# Materials ScienceExploration - Challenge n°2 - 40'

## COOL ROOFS: PAINT IT COOL!

*Rising energy costs, pronounced urban heat-island effect and global warming, increase the need for intelligent solar heat management solutions such as cool paints. Roughly 50 % of solar radiation are absorbed at the Earth's surface. Black surfaces usually absorb up to 90 % of this energy and therefore get hot. White surfaces, on the other hand, absorb only up to 25 % and tend to stay much cooler. The impact in building can be dramatic. It's a well known experience that rooms directly under the roof become suffocating and stuffy. Cool paints may help in that.*
*But white is not always an option, much more often colour and especially dark shades are desirable (like in cars) or even required. Cool roof paints have a very high reflectance together with a high emissivity.*

On the desk you have a model village with 4 houses. Their roofs have been painted with different colours.

**Q1.** Which house do you think will reach the highest temperature inside if exposed to light/IR? Which one the lowest? Why?

**Q2.** Take a picture with the thermal camera of the four roofs BEFORE switching on the light. What do you observe? Can you explain it?

At your disposal you have:

- 4 sensors:
  a. a temperature probe (placed under the roof - inside) - **Arduino1**
  b. a surface temperature probe (placed on the roof - outside) - **Arduino2**
  c. 2 IR contactless temperature probes (a little over the roof, one directed upward, measuring IR incoming radiation on the roof; the second directed downward, measuring IR outgoing radiation from the roof, both reflected and/or emitted) - **Arduino2**
  [*NOTE: they should measure temperature, but actually they do this by measuring IR radiation: so, by dividing the two measures, we will get the (percent) ratio between outgoing and ingoing IR radiation – doing so we don't have to care about unit of measure*]
- Arduino connected with the four sensors: you can read the measures of the four sensors on the serial monitor of Arduino on the PC connected to them (time sampling is set on 1 sample/5 sec)

A Choose one roof, position the halogen lamp focusing on it (this will be our "sun") and:
1. Write down the (initial) temperature both inside and outside;
2. Write down the measures of the IR probes, both upward and downward;
3. Switch on the light and leave it on for exactly 5 minutes;
4. During the illumination time (let's say approximately at half the time) write down the measures of the IR probes, both upwards and downwards;
5. Just before switching off the light, write down the (final) temperature, both inside and outside;
6. Just after having switched off the light (it will be our "night"), write down the measures of the IR probes, both upwards and downwards;

B Fill in the Table (on the Answer sheet) with all the data collected and do the requested calculation.

C Repeat experiment A (from point 1 to 6) for the other roofs.

***Warning:***

- *BE SURE that the distance from the lamp and the roof is the same during all 4 Data Collections!*
- *During each measurement be sure that light DO NOT fall on the other "houses" that you are not testing (otherwise they will warm up!): protect them from incident light with a cardboard.*

**Q3.** After you have completed the test with all 4 houses, can you tell which/which ones are "cool paints"? Why? Justify your answer basing on the collected data.

☞ **OUTPUT WANTED : Answer to Q1 ... Q3 + Data Tables + 1 photo of apparatus and/or detail**

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## Answer sheet

**GROUP N°___________**

# COOL ROOFS: PAINT IT COOL!

**Q1**

**Q2**

| **House n.** | **Colour and texture of roof:** | | | | |
|---|---|---|---|---|---|
| | **T inside** | **T outside** | **IR incoming** | **IR outgoing** | **R% = $IR_{out}/IR_{in}$ 100** |
| **Initial ->$T_i$** *[Before lightening]* | | | | | |
| *[During lightening]* | ### | ### | | | |
| **Final ->$T_f$** *[Just **before** turning light off]* | | | ### | ### | ### |
| Final *[Just **after** turning light off]* | ### | ### | | | |
| Temperature change **$\Delta T = T_f - T_i$** | | | ### | ### | ### |

| **House n.** | **Colour and texture of roof:** | | | | |
|---|---|---|---|---|---|
| | **T inside** | **T outside** | **IR incoming** | **IR outgoing** | **R% = $IR_{out}/IR_{in}$ 100** |
| **Initial ->$T_i$** *[Before lightening]* | | | | | |
| *[During lightening]* | ### | ### | | | |
| **Final ->$T_f$** *[Just **before** turning light off]* | | | ### | ### | ### |
| Final *[Just **after** turning light off]* | ### | ### | | | |
| Temperature change **$\Delta T = T_f - T_i$** | | | ### | ### | ### |

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# Answersheet

**GROUP N°___________**

## COOL ROOFS: PAINT IT COOL!

| **House n.** | **Colour and texture of roof:** | | | | |
|---|---|---|---|---|---|
| | **T inside** | **T outside** | **IR incoming** | **IR outgoing** | **R% = $IR_{out}/IR_{in}$ 100** |
| **Initial ->$T_i$**<br>*[Before lightening]* | | | | | |
| *[During lightening]* | ### | ### | | | |
| **Final ->$T_f$**<br>*[Just **before** turning light off]* | | | ### | ### | ### |
| Final<br>*[Just **after** turning light off]* | ### | ### | | | |
| Temperature change<br>$\Delta T = T_f - T_i$ | | | ### | ### | ### |

| **House n.** | **Colour and texture of roof:** | | | | |
|---|---|---|---|---|---|
| | **T inside** | **T outside** | **IR incoming** | **IR outgoing** | **R% = $IR_{out}/IR_{in}$ 100** |
| **Initial ->$T_i$**<br>*[Before lightening]* | | | | | |
| *[During lightening]* | ### | ### | | | |
| **Final ->$T_f$**<br>*[Just **before** turning light off]* | | | ### | ### | ### |
| Final<br>*[Just **after** turning light off]* | ### | ### | | | |
| Temperature change<br>$\Delta T = T_f - T_i$ | | | ### | ### | ### |

**Q3**

**PICTURES** *[Sent by Whatsapp to your group – See general instruction to share pictures or files]*

- **Pictures description:**


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## Teacher's notes

**Technical notes:**

- The best option would be to work outdoor in the sun, if this is not possible than halogen lamps are an option BUT be very careful in ensuring that each "roof" is getting the same amount of light. IR lamps may be ok as well although they do not ensure the complete sun spectral wavelengths.

**Organizational notes:**

- Each student will keep a copy of the students' sheet but the group will collectively fill in the answer sheet and give it over to the teacher in charge at the end of the lab.

**Correction grid**

| Question or Request | Note | Max. score |
|---|---|---|
| Q1 | • Evaluate if answer are well motivated | 2 |
| Q2 | • Evaluate if answer are well motivated and based on the data collected by the thermal camera | 2 |
| Table 1 - 4 | • 2 point for each table filled (data collected; calculation done);<br>• 1 more point for each table if there are NOT evident mistakes (i.e. unit e/o calculation wrong) | 3*4=12 |
| Q3 | Evaluate if answer are well motivated on the data collected | 2 |
| Picture 1 | Meaningful (Yes/No: 1 point); beautiful (Yes/No: 1 point)* | 2 |

***Pictures**: are the pictures meaningful? [*To evaluate the "meaningful" see also the "Picture Description" on the Answer Sheet*] Are they focusing on significant details or clearly showing the apparatus structure or the investigation results? Are they aesthetically beautiful?

## Key to Answer

The students will easily measure increasing temperatures inside the model houses without cool paint in the roof. They will probably marvel at the fact that the "cool black" is not that hot (but however hotter than any white). What usually puzzles them at the beginning is that the cool roof actually feels warmer than the untreated one if you put your hand near to it. This is consistent with the fact of cool roof paint high reflectance and emittance: due to this the outside temperature just near the roof surface IS HIGHER! But not the outside one. Thermal cameras picture show this very well.

In northern latitudes the paint may be used for indoor walls, thus ensuring that the heat is reflected back and kept inside.

Generally speaking (see also the presentation listed at the end of this document in *MoM Resources*) any object /body shows three radiative properties: ***assorbance, reflectance and emissivity***.

- **Emissivity** is the amount of energy irradiated by the object compared to the energy of a *black body* at the same temperature. For an ideal *black body* such ratio is 1, while for any other object it is between 0 and 1. Emissivity of an object is not constant but varies with surface temperture, incident wavelength and emission angle. Emissivity should not be confused with emittance (power emitted by surface unit)
- To understand **assorbance** let's imagine a monochromatic ray **hitting a specific surface**: some of the radiation is absorbed. This means that radiation going through the object is just one fraction of the total amount of the incident radiation..

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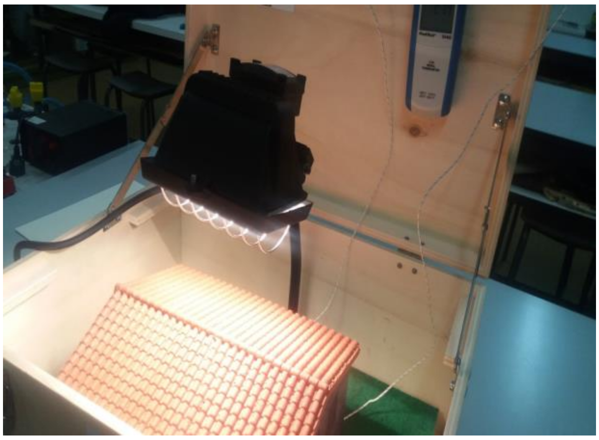
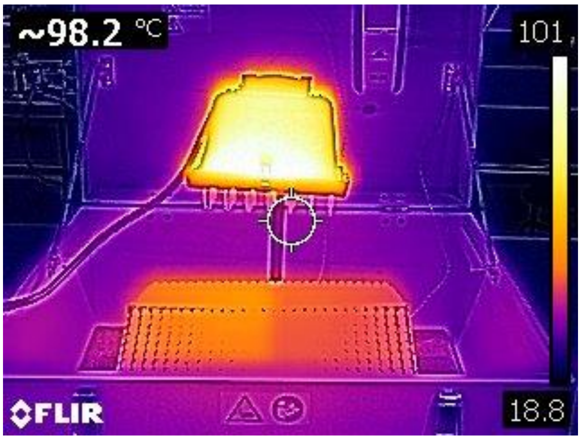
- Solar **reflectance** of any object is the ratio between the reflected and the incident amount of radiation. Therefore reflectance is an index, specific of the single object, of the reflecting power of a body subject to irrradiation

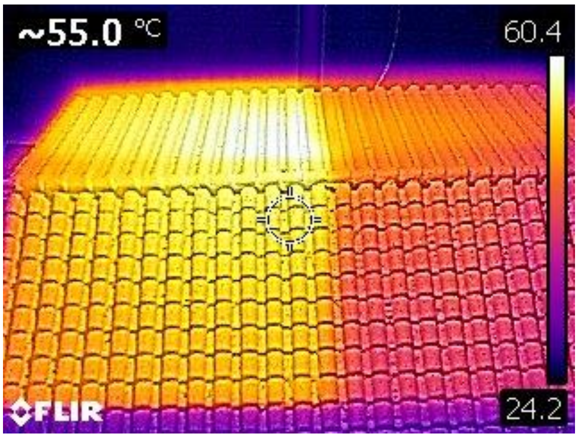
$$R = \frac{reflected\ radiation}{incident\ radiation}$$

It's very important to notice that the reflectance index varies with wavelength for the same object. Such an index can be very different when measured in the IR, VIS, UV.

Due to thermodynamics laws, the sum of absorbed, reflected and transmitted radiation should be equal to the total incident radiation (energy conservation).
The phenomenon of the *Hurban heat island* calls for new solutions, cool roofs are one of them together with grass roofs, more vegetation/parks, cool pavements, etc…Cool paints exhibit a high reflectance (>0.40/0.50 for typical colours of traditional architecture such as light grey and brick red, much higher for white) and extremely high thermal emissivity >0.90. this means that most of the energy is immediately reflected back and never reach the interior building, while the high emissivity ensures that once the bulding gets warm it will cool by radiative emission at a very fast rate.
Cool paints are basically hollow nanospheres with a super high reflectance and enhanced thermal properties which are added to conventional paint or matrix. See References[1].






Following an additional sheet for students. They have pictures taken with the thermal camera of two aluminium sheets painted with conventional and "cool roof" paint. From the pictures and the info reported next to them they have to devise and motivate which is which explaining what's happening. This can be used either to reinforce learning or as an alternative to outdoor exploration (which still is the best option for first hand investigation).

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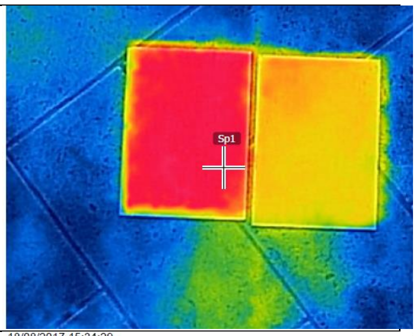
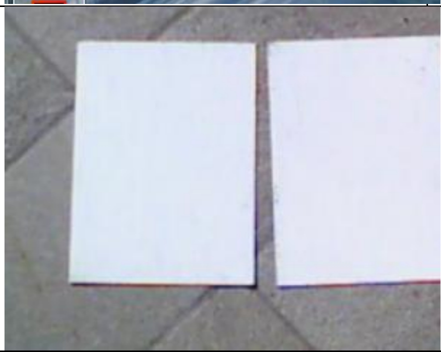
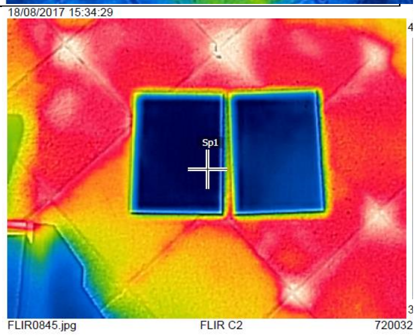
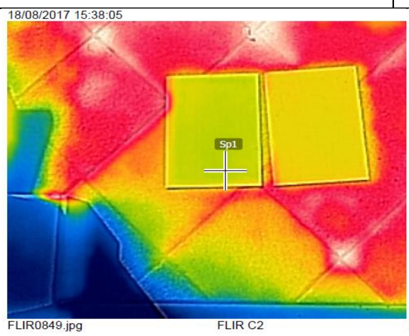
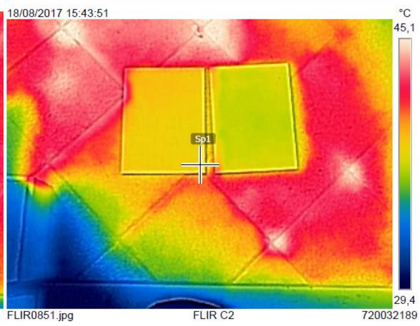
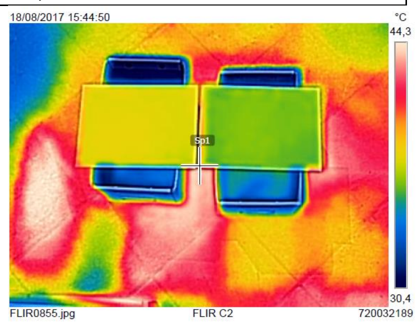
# Cool Roofs - CASE 1

Aluminium sheets 1 mm thick with one side painted white (only one is cool roof paint!)
The thermal camera is shooting perpendicular to the plate surface from a height of 50 cm approx. Left sheet A, Right sheet B. the position of the plates is always the same.
**CAN YOU GUESS WHICH IS WHICH? Are the pictures consistent with the info you know about cool roof paints? Can you explain what is happening?**

| | | |
|---|---|---|
| **INDOOR**<br>afternoon -30°C<br>At hambient temperature<br>**BEFORE exposition to the sun** |  | <br> |
| **OUTDOOR** –exposition to the sun, first the plates are on the terrace tiles and then on cardboard boxes. |  | <br> |
| | | 30,4 °C Time: 15:34 |
| <br> | <br> | <br> |
| 42,6 °C- Time: 15:38 4'after | 40,2 °C Time: 15:38 5'after<br>**SHIFT!** | 43,6°C on cardboard boxes |

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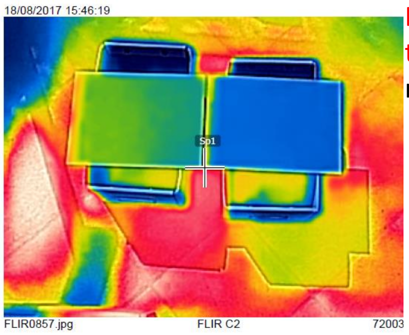
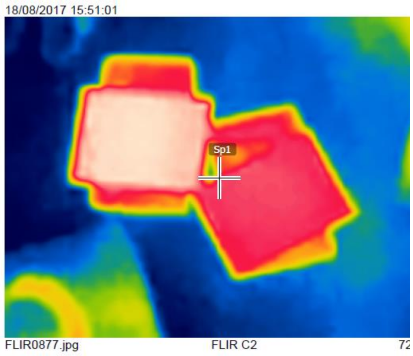



INDOOR IMMEDIATELY AFTER the exposition to the sun.The room was totally darkened




# Cool Roofs - CASE 2

Paper sheet painted with different white samples of thermal paint. From left to right: the fourth quarter(left) is just white sheet! No paint at all !

The thermal camera is shooting perpendicular to the sheet surface from a height of 50 cm approx. Left sheet A,

**CAN YOU FIGURE OUT WHICH IS THE BEST PERFORMING THERMOREFLECTANT PAINT? Can you support your conjecture with the pictures below?**

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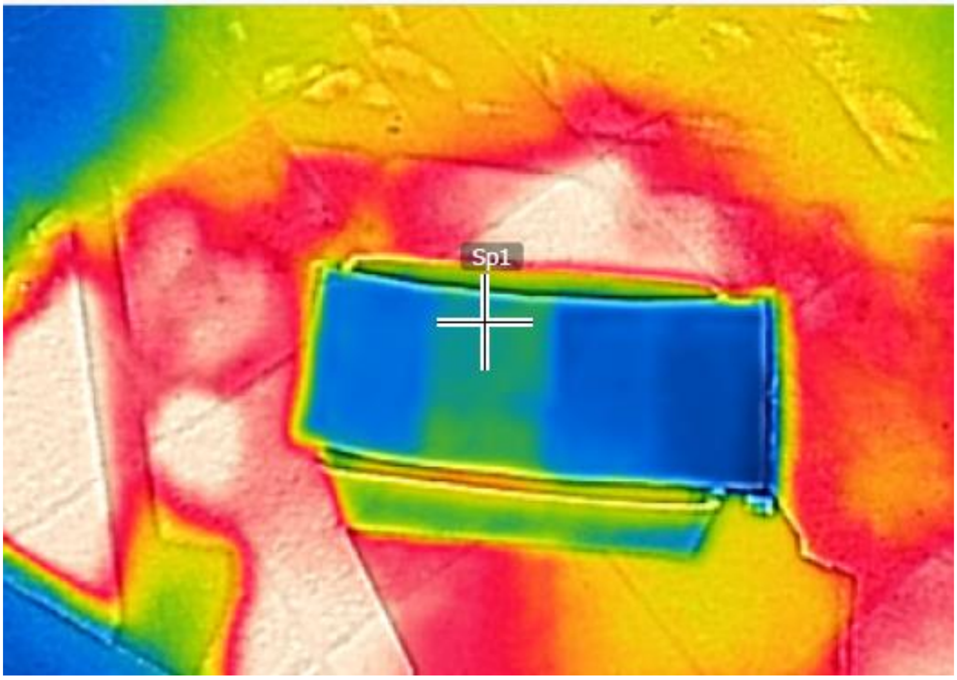


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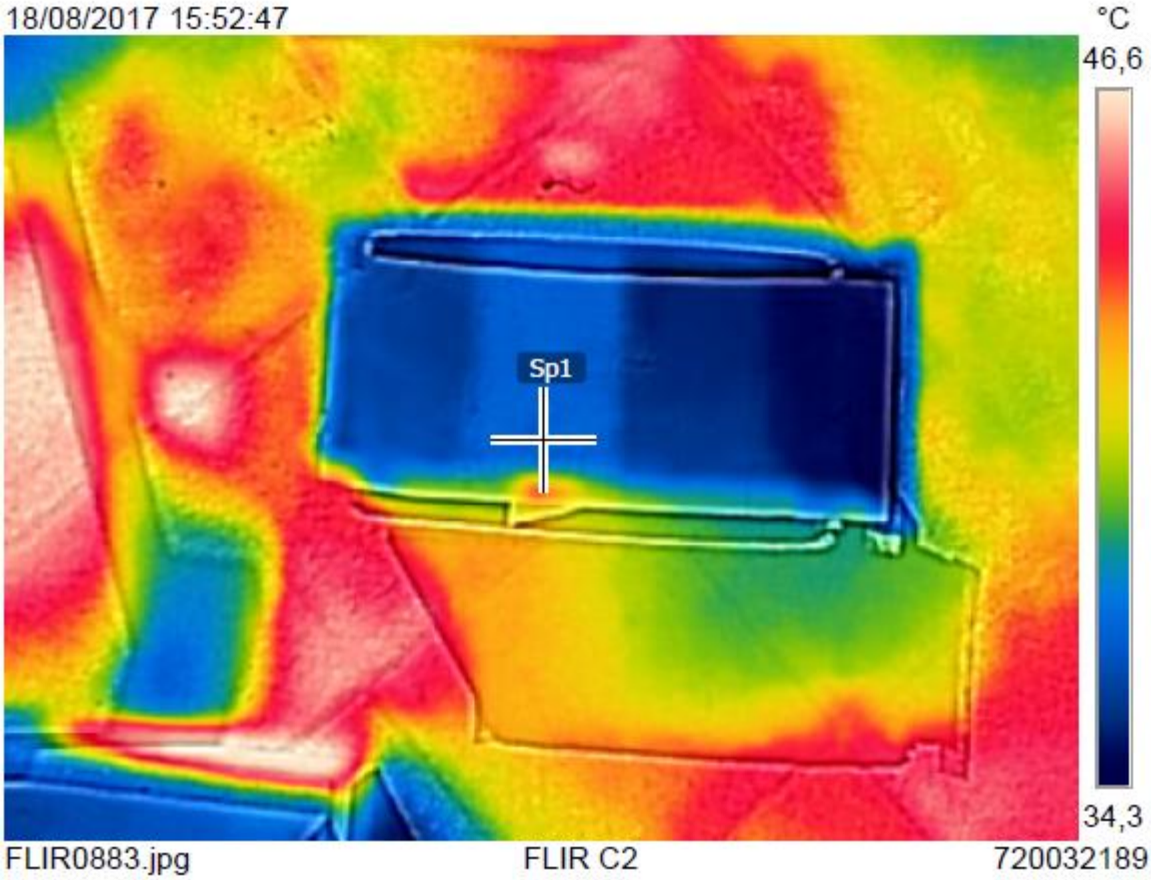


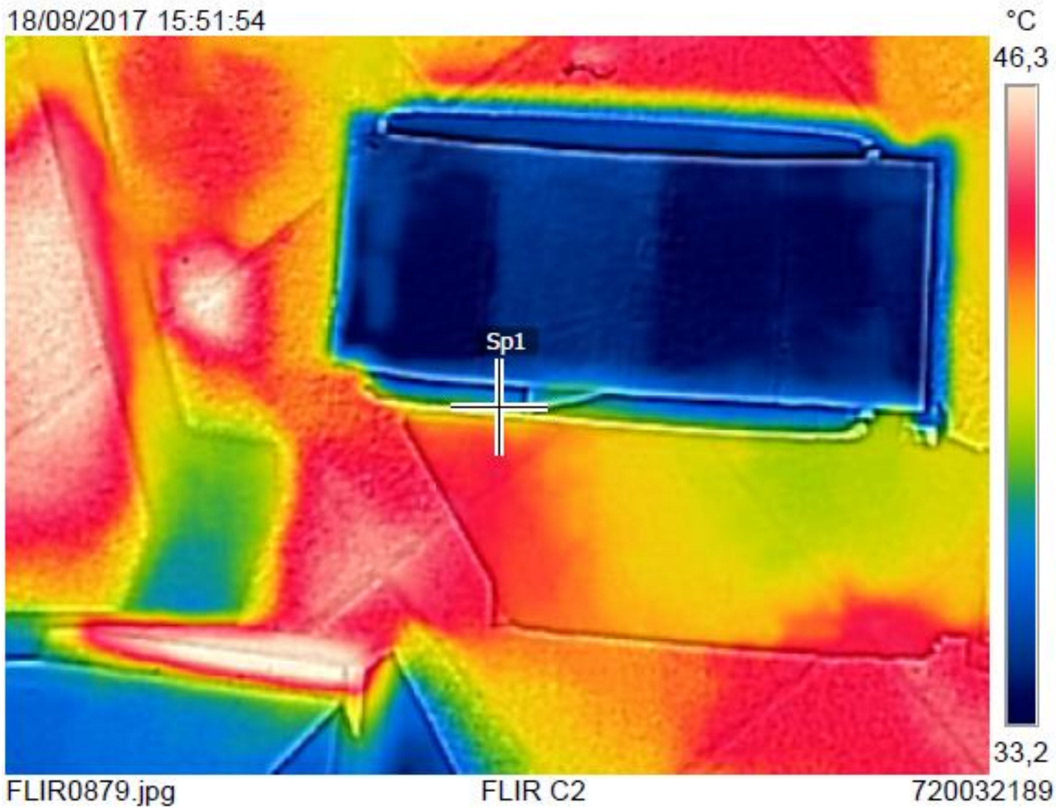


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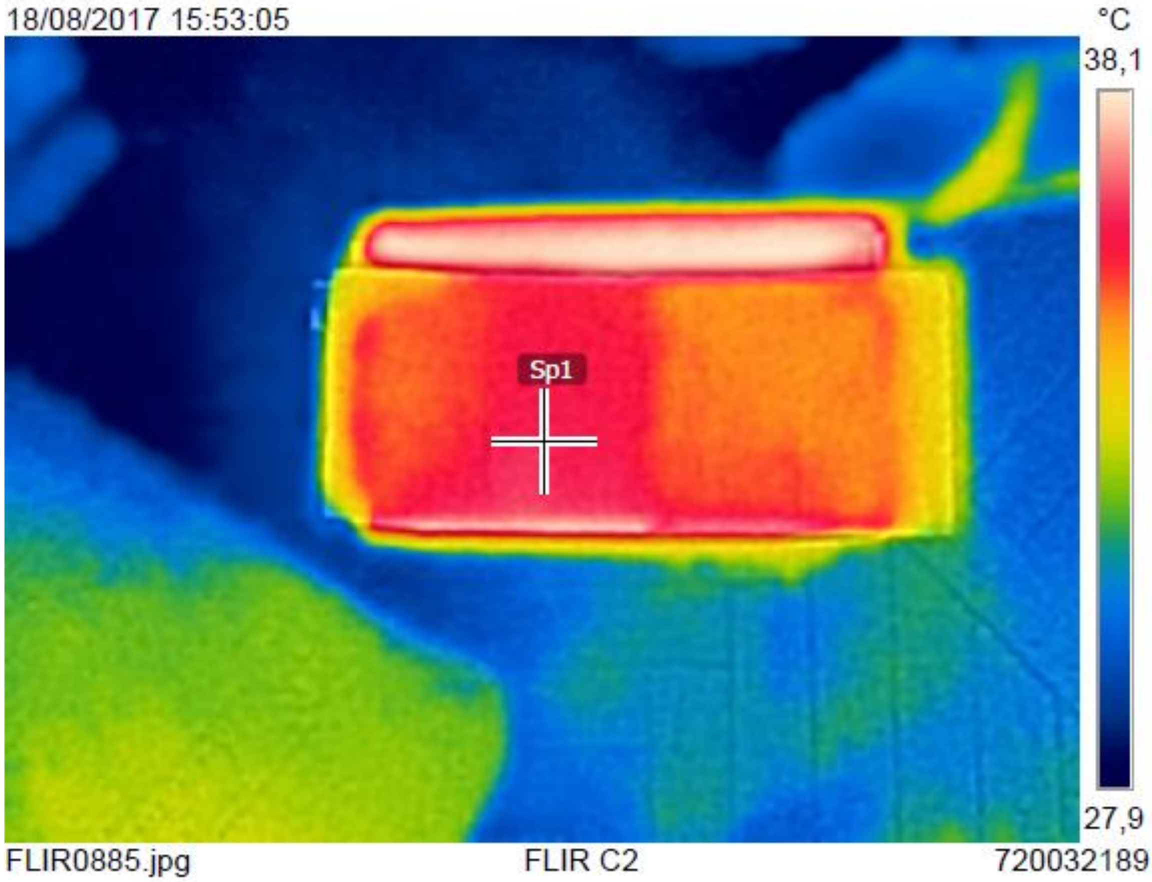


**DESIGN YOUR OWN EXPERIMENT -** How would you improve the experiment?

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## MoM Resources (http://www.mattersofmatter.eu/mom-materials/)

- MoM_PRESENT_Thursday_The 2 degrees challenge -materials for resiliency
- Ch2_TEACH_EN_Seeing NIR
- Ch8_TEACH_EN_Temperature&IR
- FCh1_TEACH_EN_window film for solar control
- MOM_Cool rooves_EXP_IT
- MOM_Lesliecube_EXP_IT

## References


1. http://www.nanoceramix.com/docs/NanoceramiX%20PicoceramiX%20Nanotermica%20-%20Brochure%202015.pdf free download of the brochure (IT) with nice SEM pictures of the nanospheres and lots of clear illustrations on mechanism and effects
2. https://www.dispersions-pigments.basf.com/portal/streamer?fid=560474 (EN)
3. www.iuav.it/SISTEMA-DE/Archivio-d/approfondi/.../Carattin-lex-cool-roof.pdf
4. www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema.../rds-146.pdf
5. http://fisicatecnica.pbworks.com/w/page/13977816/09%20Irraggiamento%201
6. Cool Roofs come rimedio alla hurban heat island A.Muscio UniMORE(pdf free download - just google the title)
7. http://www.nrs.fs.fed.us/pubs/gtr/gtr-p-94papers/32bristow-p94.pdf (Parks and the Urban Heat Island: a longitudinal study in Westfield, Massachussets" - Robert S. Bristow)
8. http://coolcolors.lbl.gov/assets/docs/OtherTalks/Advances-in-measuring-solar-reflectance-2009-06-30.pdf


## Where to buy

- At colour paint shops you can buy conventional thermal paints and now also "cool roof " paint, Surfapaint (NANOSILV), Nanoceramix are the ones we were able to find in our area.

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- Thanks to AESS Modena for lending samples, offering support, knowledge transfer and a free seminar
- Thanks to NANOSILV for donating samples to our project for testing



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