Butterfly Wings

Biomimetics of Thermoregulation

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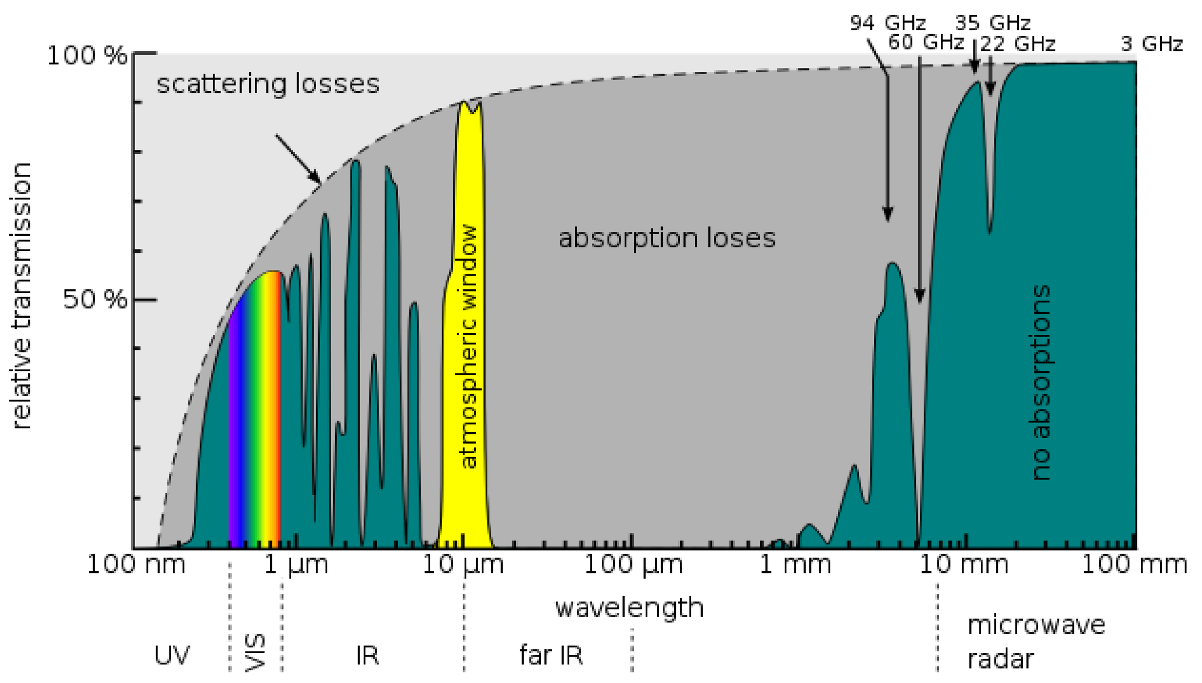
Passive Radiative Cooling (PRC)

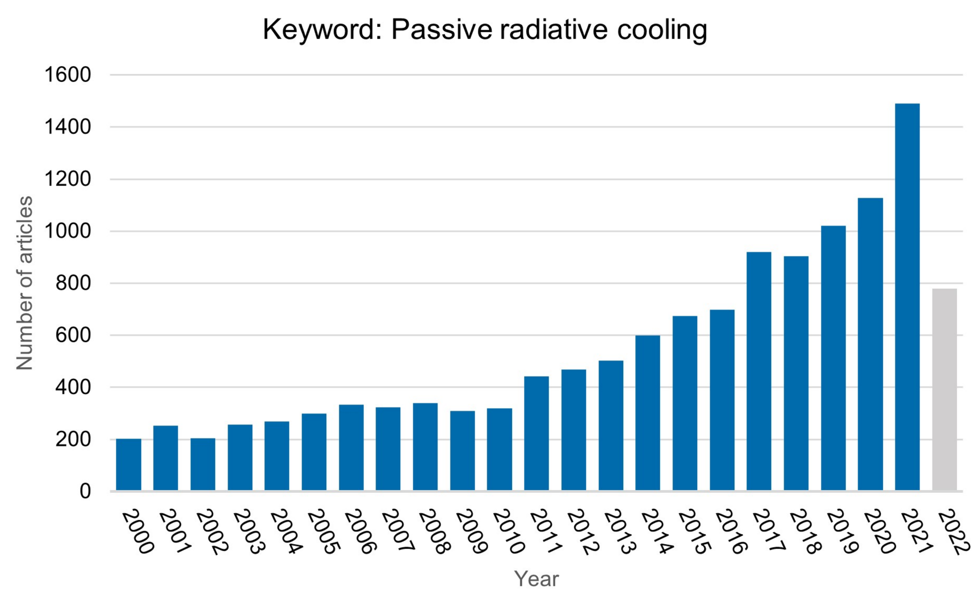
Passive radiative coolers (PRC), through material or nanostructure, have a very high reflectance in nearly all wavelengths, but from 8-14 μm. In this region the atmosphere is transparent (atmospheric transparency window) and with selective emission in this spectral area, cooling can occur with outer space as heat sink. With those properties properly met, the effect is possible even under direct sunlight and with no extra energy conversion. Although it is dependent on the weather, it works best in dry places with clear sky.[2]



Transmission windows of the atmosphere

What for?

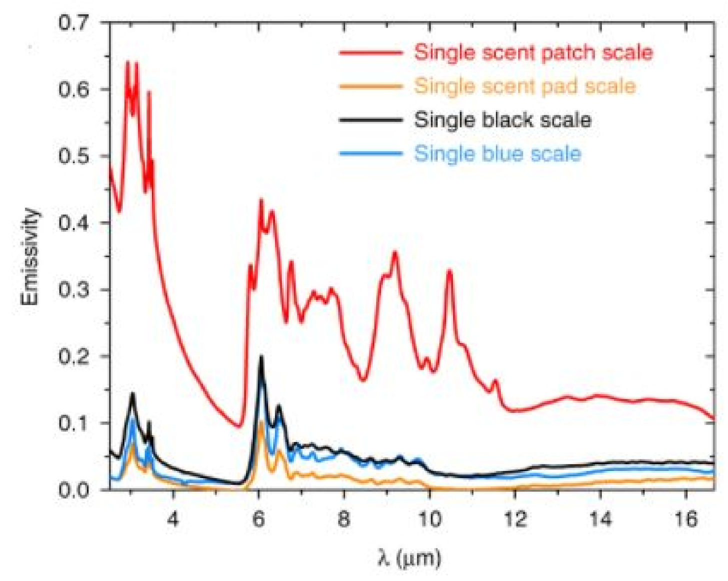
PRC is a topic with much research activity, because it can be used widely. Examples are in textile compositions, in refrigerated transport, for enhancement of the efficiency of solar panels or as energy saving approach in the cooling of buildings with a calculated saving potential of 21% under perfect conditions. This could also be an enormous help in tackling climate change. [2]



Number of articles per year published on ScienceDirect

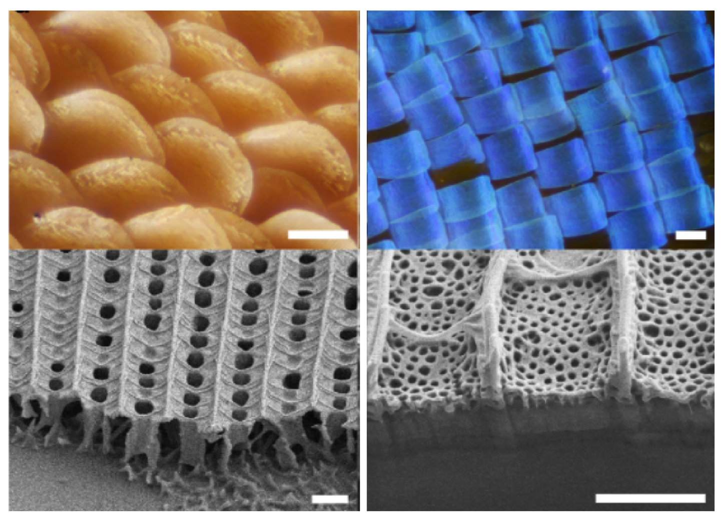
Recent Study

The thin wings of butterflies are not only lifeless tissue, but consist as well of living cells like veins or scent patches, which need an extra prevention mechanism from overheating. Scent patches are organs for pheromone production found in many male butterflies. A study discovered that in all 50 examined species, those parts remain cooler than others. This comes from a higher emissivity and therefore enhanced passive radiative cooling capability. The graph on the right shows the emissivity spectra of four different scales. It is apparent that the scent patch scale has the highest emisivity, which results from its specific nanostructure. Two scale types and their scanning electron microscopy (SEM) images from a male *Bistonina biston* are displayed below.

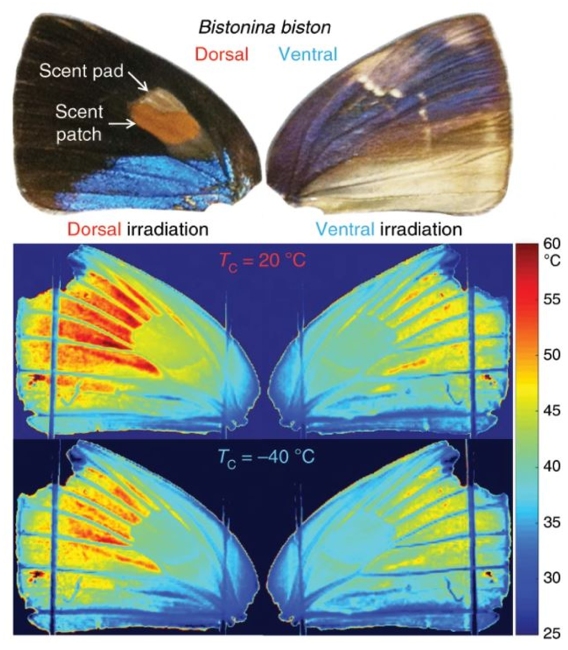


Emissivity of individual scales of *Bistonina biston* [3]

It is complicated to determine the exact wing temperature, because of the butterfly's semi-transparency in the infrared part of the electromagnetic spectrum. This leads to measurement artifacts due to the contributions of thermal radiation in the surrounding reflected from the wing and transmitted through it. Therefore, it had to be done in a specific way. At first, the infrared radiation is measured with a thermal camera. Secondly, with hyperspectral imaging, the transmissivity, reflectivity and emissivity are being determined. With this data, one can calculate the correct wing temperature, which is shown in the right picture below. [3]



Scent patch and blue scales of *Bistonina biston*: optical image (top row, scalar bar 50 μm) and SEM images (bottom row, 2 μm) [3]



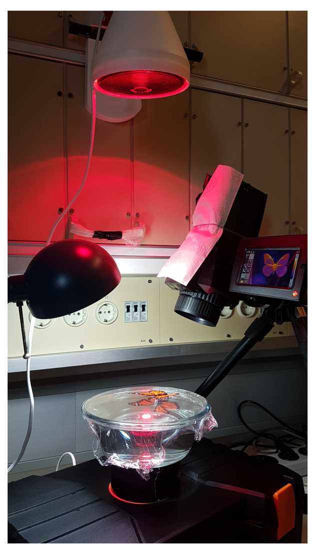
Real temperature distribution of *Bistonina biston* wings [3]

Experiment

In this study (ongoing bachelor thesis in technical physics) until now, various butterflies were investigated with a thermal camera (testo 890, resolution 640x480 pixel, spectral range 7.5 to 14 μm [1]). The objective was to compare exotic and domestic butterfly species and search for scales with radiative cooling properties.

Set Up

For irradiation two different lamps were used to mimic the sun as accurately as possible. One was emitting in the IR-A region and the other one in the visible spectrum. As heat sink a glasbowl, 18 cm in diameter and filled with cold water (9-13°) was used. The water had to be mixed and changed constantly to keep a constant background temperature. On a cling film on top of the bowl, the butterflies were placed. The thermal camera was positioned 13 cm above, at an angle of 15°.



Experimental set up

Results

For all 18 different butterfly species, the veins appeared to be the hottest on the wing. According to the paper [3], veins have an emission near unity, because of their physical thickness. The male *Danaus plexippus*, widely known as Monarch butterfly, has scent glands, which appeared hotter in the infrared image. Although it is not clear if the higher emission is due to their thickness or nanostructure. No other scent patches could be seen in either domestic nor exotic species.

Danaus plexippus with scent glands

Morpho achilles

Neptis rivularis

Outlook

To determine the real temperature of the different wing parts, it will be necessary to make a hyperspectral image in the spectral range of 7-14 μm and use these data for calculations. Following this study, the nanostructure of different scales is going to be examined via SEM. Especially interesting is the *Danaus plexippus*, due to his scent glands. The research objective is then to copy nanostructure, capable for passive radiative cooling on technically relevant materials, which ultimately can be applied in various fields.

Acknowledgements

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No butterflies where harmed in this study.

References

[1] Version 0981 8854/msp/I/08.2020. URL: https://www.testo.com/en/testo-890/p/0563-0890-X6#tab-downloads.

[2] XiaoZhi Lim. "The super-cool materials that send heat to space". In: *Nature* 577.7788 (Dec. 2019). DOI: 10.1038/d41586-019-03911-8.

[3] Cheng-Chia Tsai et al. "Physical and behavioral adaptations to prevent overheating of the living wings of butterflies". In: *Nature Communications* 11.1 (Jan. 2020). DOI: 10.1038/s41467-020-14408-8.