Warm colours and cold

By Peter Svane[1]

Surfaces are heated by the sun, but the temperature does not only depend upon absorption and reflection of visible light. The near infrared part of the spectrum is equally important; heat emission by long wave infrared radiation also plays a role, and so does the emissivity of the surface. Whether you wish surfaces to be heated as much as possible by the sun or they should be kept cold it is useful to understand the conditions controlling radiation in a wider part of the electromagnetic spectrum than just its visible part.

Colours

"Colour" is an impression in the (human) brain. When light enters the eye, the brain is interpreting the signal translating it to red, green etc. Normal humans can do this only with wavelengths between 400 and 700 nanometer (nm). This part of the electromagnetic spectrum is called "visible light"

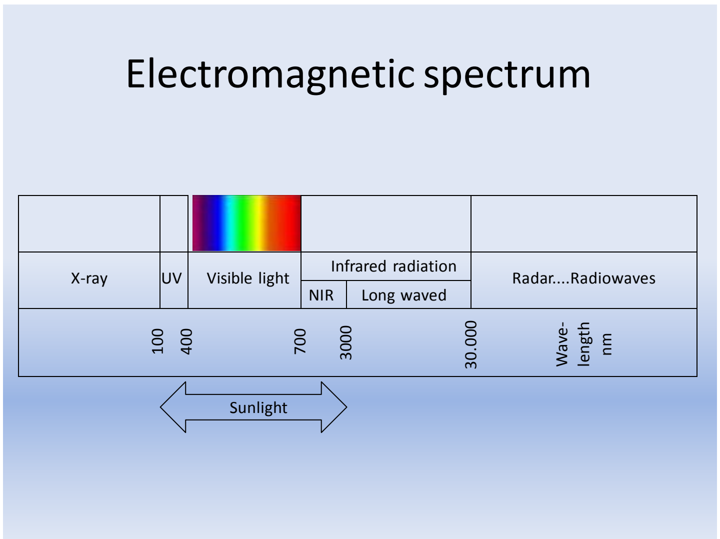

Fig. 1) Simplified overview of the different parts of the spectrum. Visible light only makes up a tiny part of the entire spectrum; in the figure its width is exaggerated. The limits between the different bands are subject to discussion; some sources e.g. state that the infrared region first ends at 1.000.000 nm (1 mm)

A red colour is perceived as red because the surface *absorbs* the other wavelengths in the visible region, i.e. blue, green and yellow. Contrary the red wavelengths are *reflected*

The visible impression of the red colour however does not reveal what is happening in the other parts of the spectrum – for instance whether the surface absorbs or reflects ultraviolet "light" and infrared radiation; that cannot be seen – but it can be measured.

[1] Peter Svane, Coating Consultancy Copenhagen. www.overflade.dk

The rays of the sun are filtered by the atmosphere (luckily, because that removes the most aggressive wavelengths) Less than half of the radiation reaching the earth's surface is visible light, and only 5 % is UV-radiation, however this part plays an important role in a material's degradation, sun tanning etc. Its role in heating of surfaces nevertheless is insignificant – what counts here is the visible light and the infrared radiation.

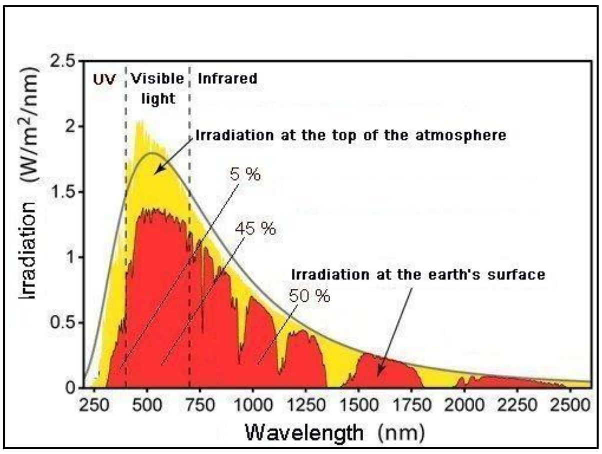

Fig. 2) The spectral composition before and after passing through the atmosphere (Courtesey to ASTM G-173-03). 5 % of the energy is in the UV-region at the earth's surface, 45 % is visible light, and 50 % in the near infrared (NIR) part of the spectrum

Heating

When the sun is shining on a red tiled roof it heats up because the surface absorbs a part of the incoming spectrum (the "irradiation"). A red roof absorbs blue, green and yellow light – but not red. According to fig. 3 we may assume that the roof at least absorbs around 30 % of the energy from the incoming sunlight

But what about the remaining part of the spectrum? - We don't know. Maybe the roof absorbs in the infrared and in the ultraviolet region too, maybe not. The only thing we know for sure is that it does not absorb the approximately 15 % of red light, for that is reflected. So, the roof absorbs a minimum 30 % and a maximum 85 % of the irradiation. Obviously there will be a large difference between the two extremes in the resulting heating up of the roof.

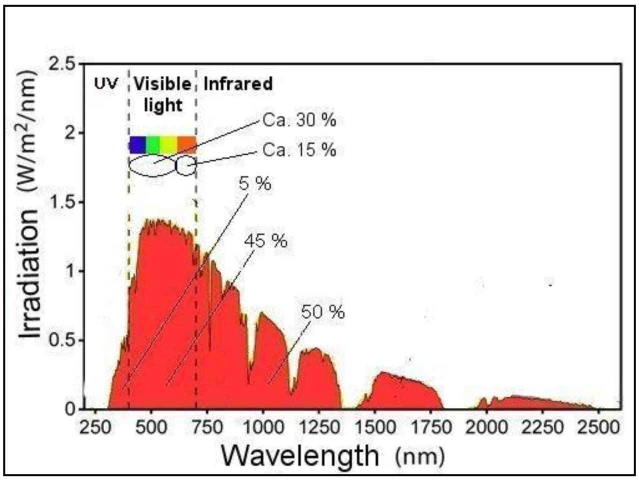

Fig. 3) Irradiation at the earth's surface (at sea level). A red surface absorbs blue, green and yellow light; that corresponds to appr. 30 % of the incoming energy. The surface does not absorb red light (ca. 15 %); but it takes measurements to reveal how much of the energy is absorbed in the non-visible regions (UV and NIR that together make up 55 % of the spectral energy)

A black surface will absorb virtually all visible light, i.e. minimum 45 % of the incoming radiation. But, because the surface is black it will not necessarily absorb in the non-visible regions. Maybe it does, maybe not. Accordingly the absorption minimum will be 45 %, and it may go as high as 100 %

Finally a white surface reflects all visible light, but not necessarily radiation in the non-visible regions. The absorption consequently may be anything from 0 to 55 %. The three examples are shown in fig. 4.

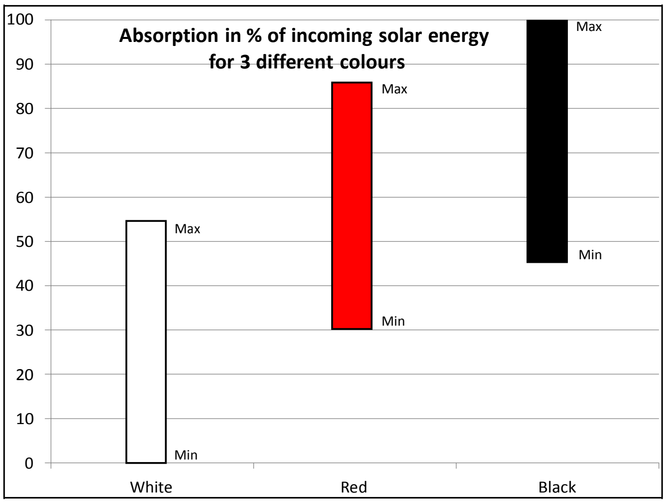

Fig. 4) Generally it seems that darker colours absorb more energy from the sunlight than light colours. In specific cases the distribution may however be quite different; that depends upon how the surfaces absorb non-visible "light". According to the diagram one might for instance imagine a white surface with 55 % absorption, and a black that only absorbs 45 %. In that case the white surface would reach a higher temperature in sunlight than the black one.

Cooling

The red tiled roof heats up when the sun is shining; the roof absorbs energy. But the temperature rise is not unlimited because the tiles also dissipate energy to the surroundings. At equilibrium – i.e. when the outgoing energy corresponds to the incoming – the temperature stabilises. See fig. 5

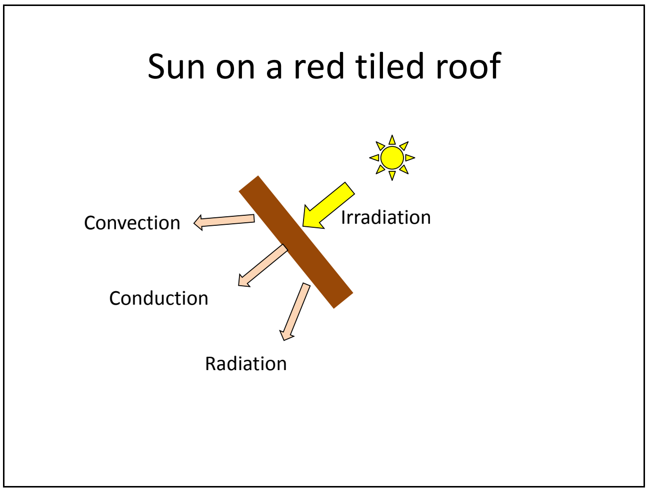

Fig. 5) The sun heats up the roof to a temperature where the incoming energy is in balance with the outgoing. Some energy is removed by convection, some by conduction (to the roof construction), and the last part is radiated as long wave infrared radiation.

Convection and conduction depend upon local conditions, e.g the design of the construction. At this stage we will concentrate on the part of the energy that is removed as radiation

Any body that is warmer than its surroundings emits heat by radiation. This is true down to the absolute zero – 273 °C or 0 K (degrees Kelvin)

The radiated energy depends strongly on the temperature – the radiation increases witht he 4th power of the temperature (T) measured in K i.e. it is proportional with T^4 (Stefan-Bolzmanns law)

The wavelength of the radiation is inversely proportional with the temperature (Wien's displacement law)

The conditions about the radiation's energy and wavelengths are shown in fig. 6. It transpires that:

- the radiation covers a broad part of the spectrum – not just a single sharp peak: the curves are wide and soft

- the energy of the sunlight peaks in the visible spectrum (around 600 nm), whereas the curve for "ambient temperature" i.e. around 25 °C, has its maximum at appr. 10.000 nm; that is in the infrared region - more precisely in the long wave infrared part of the spectrum.

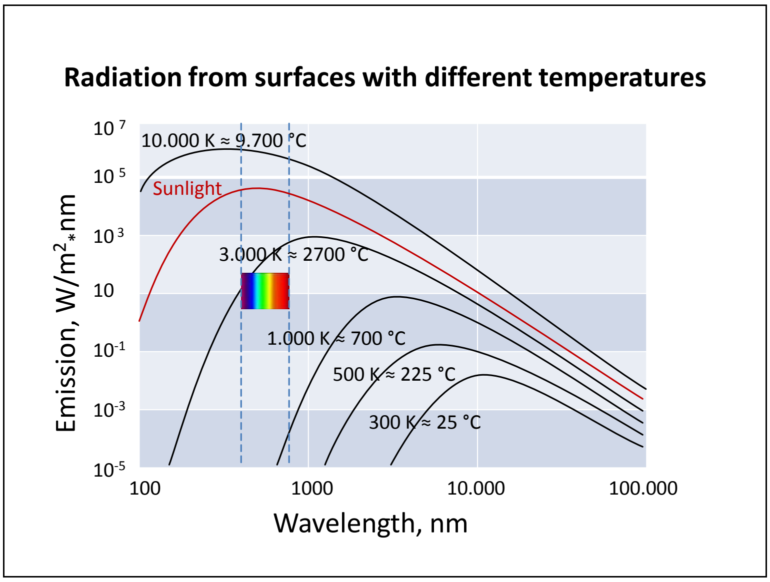

Fig. 6) Energy and wavelengths of radiation from surfaces, depending on temperature. The temperature of sunlight is around 6.000 K (with inspiration from Wikimedia commons user Sch.)

So, the red roof tile in fig. 5 receives sun-energy from wavelengths with a maximum at 600 nm (100-3000 nm). The tile is heated – maybe to 40 °C, and then radiates energy with wavelengths from 3.000 to 200,000 nm with a maximum around 10.000 nm.

Emissivity

We have seen that the radiation from surfaces depends on the temperature, but there is another factor too: the *emissivity* of the surface. This property describes how efficient the radiation is in the various parts of the spectrum. If the radiation is 100 % in a section of the spectrum, the emissivity here is 1,0 ([a]).

Most surfaces have an emissivity close to 1 (ca. 0,95) in the long wave infrared section; therefore they easily radiate energy at temperatures between 25 and 100 °C; that also applies to coated surfaces no matter which binder or colour. A black surface accordingly emits its heat as willingly as a white one.

The main exception is shiny metallic surfaces. They have low emissivity (~ 0,3) and therefore radiate heat much slower than most other surfaces. They also absorb heat at a lower rate, because the absorption – even in the sunlight part of the spectrum – is low. A shiny metallic roof therefore takes time to heat up in the sun, but it also cools down slowly. The phenomenon is applied in thermo flasks with silvery surfaces on the glass insert.
“Metallic paints” – paints that are boosted with metallic-shining pigment flakes – probably will behave as hybrids between “normal” paints and shiny metal surfaces, i.e. their emissivity will be somewhere between 0,3 and 0,95

[a] If the emissivity is 1 in the whole spectrum, the surface is called ”a black body”

Heat reflective coatings

Coated surfaces absorb (and reflect) sunlight as previously described. A green colour thus absorbs the red, yellow and blue parts of the visible spectrum. The absorbed light heats up the surface. If you want to keep the temperature as low as possible you must consider the remaining parts of the solar spectrum, particularly the NIR-section. Pigments that reflect as efficient as possible in the near infrared region should be preferred; remember that approximately half of the sunlight's energy is invisible NIR-irradiation. See fig. 7.

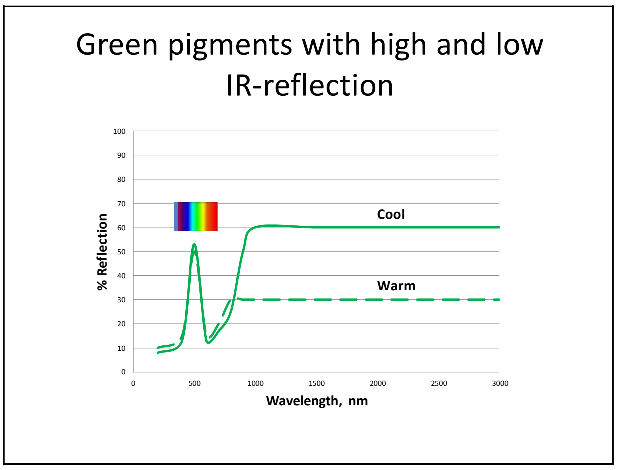

Fig. 7) Theoretic example showing two green pigments; one ("cool") with reasonable NIR-reflection, whereas "warm" absorbs NIR. The latter will absorb more energy and therefore get warmer than the former.

Nature brings inspiration - it appears that the green colour – chlorophyll and carotenoids - in plant leaves actually have relatively high NIR-reflection. See fig. 8 where the reflection-spectrum for natural leaves is compared with the very white titanium dioxide TiO_2.

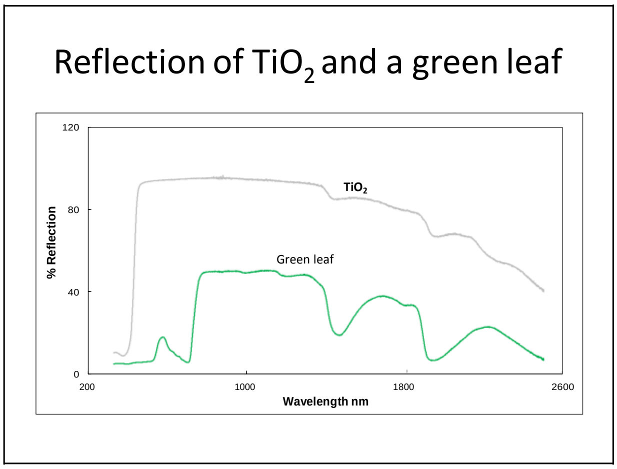

Fig. 8) Titanium dioxide reflects well both in the visible part of the spectrum and in NIR. Naturally the green leaf reflects green, but it is also reasonably efficient in NIR [1]

In a fairly new (2014) publication from ILF in Magdeburg, Germany (Institut für Lacke und Farben) Neumann et al. have tried an alternative pigmentation of a 2-pack PU-paint with a particular colour (RAL 3031 "Orient red") in order to reduce the heating up in sunlight. One of the results is presented in fig. 9.

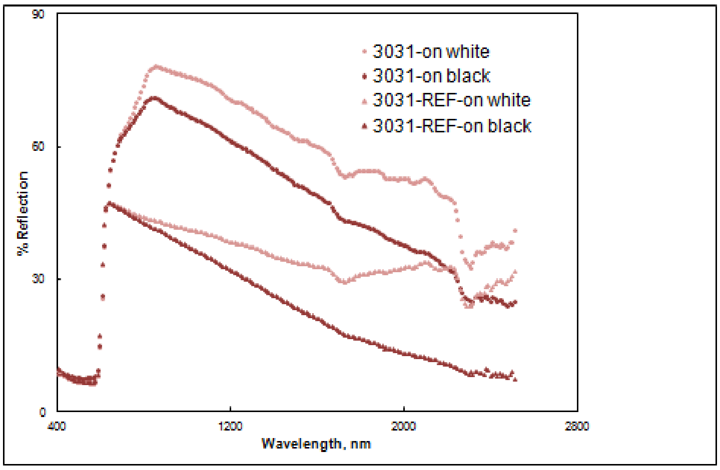

Fig. 9) The coatings (both RAL 3031 – "Orient red") have been applied to white and black contrast cards. First of all it appears that there is a difference between the experimental paint and the reference product – the experimental paint reflects better in NIR. But: the substrate "shines through"- that is in the NIR-section of the spectrum; visually the colours are the same. When the NIR-reflection apparently depends upon the colour of the substrate, it probably is because the long waved radiation manages to penetrate the coating layer – that is not the case in the visible part of the spectrum (1) .

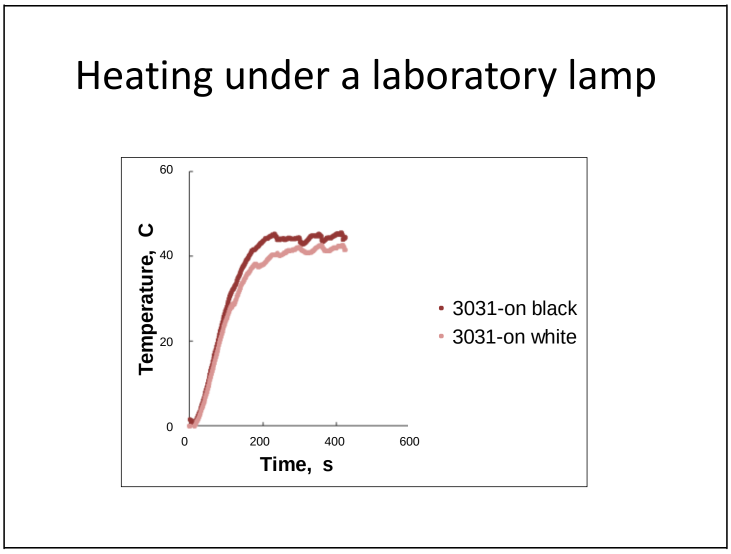

Fig. 10) Heating up one of the colours from fig. 9 under a laboratory heat-lamp. The coating on black substrate heats up more than the same paint on a white background (1)

Neumann et al. (1) can calculate the the temperature reduction by means of a property called ”TSR – Total Solar Reflection”. TSR is an expression of the total reflection integrated over the entire solar spectrum, expressed as a percentage. The higher the TSR, the lower the heat build-up.

Obviously the pigmentation is important for the reflection and heating up of a coating. In another investigation ([2]) from a pigment manufacturer (Heubach) L. Frischmann however demonstrates that both binders and fillers also play a role. One detail is the particle size – large particles reflect radiation with long wavelengths, small particles reflect shorter wavelengths. Frischmann’s paper has the title “Black, but nevertheless cold”. A black colour probably never ends up cold when the sun is shining, but with some effort it may end up just lukewarm.

What’s the use?

Surface temperatures are relevant issues when dealing with energy; heating and cooling of buildings for instance. Temperature is also important for the degradation of materials; for polymer component’s expansion, contraction and in some cases even irreversible shrinking; for the thermal and moisture dependant deformations of wooden surfaces – included their tendency to form cracks. Finally most degradation processes are promoted by higher temperatures – something that applies to coatings too. Coloured coatings degrade at different rates, this is partly due to differences in formulation, different PVCs and hence mechanical properties. However it is overlaid with temperature effects

Acknowledgements

Thanks to Jonathan Graystone, Paint Research Association in London, for constructive comments and improvements

Literature

[1] With kind permission from Neumann, B. og C. Dreyer: Hitze verhindern und sparen. Farbe und Lack 01, 2014 p. 52-57

[2] Frischmann, L.: Schwarz und trotzdem kalt. Farbe und Lack 08, 2008, p. 30-33