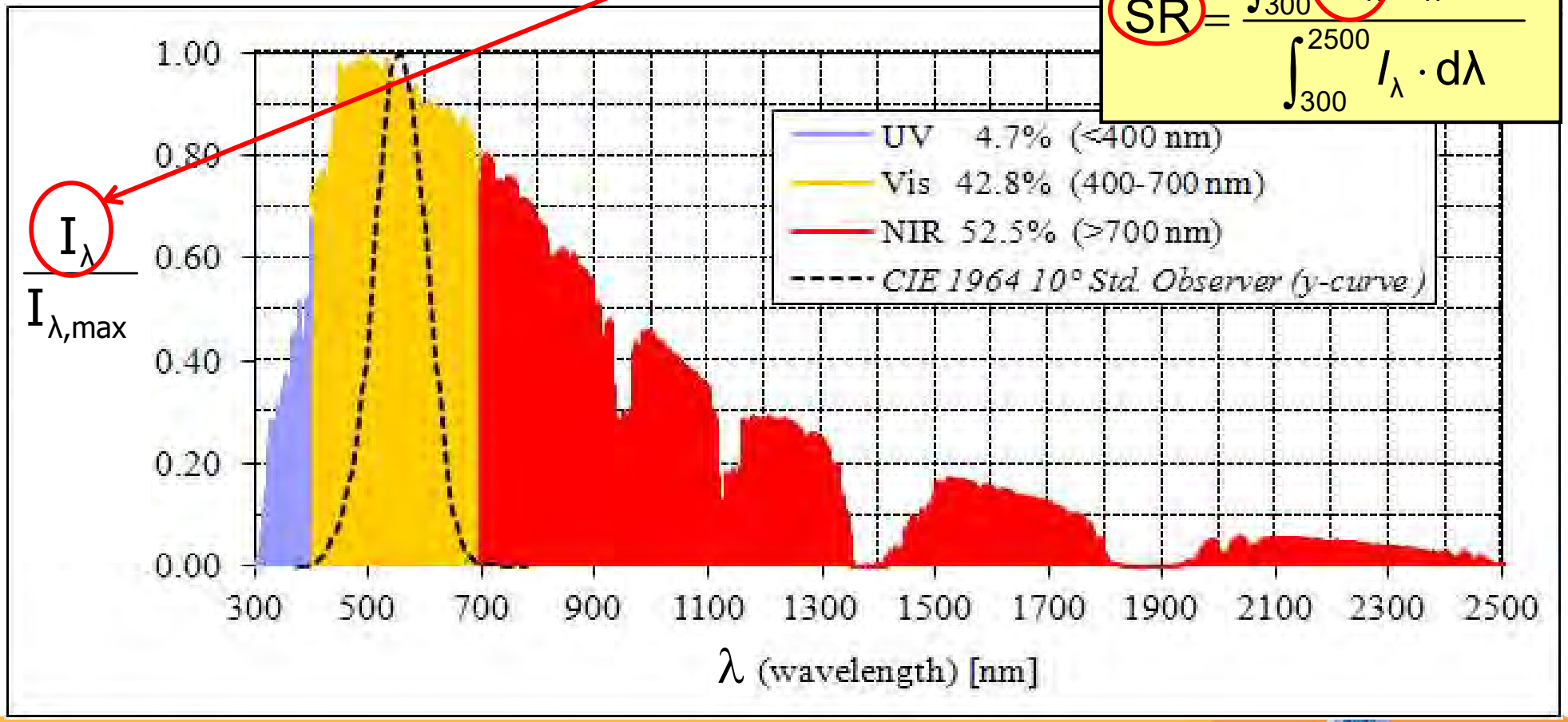
But we have gone beyond: “cool” white materials”



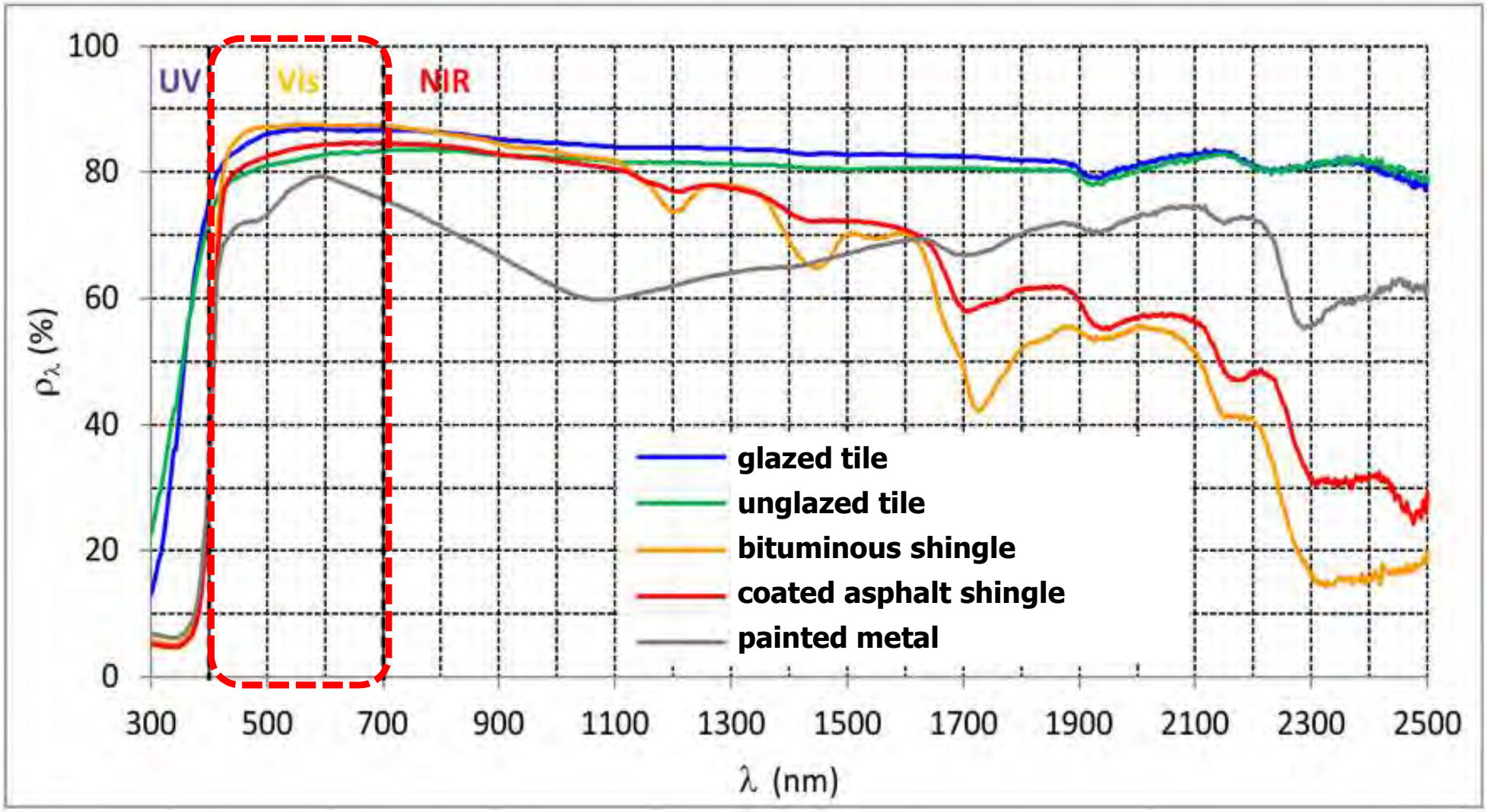
Measurement of solar reflectance (albedo) SR

It can be evaluated by integrating the spectrum of reflectivity (ρ_λ) measured over the range relevant to solar radiation (300-2500 nm), weighed by the solar spectral irradiance (I_λ).

$$SR = \frac{\int_{300}^{2500} \rho_\lambda \cdot I_\lambda \cdot d\lambda}{\int_{300}^{2500} I_\lambda \cdot d\lambda}$$

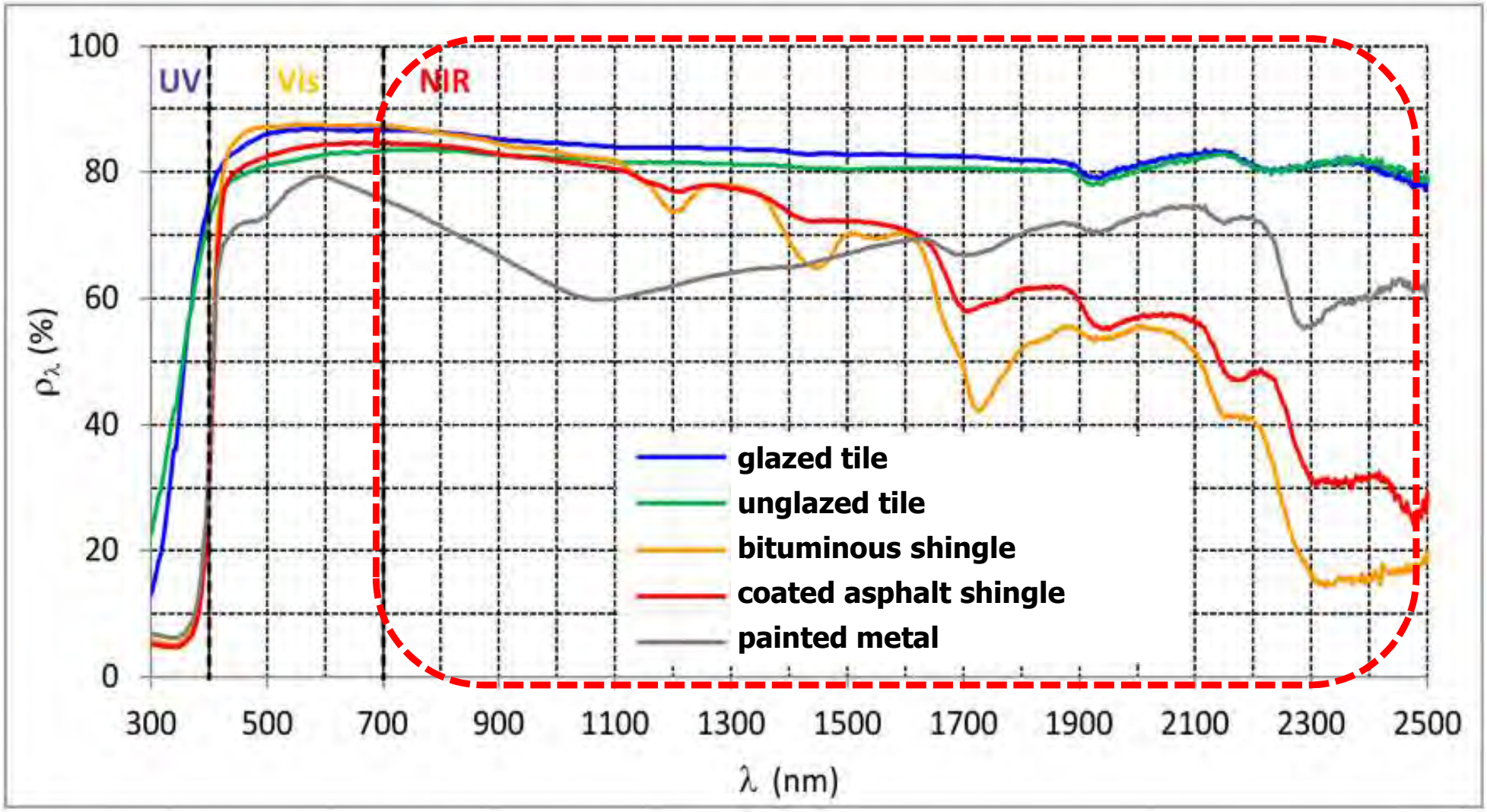


Reflectivity spectrum of "cool" white materials: Visible



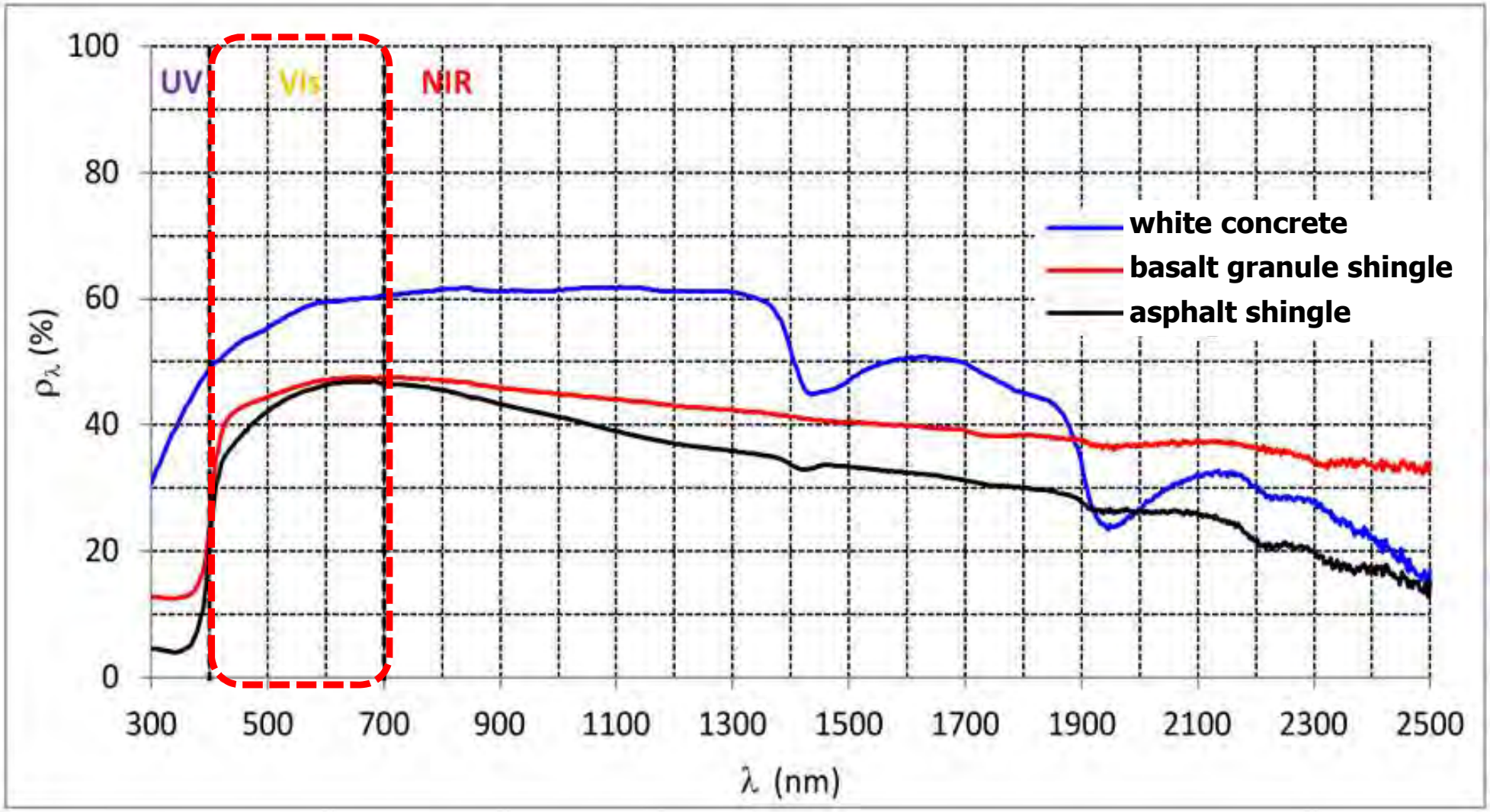
(selection of "cool" commercial materials with white color)

Reflectivity spectrum of "cool" white materials: Near IR



(selection of "cool" commercial materials with white color)

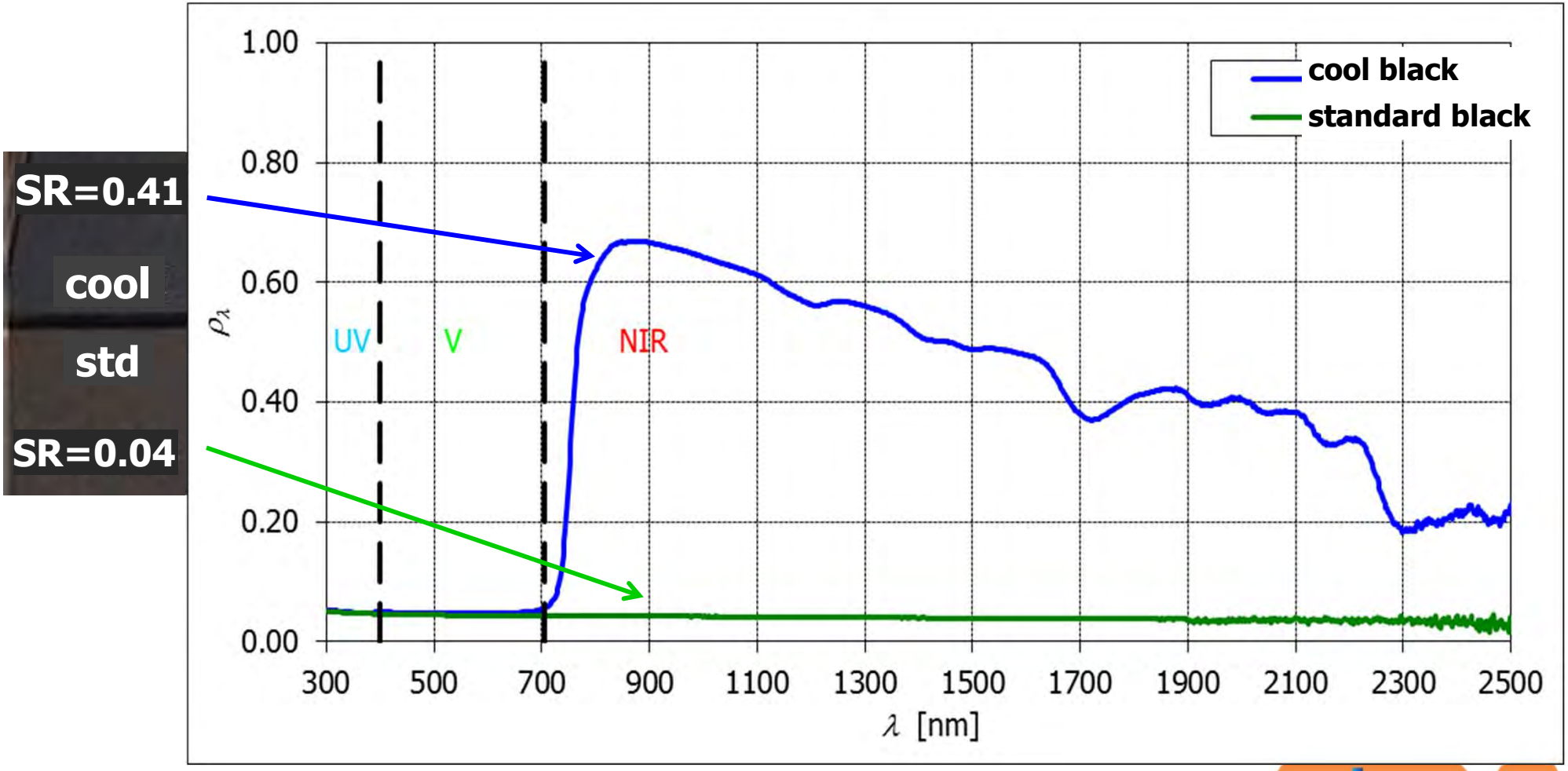
Reflectivity spectrum of "just" white materials



(selection of common commercial materials with white color)

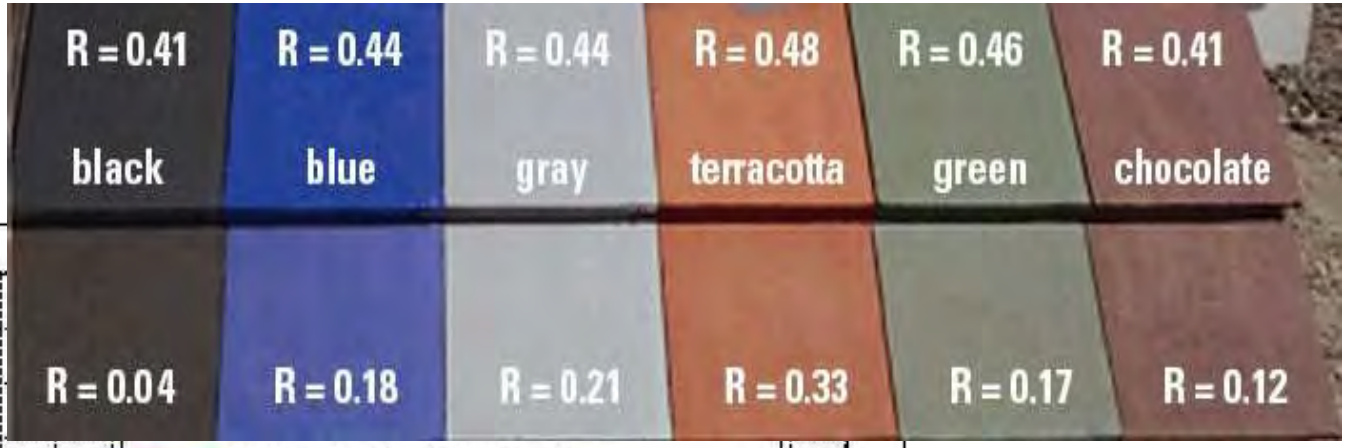
Materials with selective reflectivity

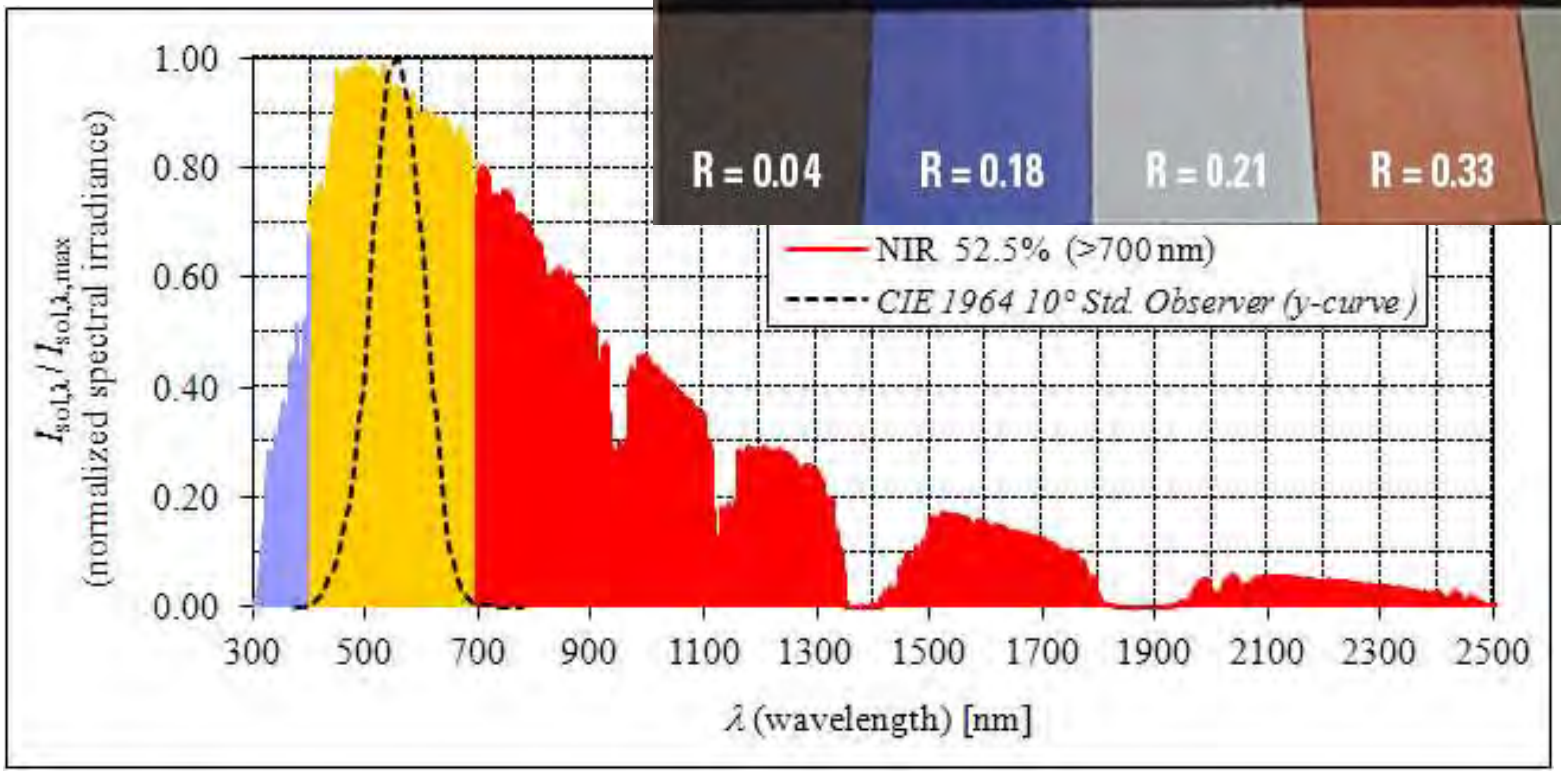
Materials with similar visible color (*e.g.* black) may show very different reflectivity spectra in the near infrared and, therefore, very different reflectance.



Cool colors

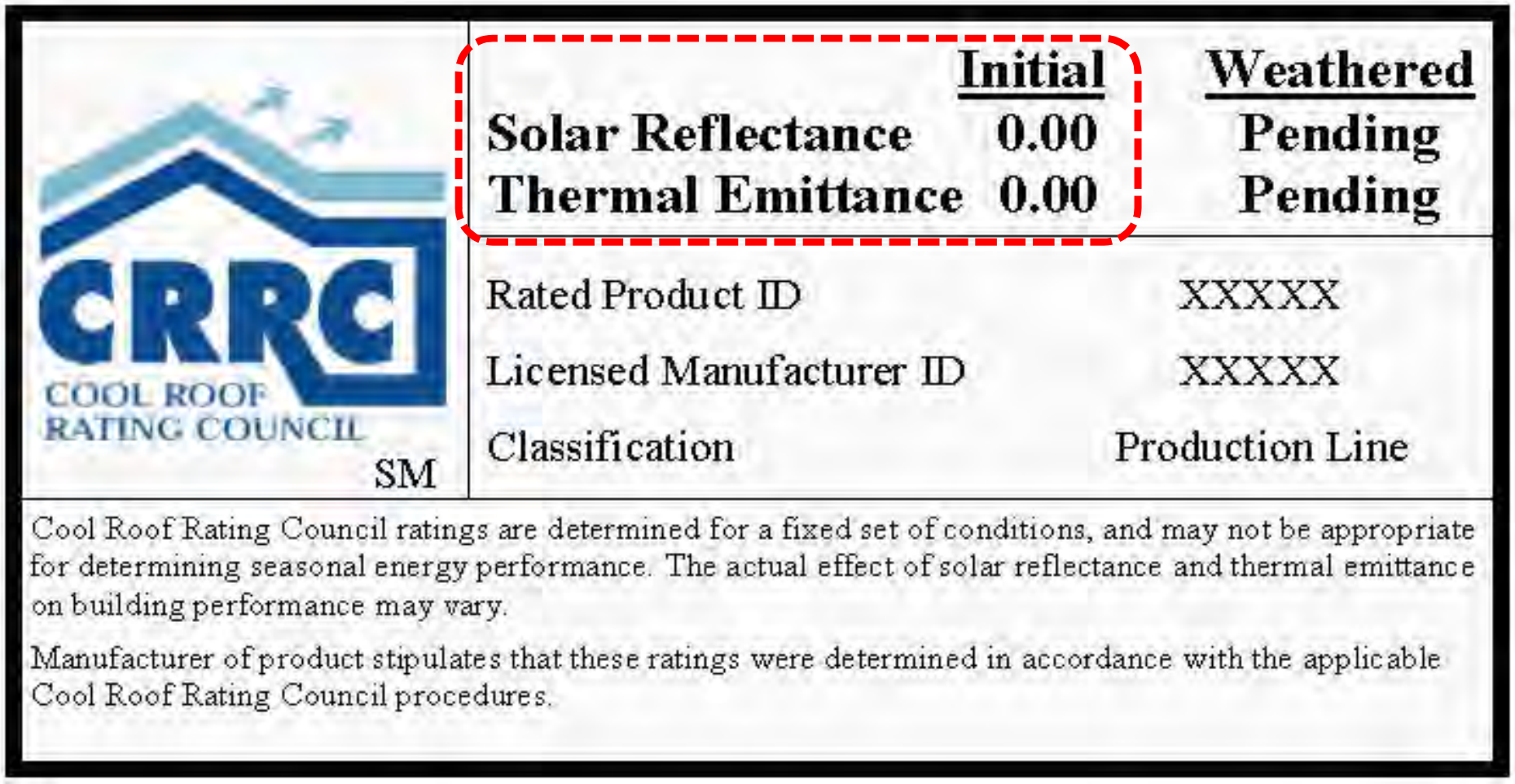
They have the same reflectivity spectrum in the visible range and, therefore, the same color of standard materials, but a high reflectivity in the near infrared and, with that, a higher solar reflectance.





Saying "white" or "clear" is not enough

The solar reflectance must be measured according to standard methods!
In the U.S. the measured reflectance can be certified since 1998.



	Initial	Weathered
Solar Reflectance	0.00	Pending
Thermal Emittance	0.00	Pending
Rated Product ID		XXXXX
Licensed Manufacturer ID		XXXXX
Classification		Production Line

CRRC COOL ROOF RATING COUNCIL SM

Cool Roof Rating Council ratings are determined for a fixed set of conditions, and may not be appropriate for determining seasonal energy performance. The actual effect of solar reflectance and thermal emittance on building performance may vary.

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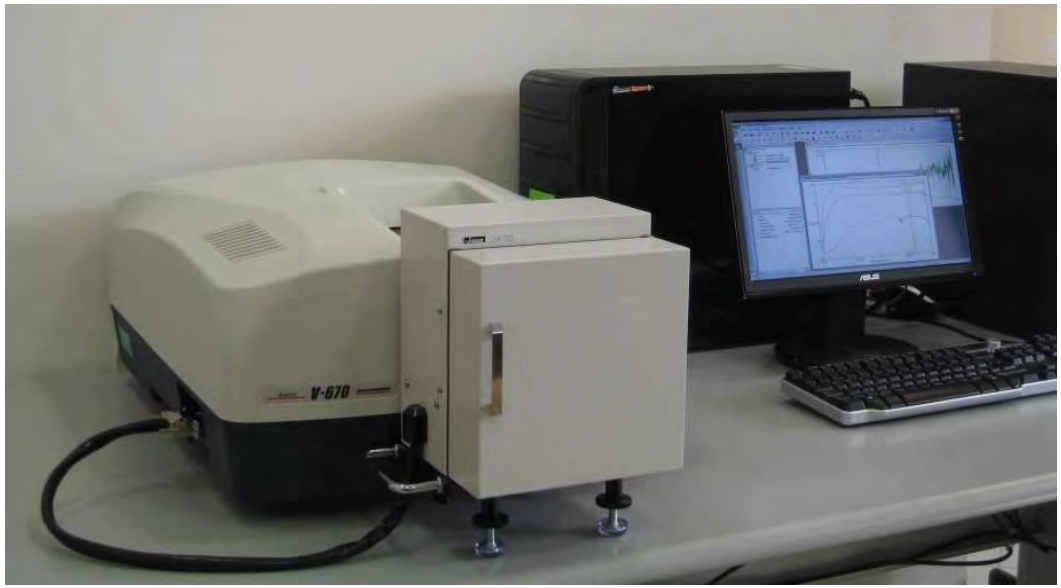
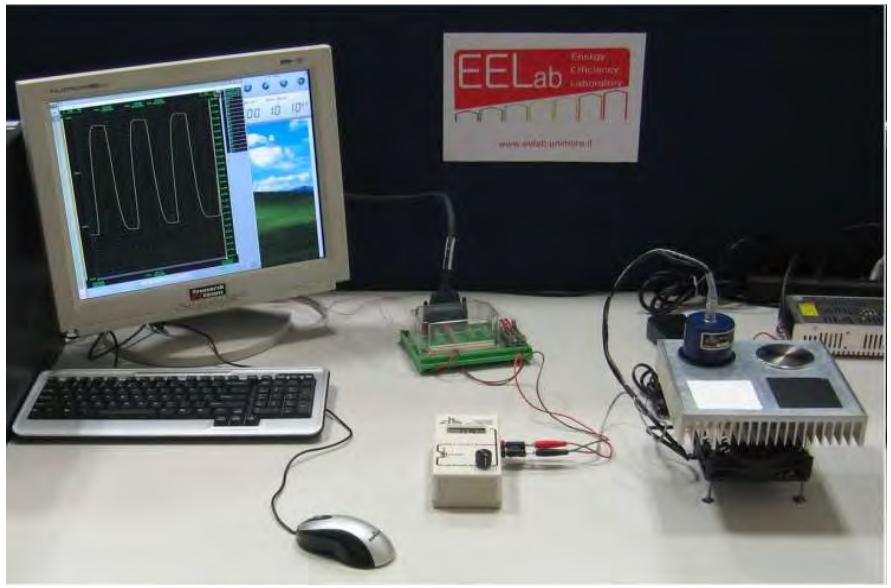
Measurement and certification of cool materials





The EELab Laboratory (www.eelab.unimore.it) can perform:

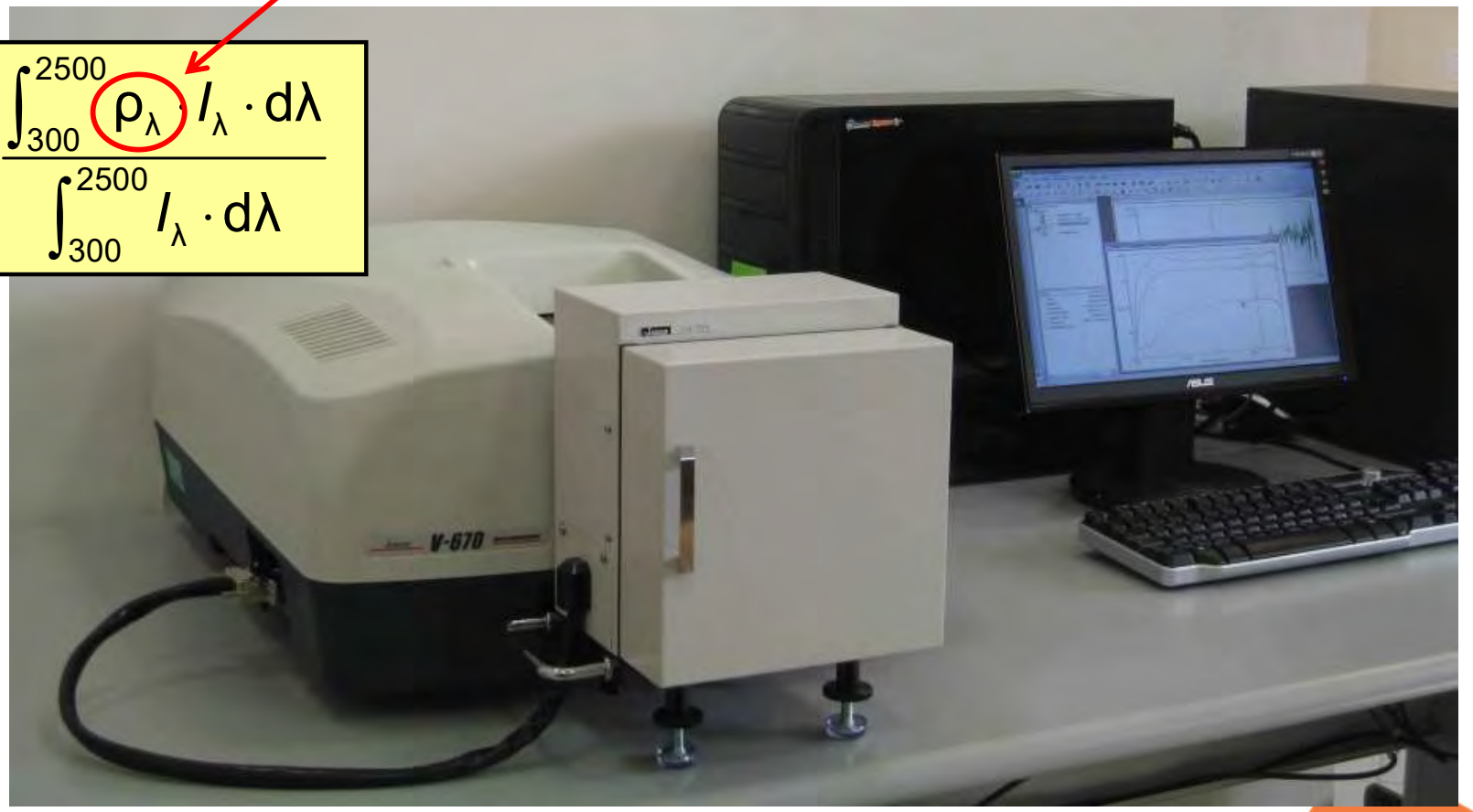
- Measurements of solar reflectance (ASTM E903, ASTM C1549, EN 410)
- Measurements of thermal emittance (ASTM C1371, UNI EN 15976)
- Determination of SRI (ASTM E1980)

Measurement of solar reflectance by spectrometer

(ASTM E903, EN 410, ISO 9050 standards)

UV-Vis-NIR spectrophotometer is used to measure between 250-300 and 2500 nm the reflectivity spectrum, from which the reflectance is calculated.

$$SR = \frac{\int_{300}^{2500} \rho_\lambda \cdot I_\lambda \cdot d\lambda}{\int_{300}^{2500} I_\lambda \cdot d\lambda}$$

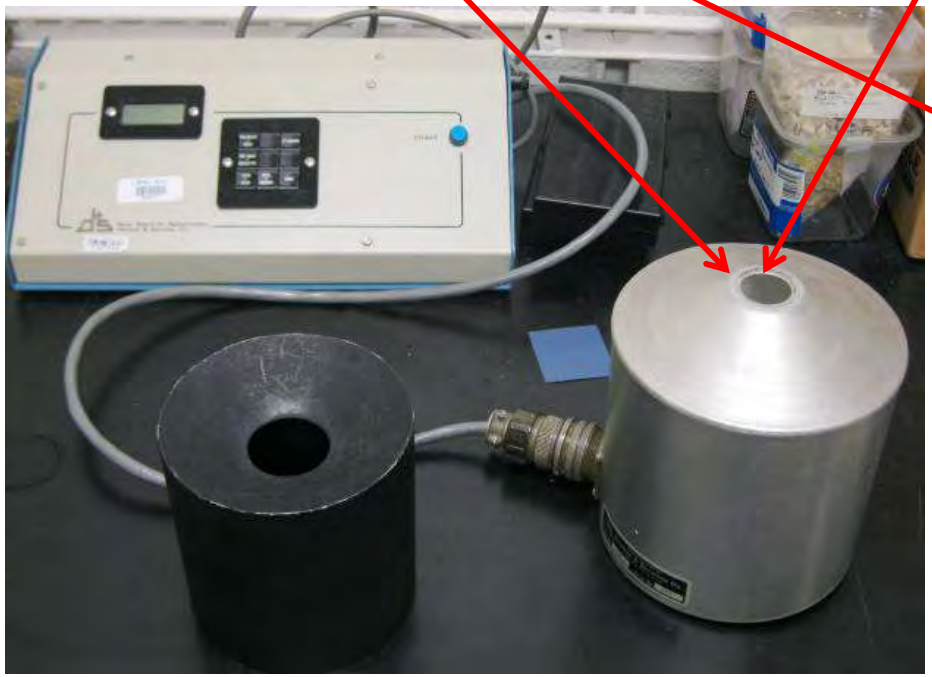


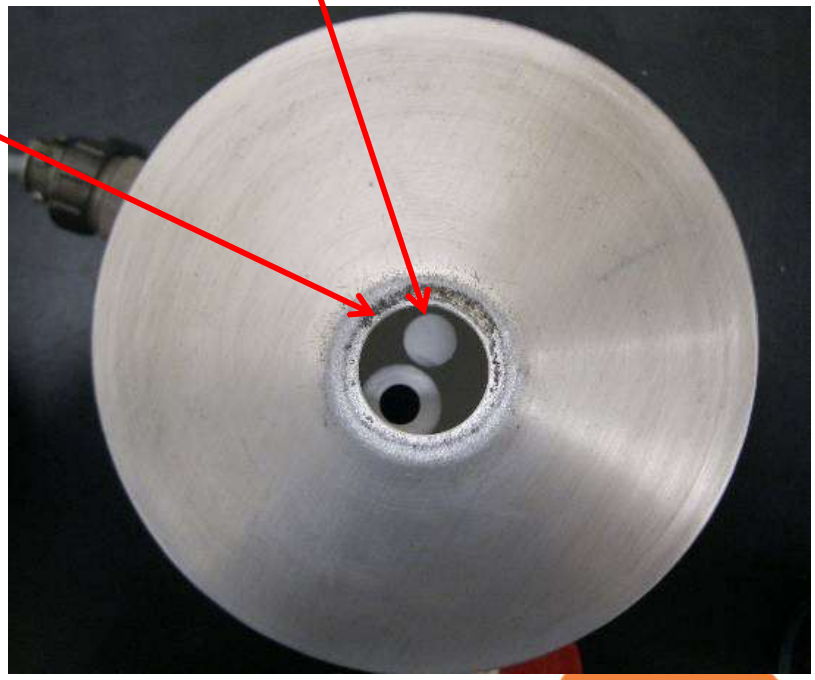
Measurement of solar reflectance by solar reflectometer

(ASTM C1549 standard)

The sample is illuminated by means of an internal source.

The reflectance is directly measured by weighting measurements of embedded sensors operating at different wavelengths, and then comparing the result with reference samples.

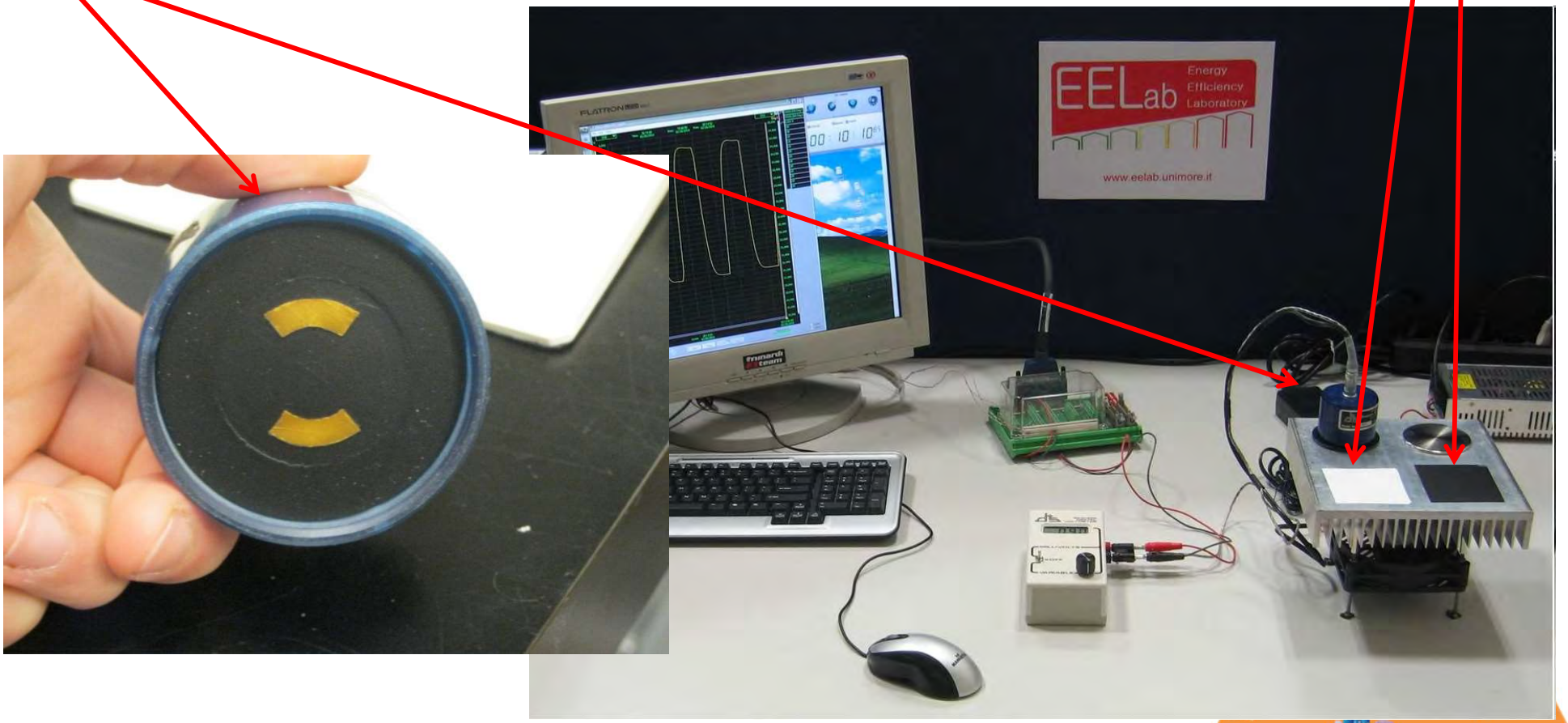




Measurement of thermal emittance by IR emissometer

(ASTM C1371 standard)

The thermal emittance is measured by comparison with two reference samples, high and low-emissive, by detecting with a electrically heated probe the heat exchanged with the sample by infrared radiation.

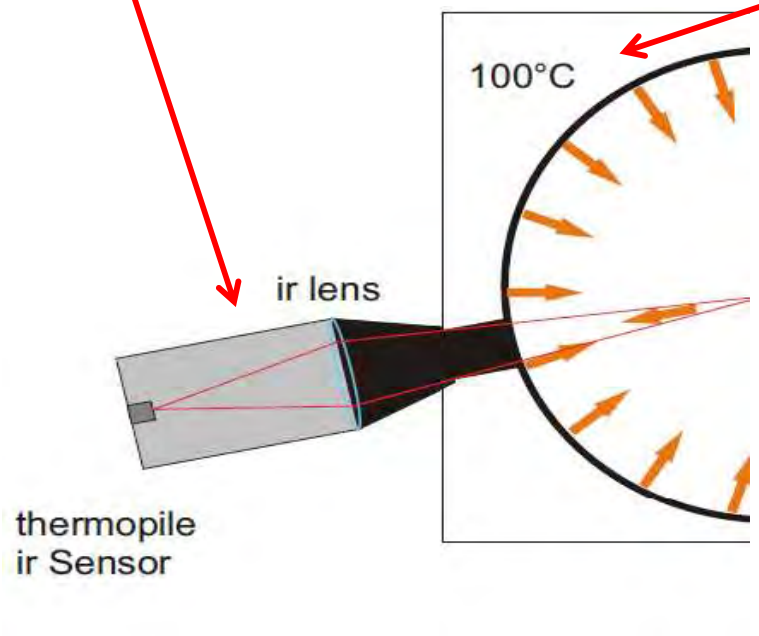


Measurement of thermal emittance by TIR emissometer

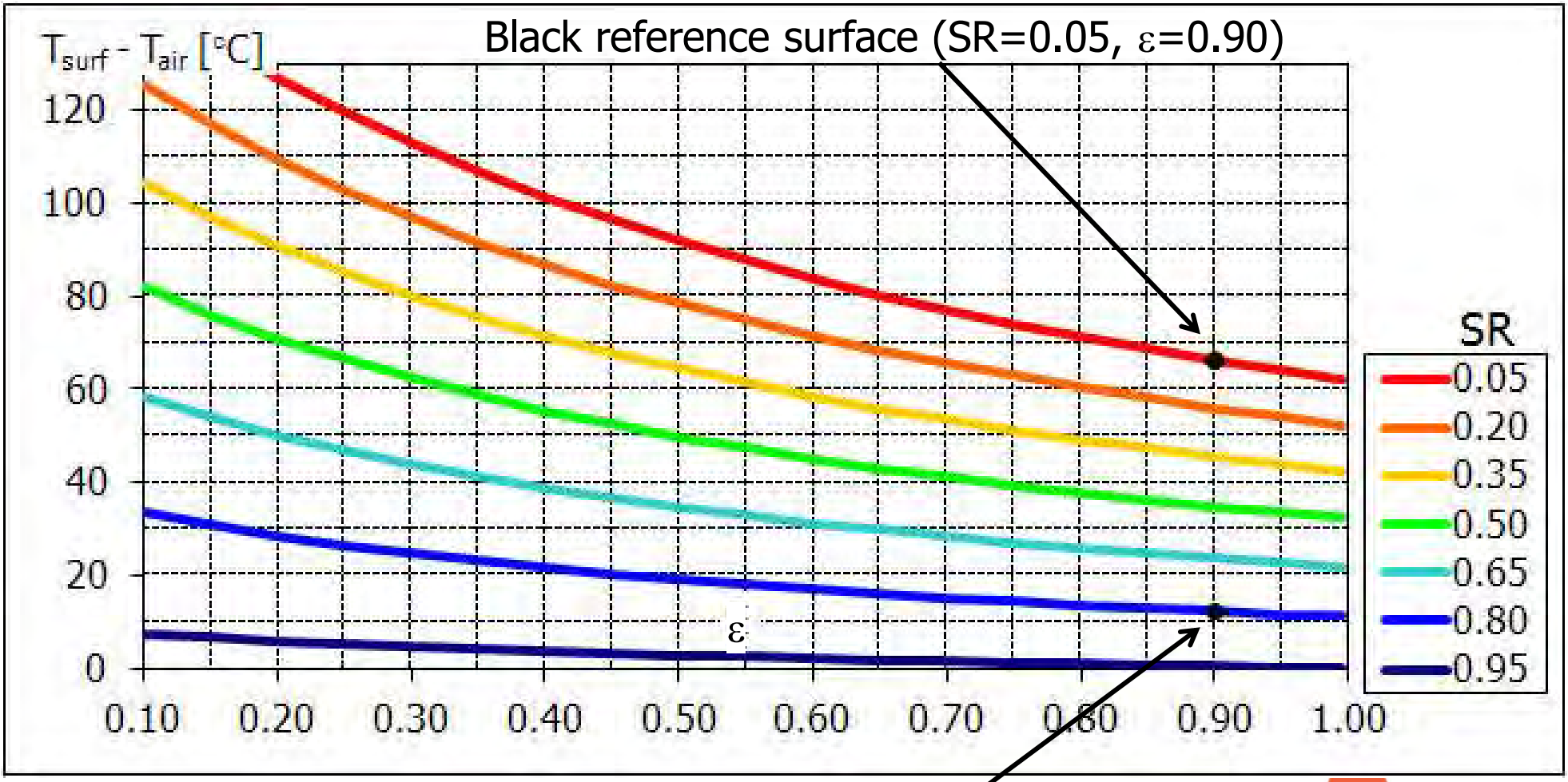
(EN 15976 standard)

Thermal emissivity is still measured by comparison with two reference samples (low-emissive and high-emissive).

A detector measures the IR radiation emitted by a hemispherical radiator at 100°C and reflected by the sample kept at room temperature.

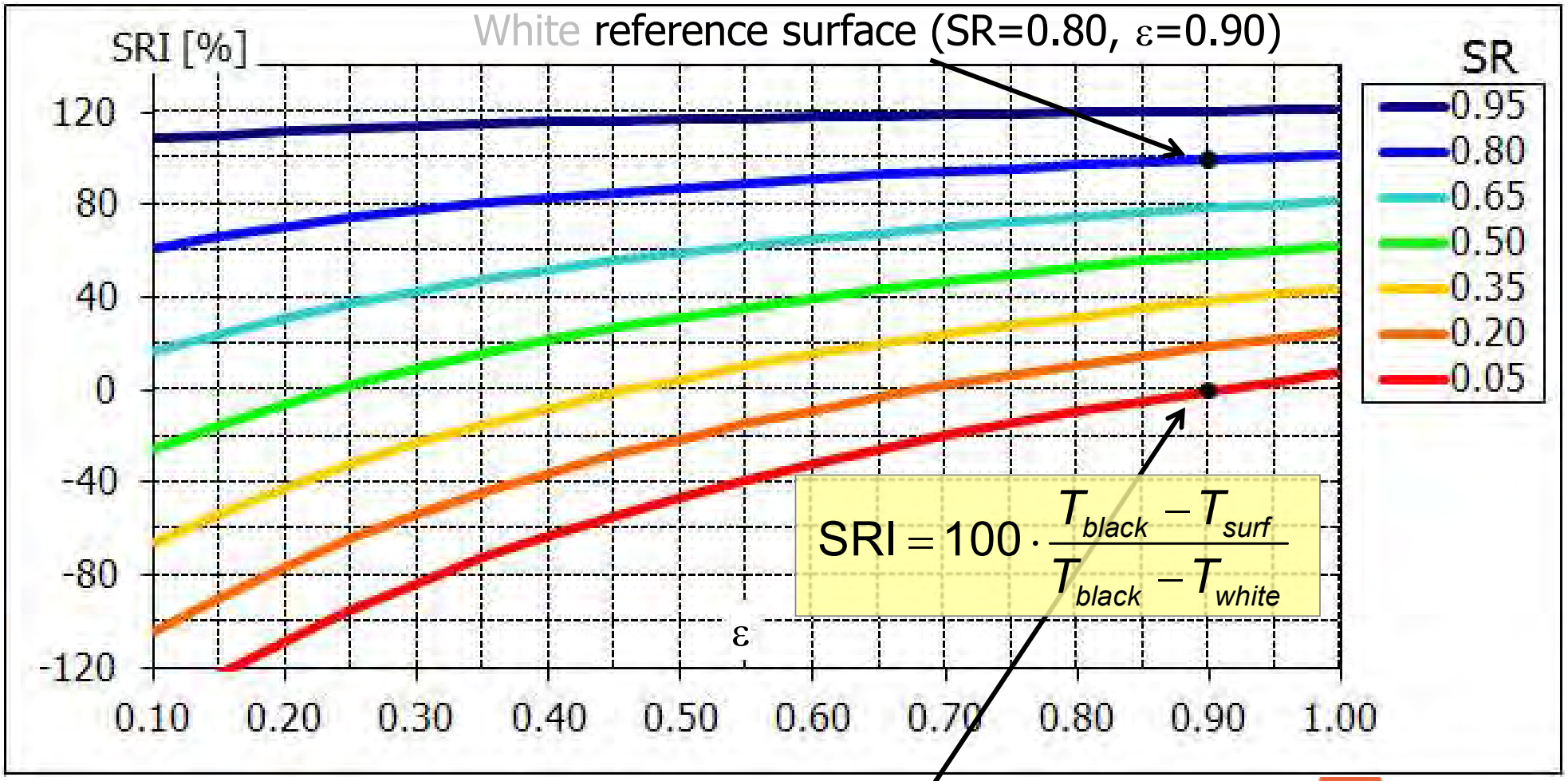


Combined effect of reflectance and emittance

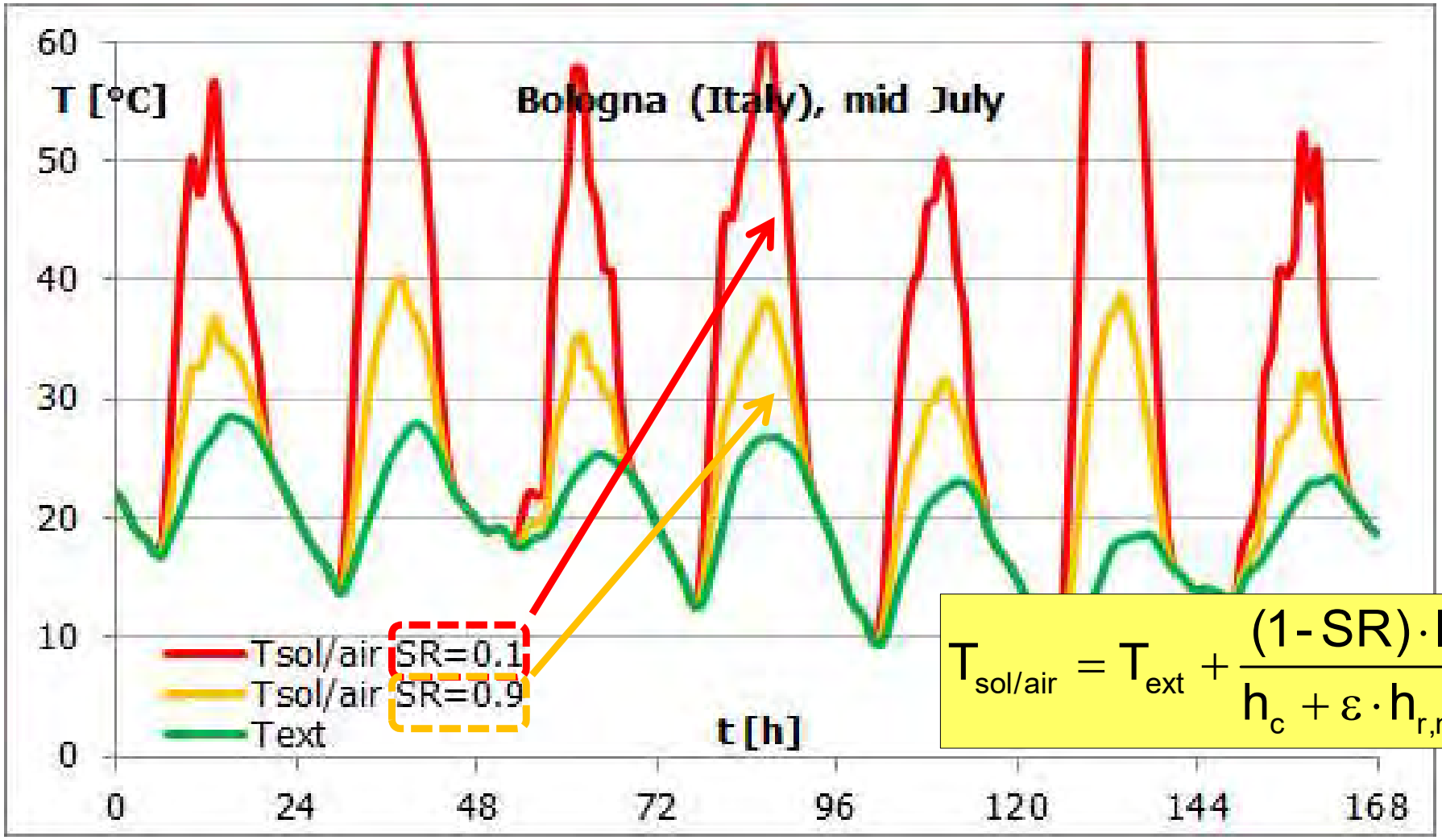


Solar Reflectance Index (SRI)

(ASTM E1980 standard)



Sol/air temperature $T_{sol/air}$



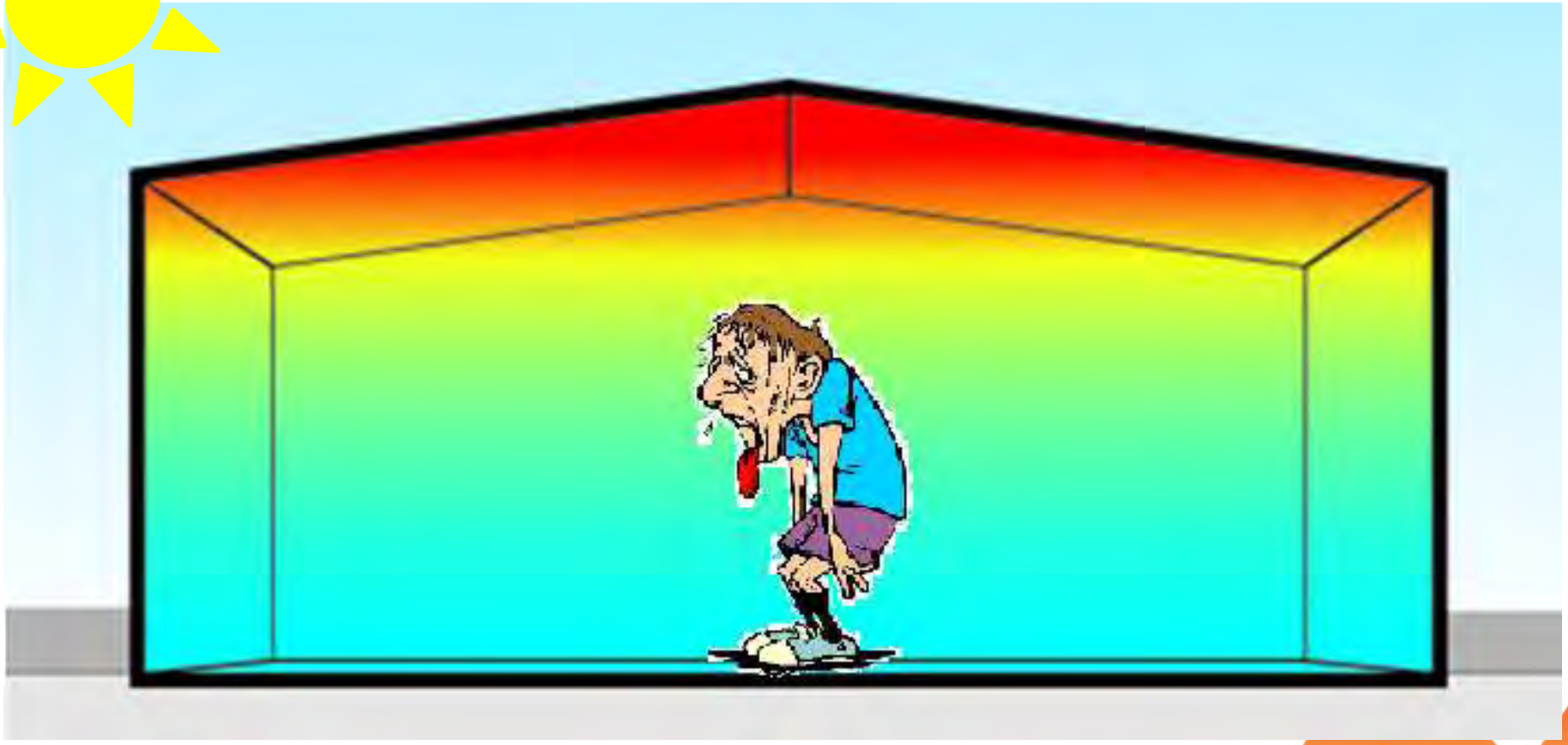
$$T_{sol/air} = T_{ext} + \frac{(1-SR)\cdot I_{sol}}{h_c + \varepsilon \cdot h_{r,max}}$$

The sol/air temperature is what the air should have, in the absence of sun, to produce the same heat input on the opaque components of the envelope as in the presence of solar radiation. It is correlated to the solar reflectance SR.

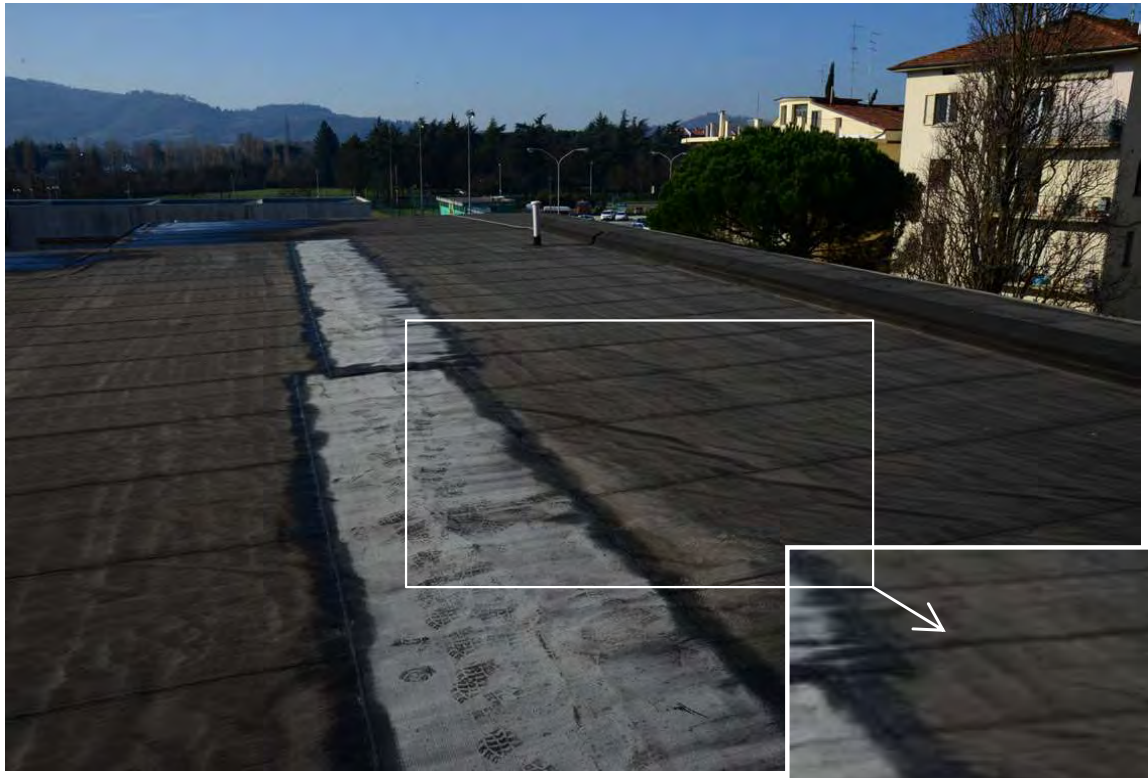
"Hot head" effect

In a room below the roof the perceived temperature is strongly affected by the sol/air temperature on the roof and ceiling temperature:

$$T_{perceived} \approx 75\% T_{air} + 25\% T_{ceiling}$$



Damage due to overheating of built surfaces



With a strong insulation, the surface temperature is close to the sol-air temperature.

With low solar reflectance, this can cause detachment of waterproofing membranes.

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CRRC
COOL ROOF RATING COUNCIL
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Causes of cool material ageing

- Chemical-physical degradation caused by UV rays, overheating and thermal cycles

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- Biological growth (biofouling) of bacteria, algae and fungi

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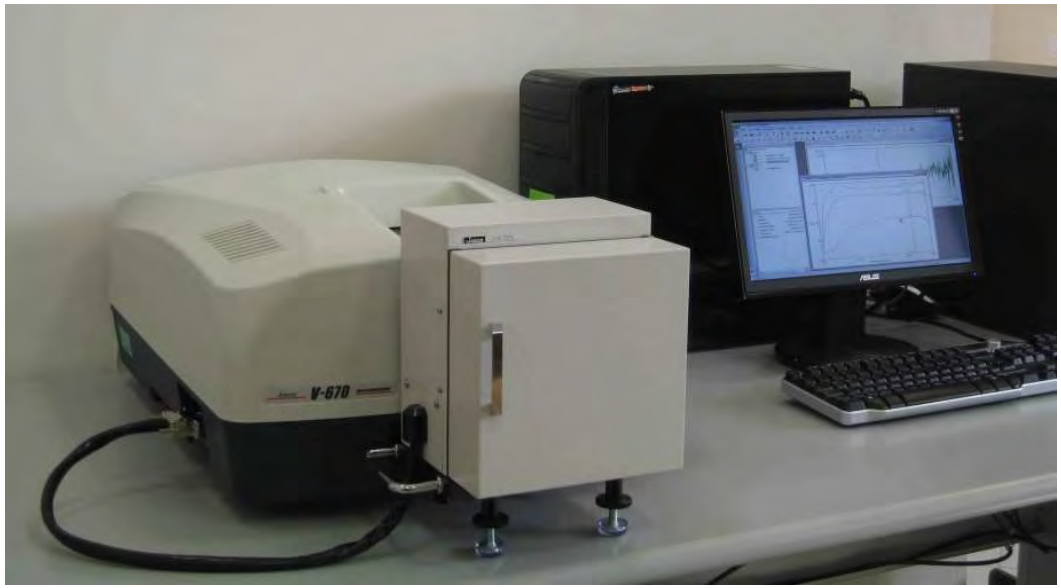

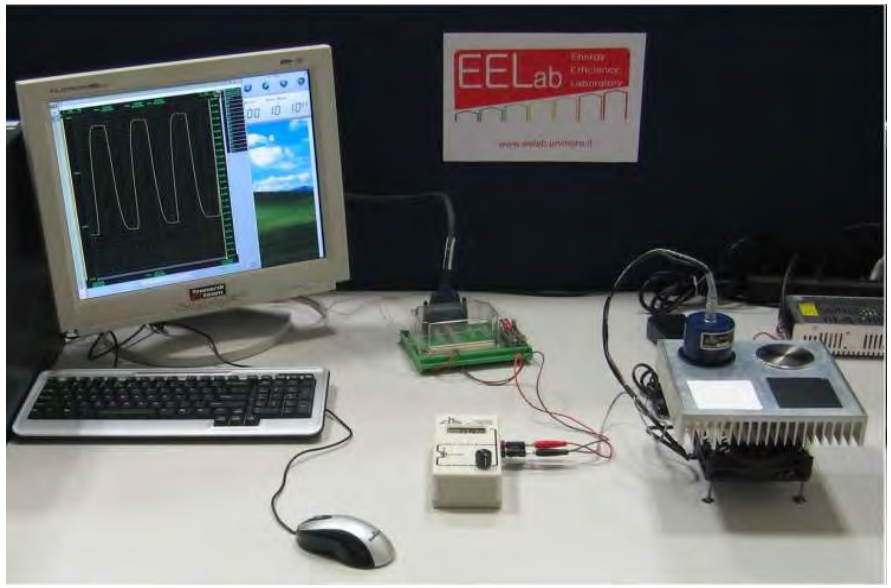

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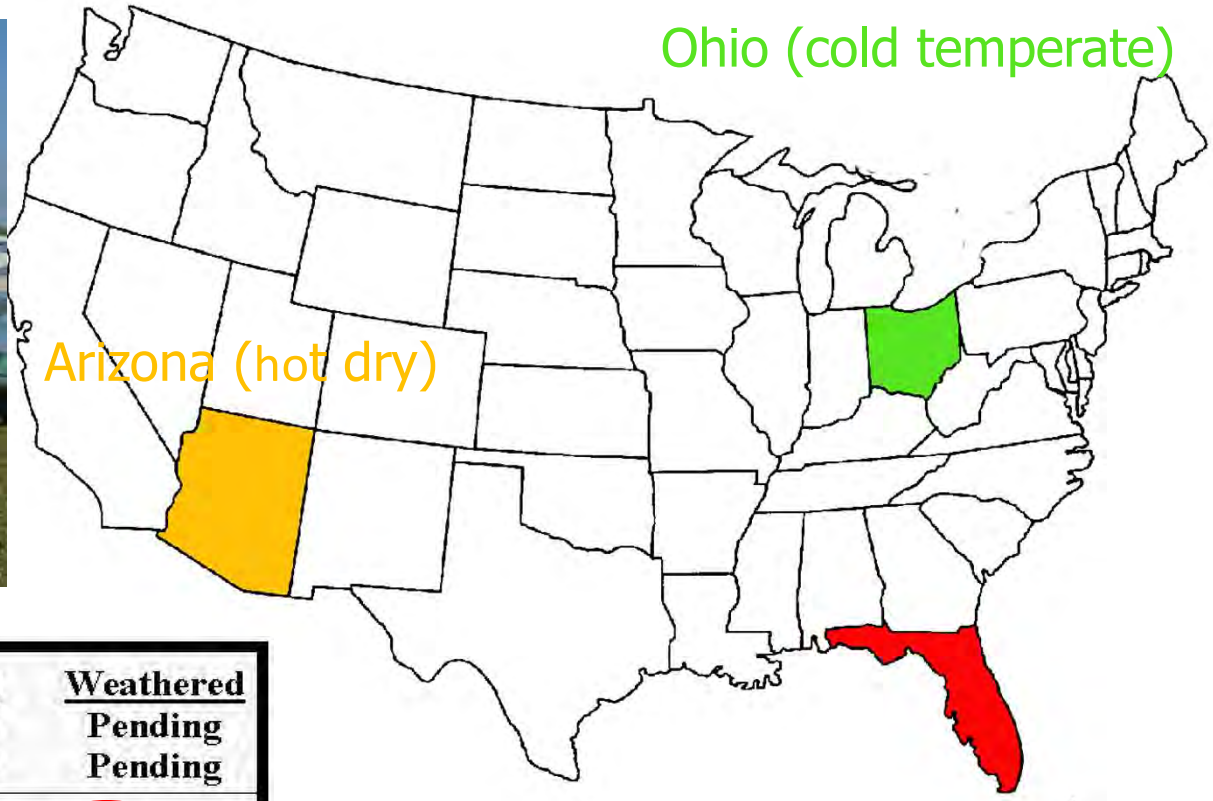
- Determination of SRI (ASTM E1980)
- Natural ageing (ASTM G7) in a weathering test site
- Accelerated ageing due to soiling (ASTM D7897)
- Accelerated bio-ageing due to biological growth (new technique)

Natural ageing in the U.S.

CRRC requires aging for at least 3 years in 3 different locations.



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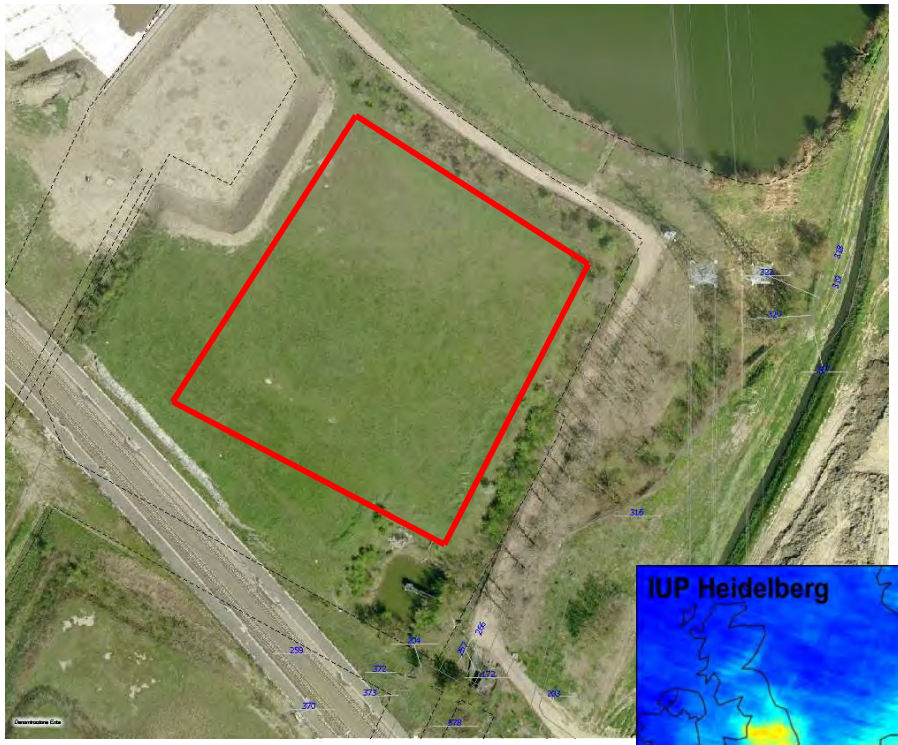
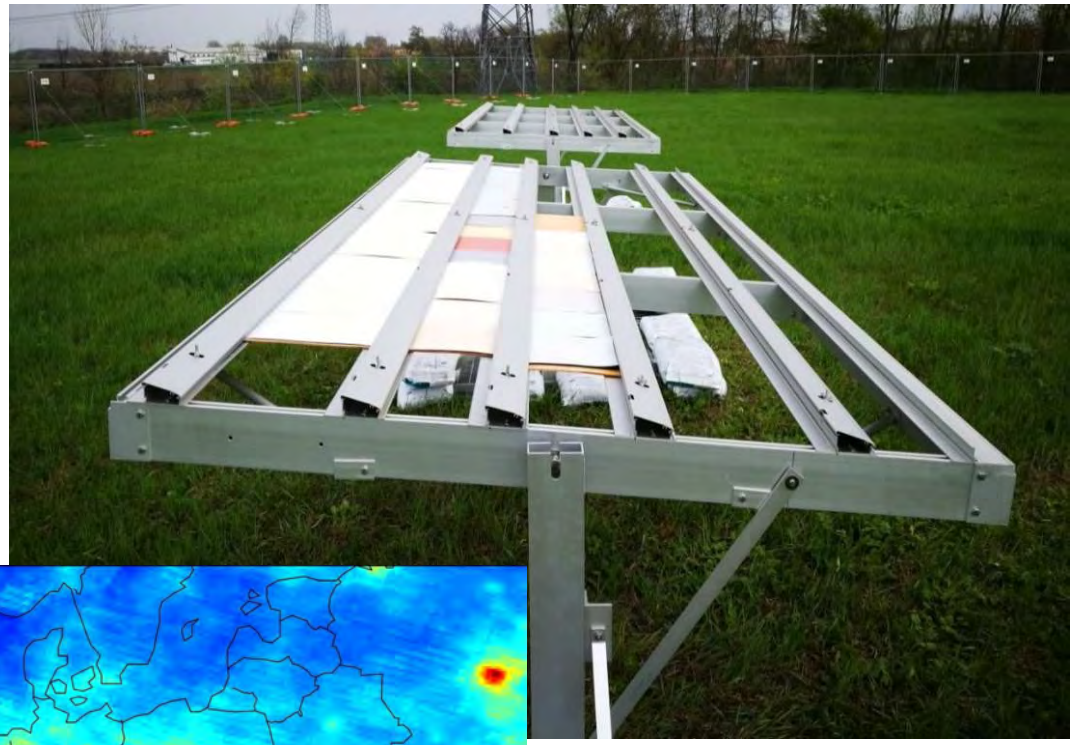
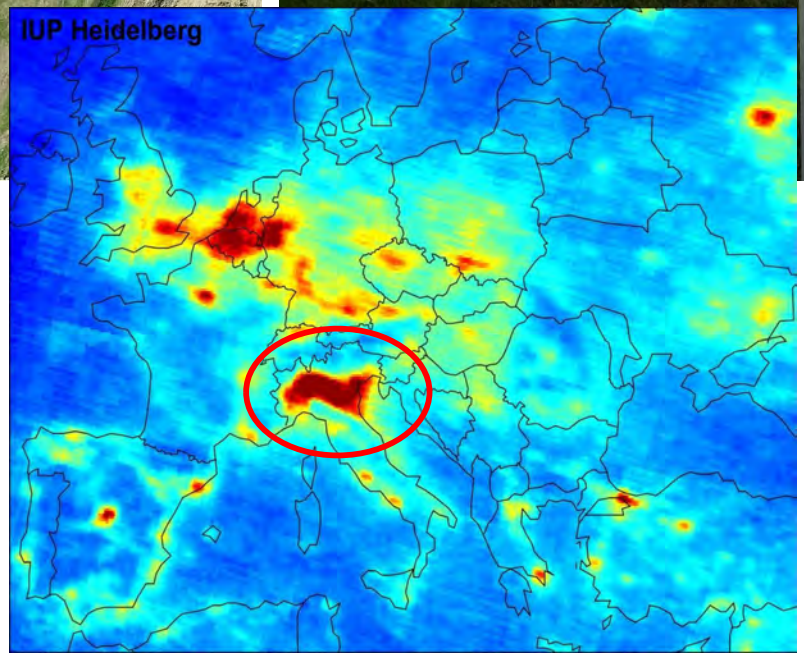
Natural ageing in Europe (with ECRC)



EELab natural aging site (operative in Modena since December 2017)



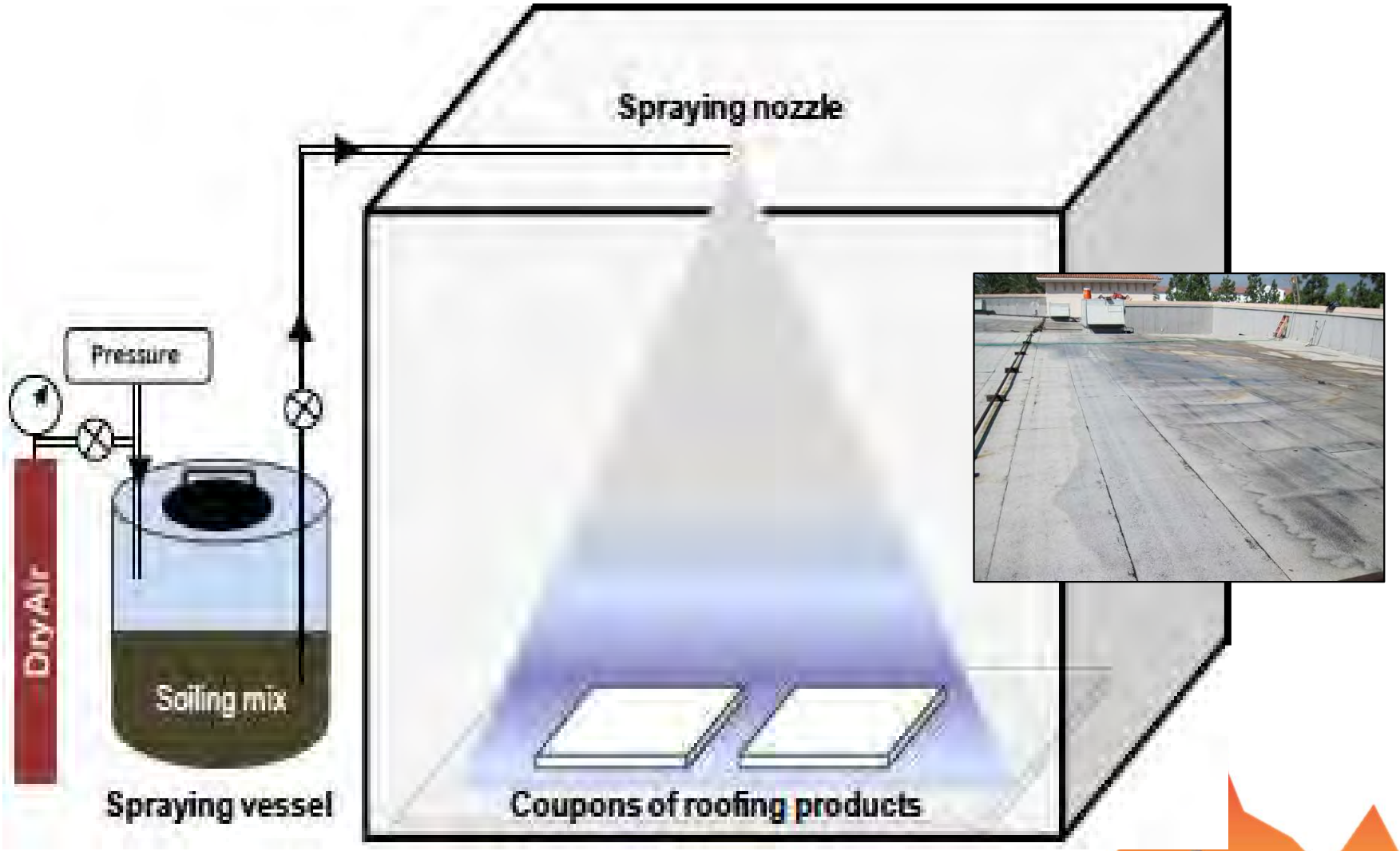
Expositors for natural aging



Pollutants concentration

Accelerated ageing (soiling)

Implemented according to ASTM D7897 standard



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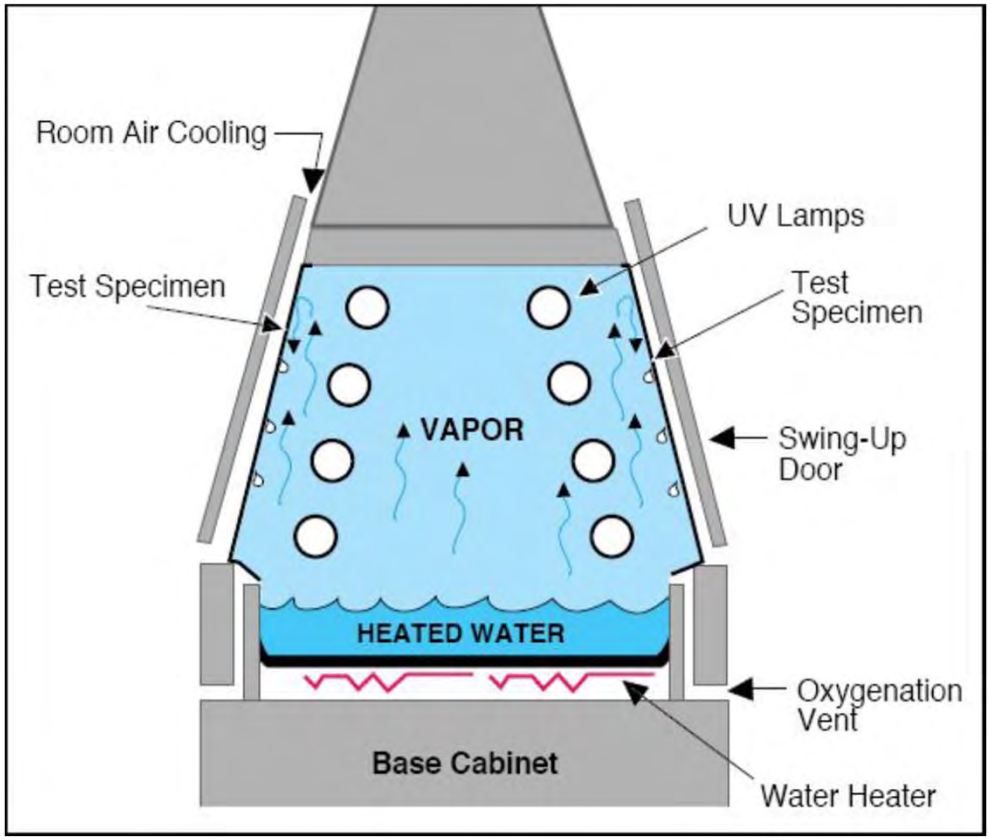

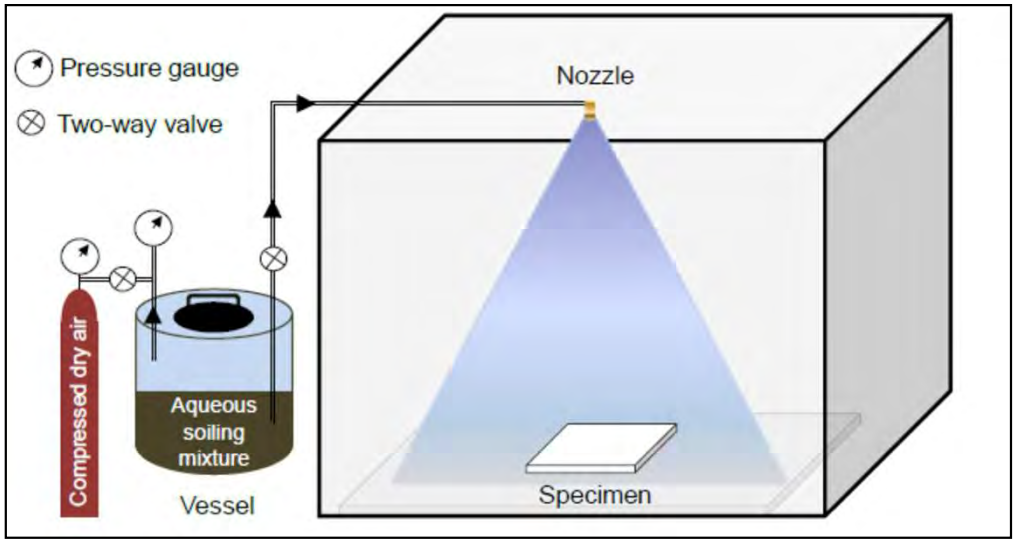

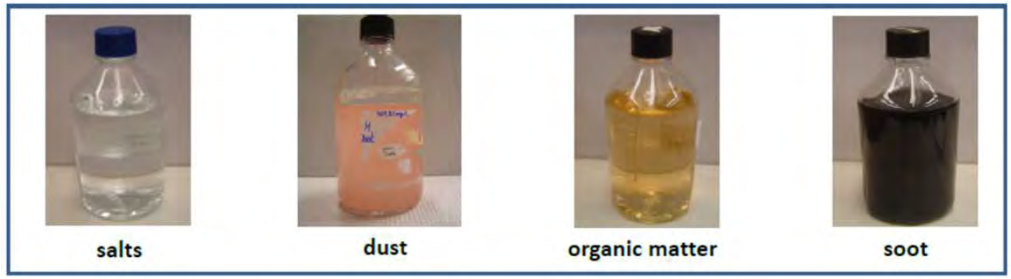

Physical aging
(UV + thermoclimatic cycles)

Chemical aging
(spraying with aggressive substances)

Accelerated ageing (soiling)

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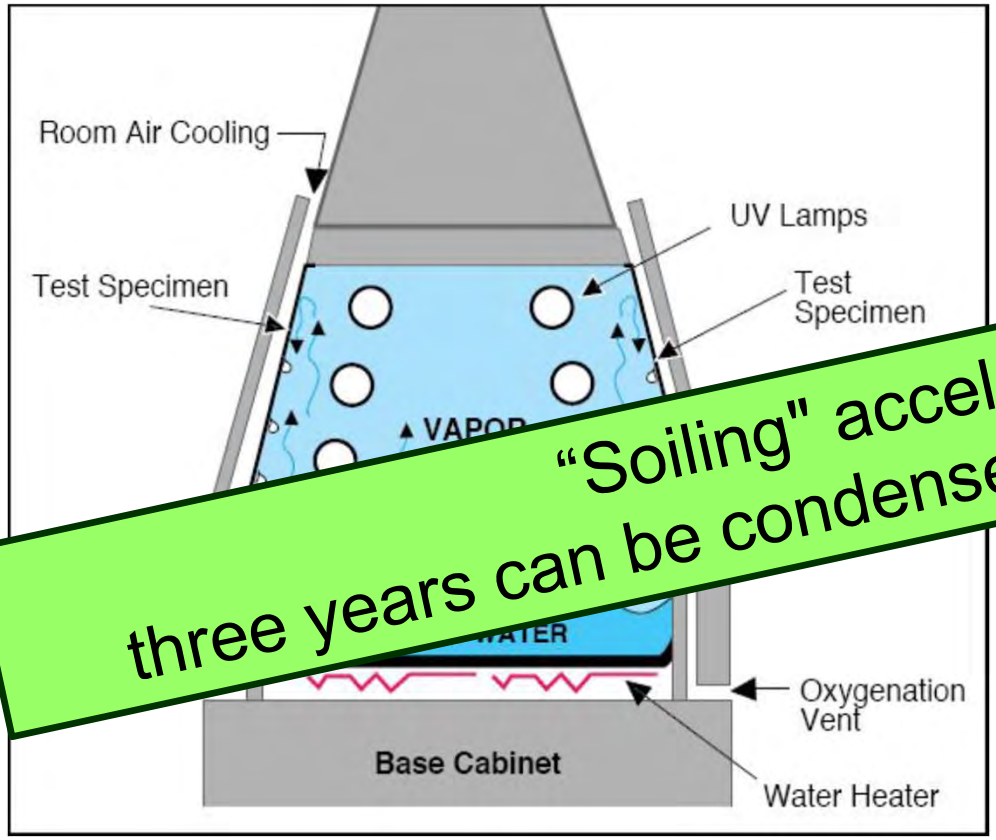
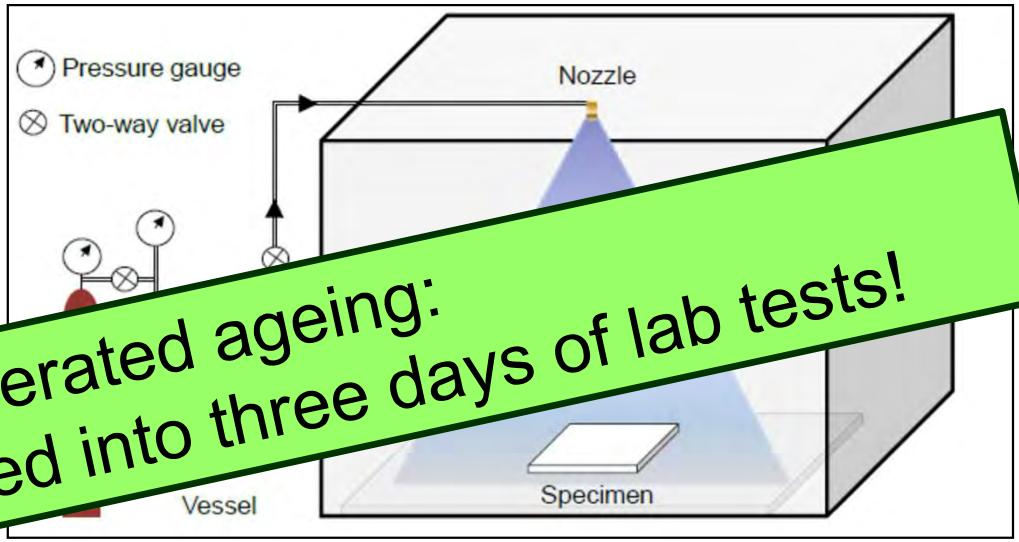
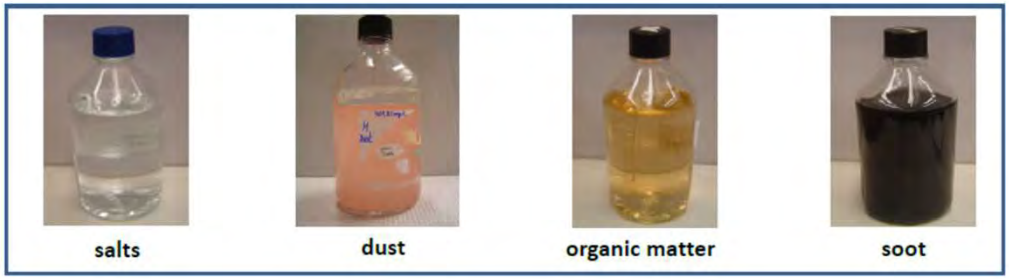




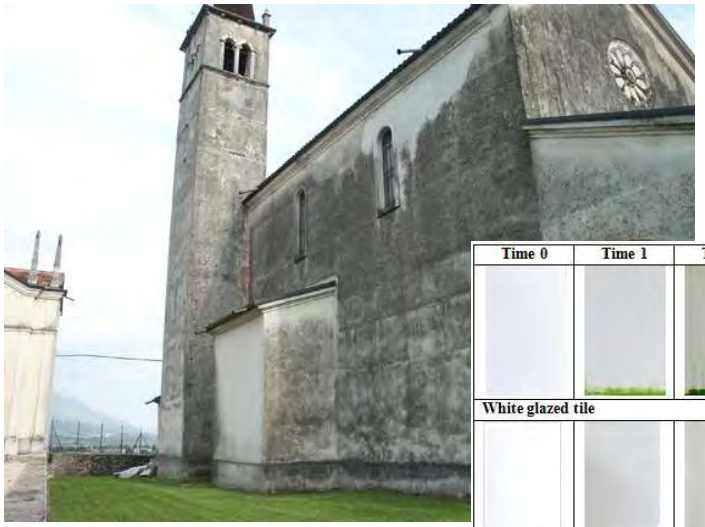


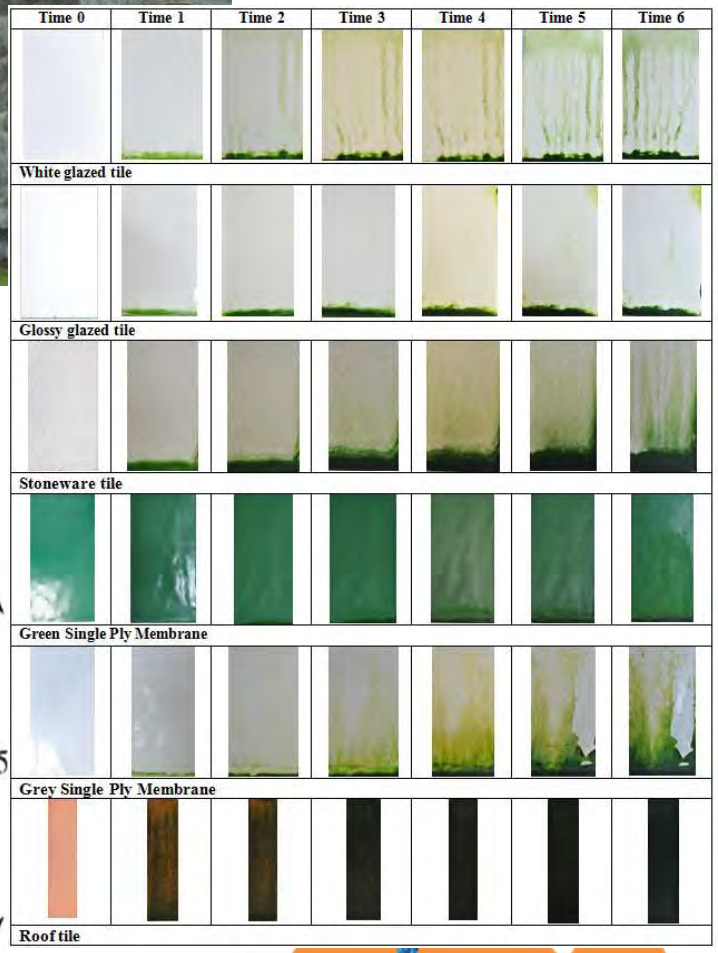
"Soiling" accelerated ageing:
three years can be condensed into three days of lab tests!

Physical aging
(UV + thermoclimatic cycles)

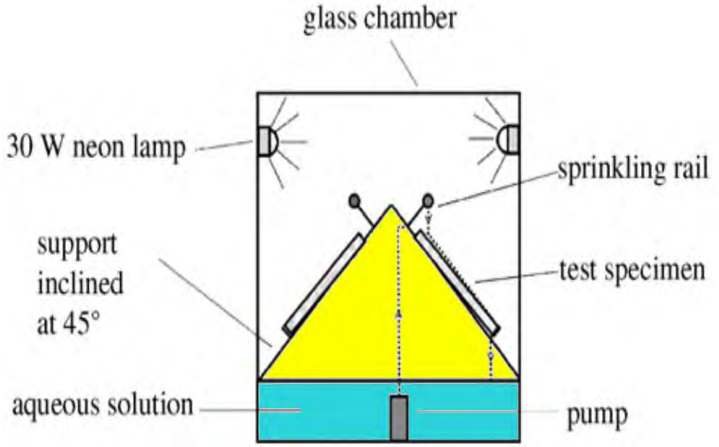
Chemical aging
(spraying with aggressive substances)

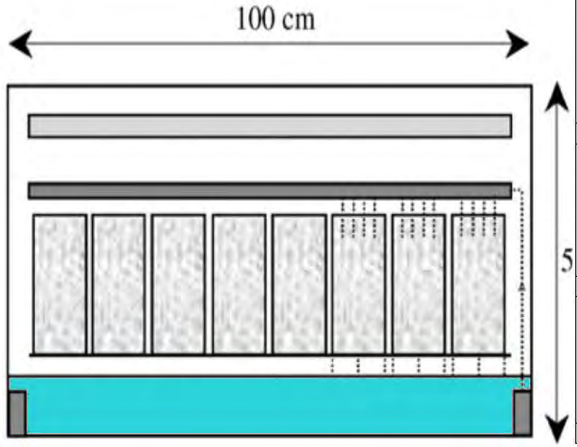
Accelerated ageing (bioageing)





EELab experimental apparatus
for accelerated biological ageing

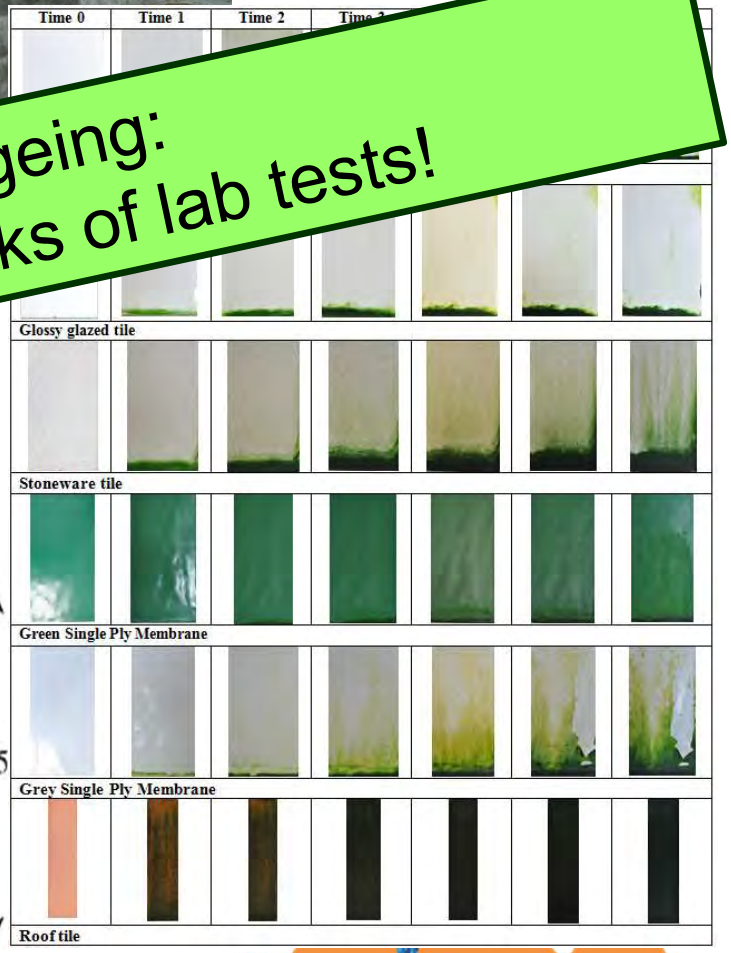


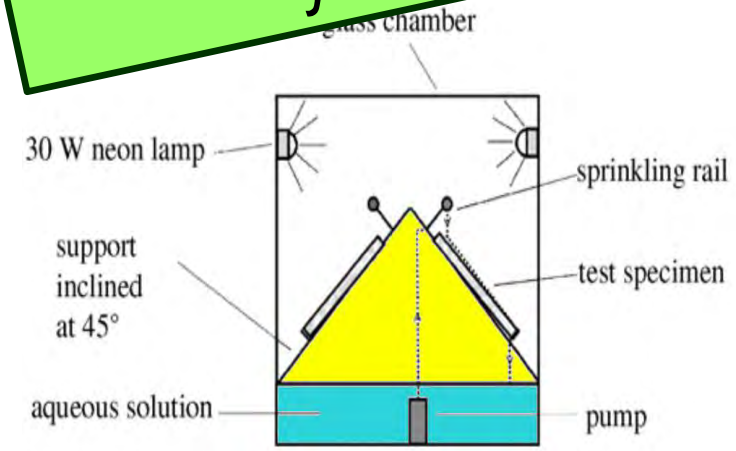


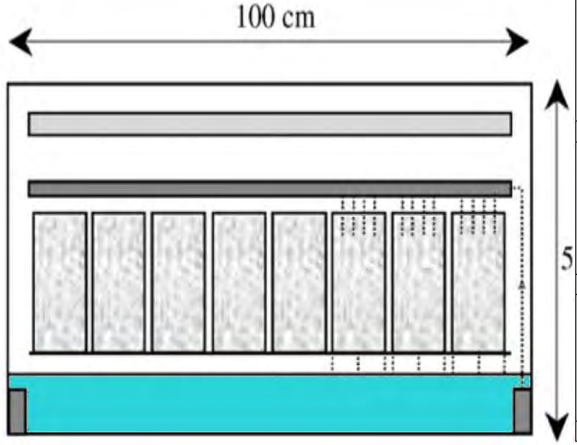
Accelerated ageing (bioageing)

"Biological" accelerated ageing:
years can be condensed into weeks of lab tests!

EEL… …ageing







Conclusive remarks

- In Italy and elsewhere in Europe the use of "cool" solar reflective materials has quickly widened as soon as they have been considered in building codes.
- The use of cool materials makes possible the safe use of high-performance thermal insulation by countering its surface overheating.
- Of course, it also results in lower urban temperatures and improved indoor thermal comfort.
- The current focus is on solar reflectance and SRI, but only on their initial values (certified).
- The attention to aged values of SR and SRI is expected to increase, however, as methods to analyze the performance of cool materials after ageing are already available.

THANK YOU FOR THE ATTENTION!

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