Solar Reflectance Index (SRI)
– Background and Spectrometric Determination (Hintergrund und Spektrometrische Bestimmung)

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- Motivation and background
- Derivation of the SRI value
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- SRI value examples for typical roofing and landscaping materials
- Correlations with other optical characteristics

Background – Urban Heat Islands

Compared to nearby rural areas,
the air temperature in urban areas is higher due to:

- Higher effective absorptance of solar radiation due to urban morphology
- Higher density of local (waste) heat generation
- Lower heat losses due to convection
- Less transpiration cooling by vegetation

Further information

- http://HeatIsland.LBL.gov
- http://epa.gov/heatislands/mitigation
- http://coolroofcouncil.eu

Background – Solar Reflectance Index (SRI)

Problems caused by urban heat islands:

- overheating of buildings
- higher sickness and death rates during heat waves
- high energy consumption for cooling

Solutions include:

- increase the solar reflectance of horizontal rooftop surfaces
- increase the thermal emissivity of horizontal rooftop surfaces

Solar Reflectance Index (SRI):

- a single measure of the effectiveness of a material surface in mitigating overheating

ASTM Standard defining the Solar Reflectance Index

Designation: E1980 – 11

Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces[1]

Solar Reflectance Index (SRI) – definition:

The SRI is the relative temperature of a surface (T_s) with respect to the temperature of the standard white surface (T_w) and the temperature of the standard black surface (T_b) under the standard solar and ambient conditions.

$$SRI = 100\,\frac{T_b - T_s}{T_b - T_w}$$

Designation: E1980 – 11

Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces[1]

Solar Reflectance Index (SRI) – definitions:

The SRI is the relative steady-state temperature of a surface with respect to the standard white surface (SRI = 100) and the standard black surface (SRI = 0) under the standard solar and ambient conditions.

Standard white surface: solar reflectance = 0.80, thermal emissivity = 0.90

Standard black surface: solar reflectance = 0.05, thermal emissivity = 0.90

Values > 100 and < 0 are possible in principle!

Designation: E1980 – 11

Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces[1]

Standard solar conditions:

Solar irradiance 1000 Wm^{-2}

Solar spectral distribution AM 1.5, (presumably direct), as specified in ASTM G 173-03

Ambient conditions:

ambient air temperature 310 K

sky temperature 300 K

convective coefficients of 5, 12, 30 $Wm^{-2}K^{-1}$ (significant only for low ε)

Designation: E1980 – 11

Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces[1]

Steady-state surface temperature determined by iterative solution or approximation to:

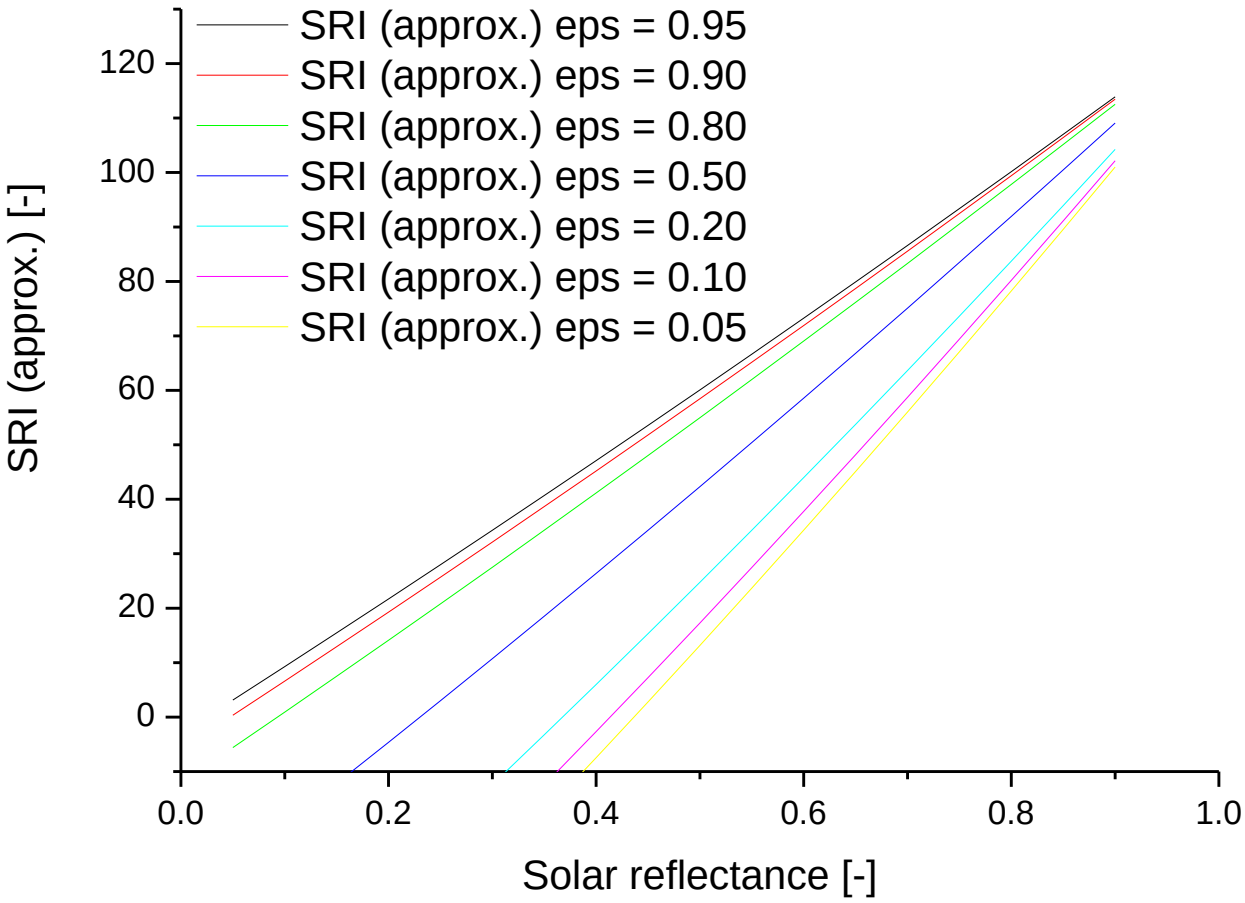
$$\alpha I = \varepsilon\sigma(T_s^4 - T_{sky}^4) + h_c(T_s - T_a) \quad (1)$$

where:

- α = solar absorptance = 1 – solar reflectance,
- I = solar flux, $W \cdot m^{-2}$,
- ε = thermal emissivity,
- σ = Stefan Boltzmann constant, 5.66961 x 10^{-8} $W \cdot m^{-2} \cdot K^{-4}$,
- T_s = steady-state surface temperature, K,
- T_{sky} = sky temperature, K,
- h_c = convective coefficient, $W \cdot m^{-2} \cdot K^{-1}$, and
- T_a = air temperature, K.

Dependence of SRI on solar reflectance

- linear dependence of SRI on solar reflectance (slope and intercept depending on thermal emissivity)

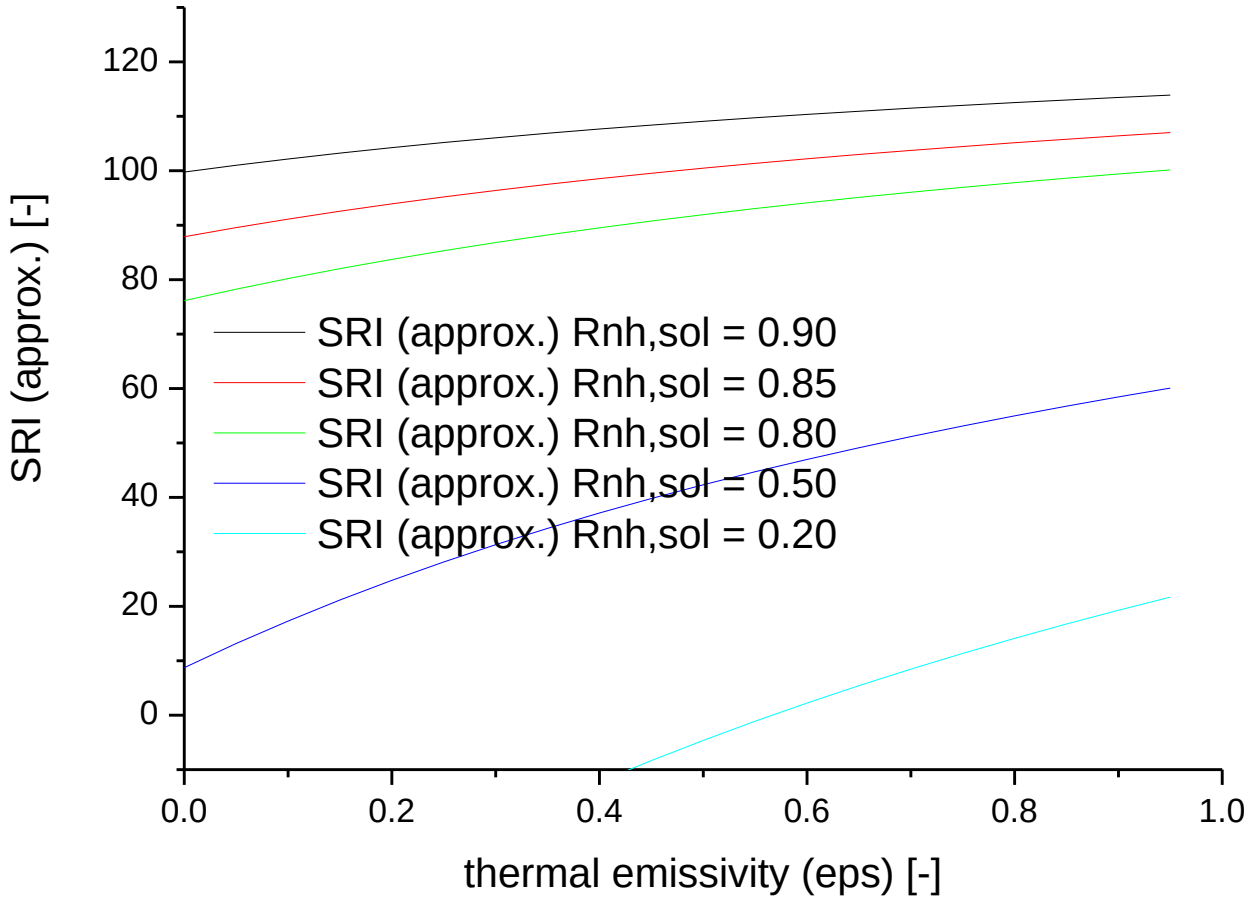


Dependence of SRI on thermal emissivity

- weaker dependence of SRI on thermal emissivity, particularly for high solar reflectance

-> the choice of black-body temperature (e.g. 300 K or 350 K) for determining thermal emissivity changes the SRI by less than 1 for typical dielectrics

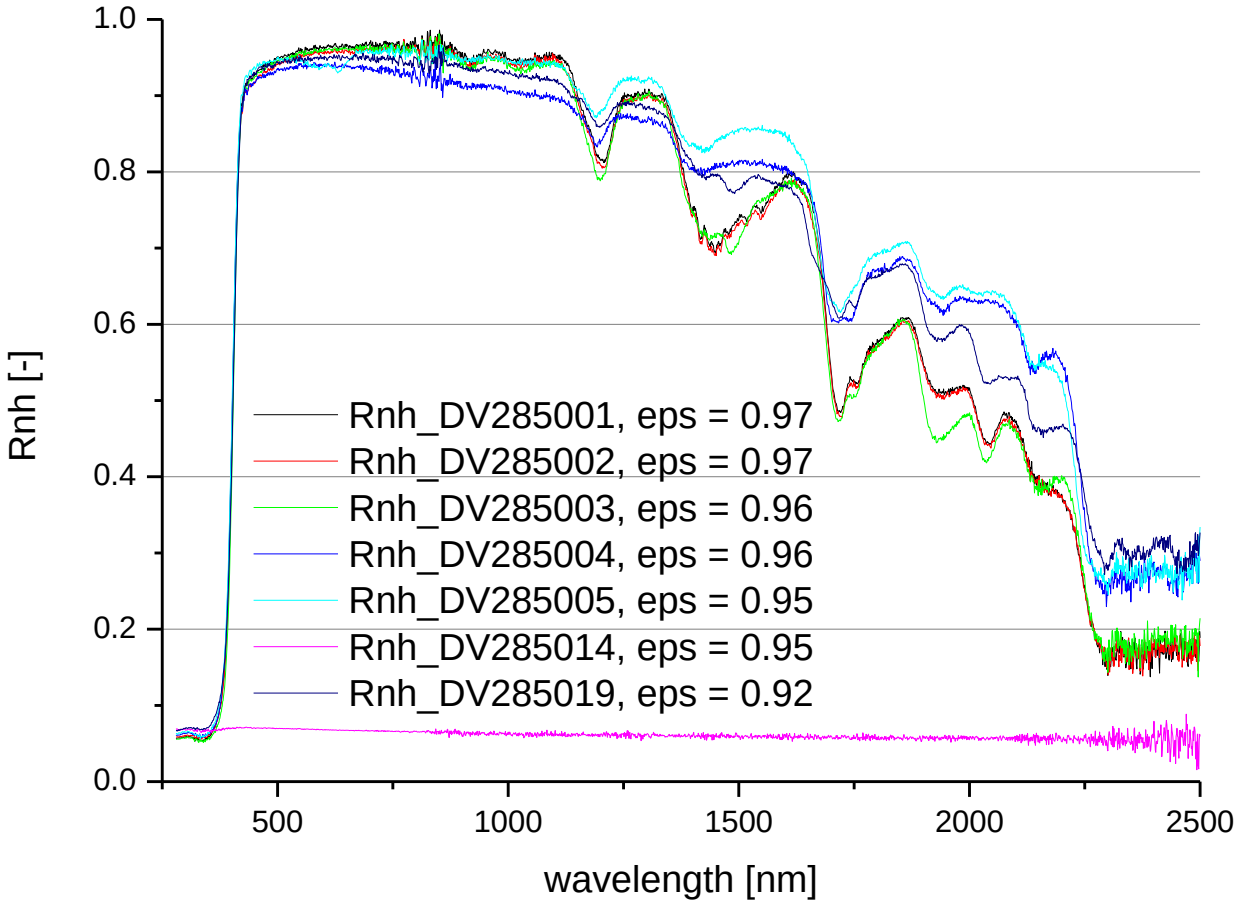
All following SRI values were evaluated with thermal emissivity for 300 K.



Reflectance spectra and thermal emissivity of white coatings and paints, and bitumen with gravel

- white coatings with Rnh,vis > 0.90 but more diversity in NIR

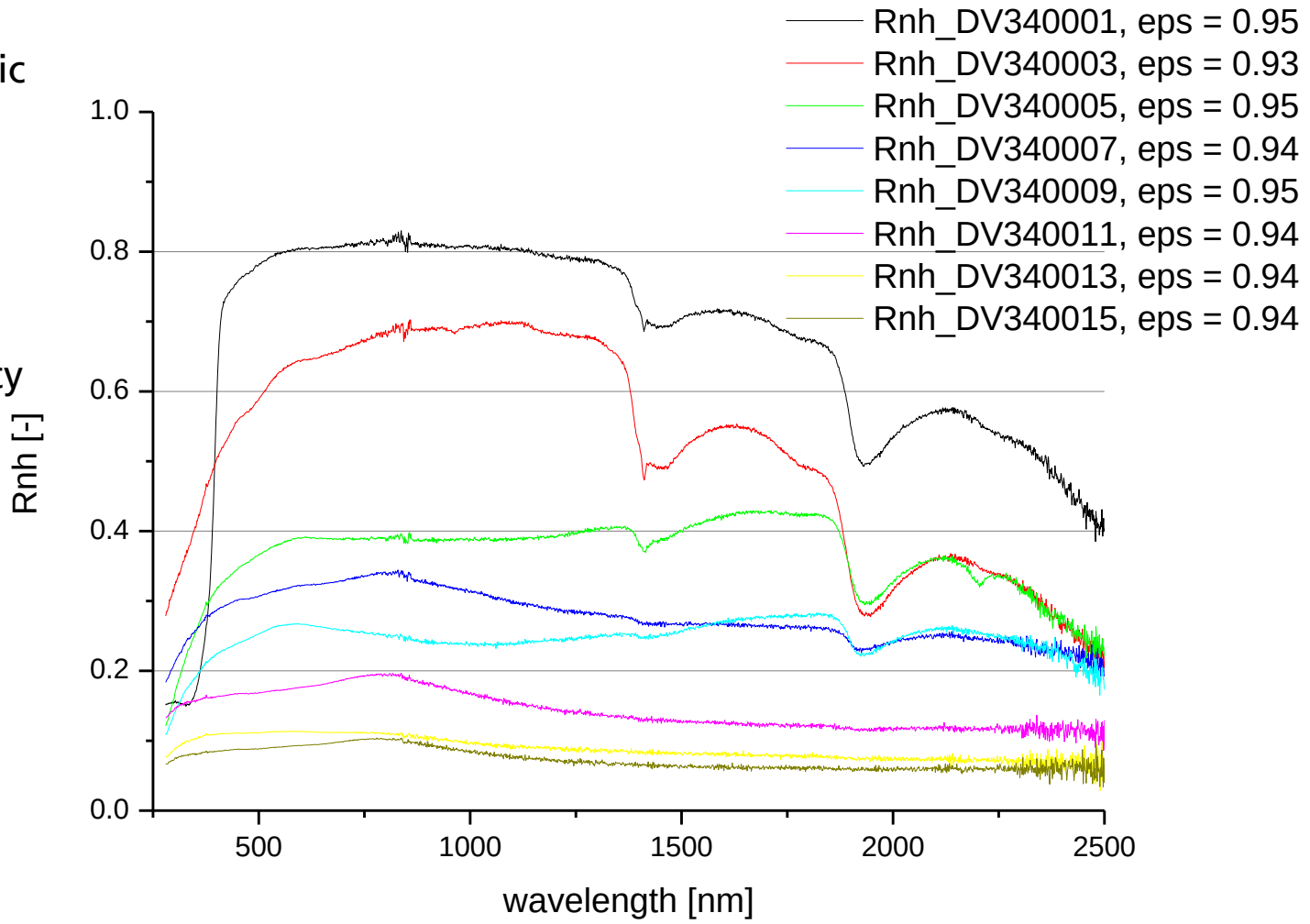
- thermal emissivity values between 0.92 and 0.97



Reflectance spectra and thermal emissivity of concrete pavers – white/grey/black

- almost monotonic gradation of reflectance from white to black samples in solar spectral range

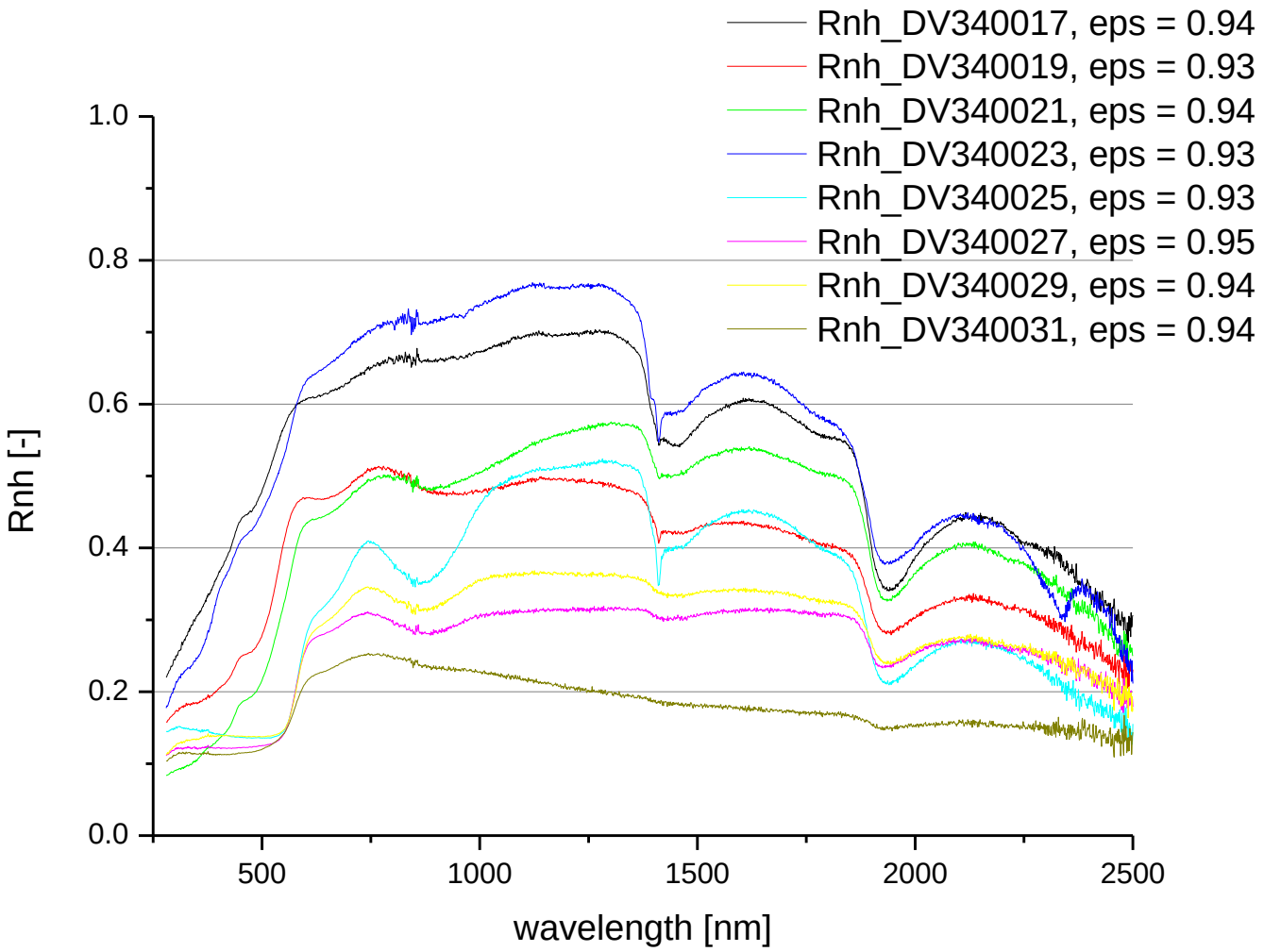
- thermal emissivity values all similar and high (0.93 – 0.95)



Reflectance spectra and thermal emissivity of concrete pavers – coloured

- more diverse spectra, as expected

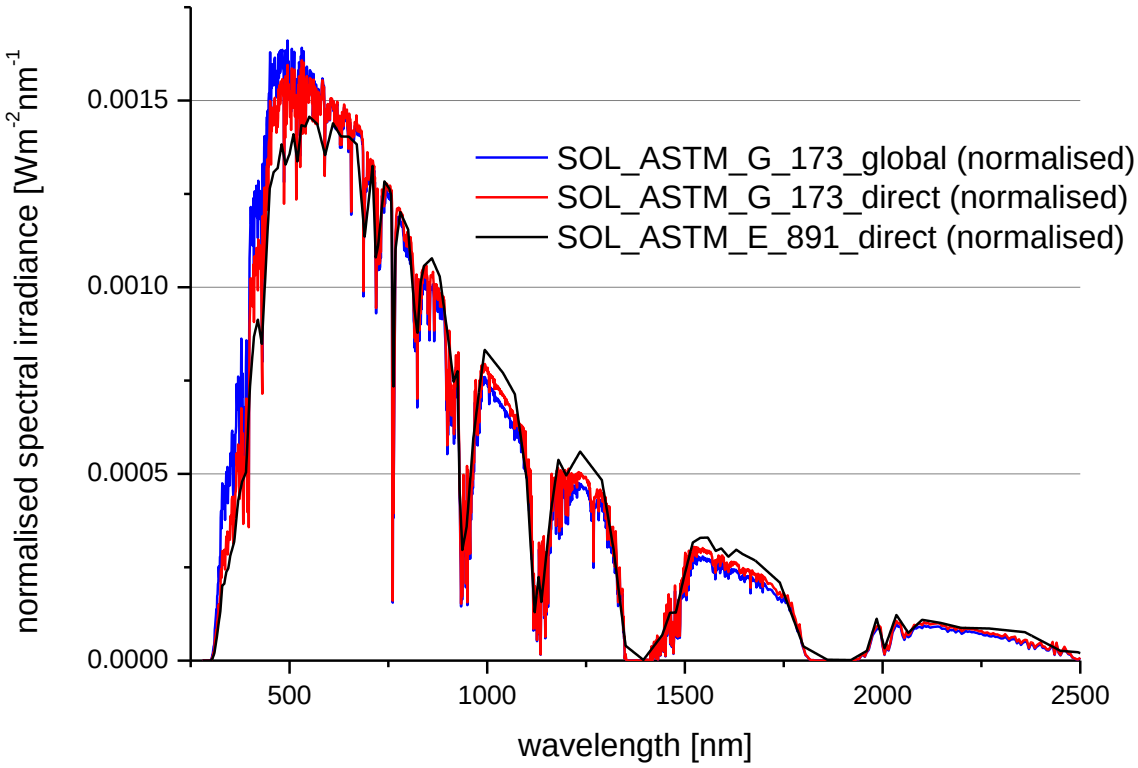
- thermal emissivity values all similar and high (0.93 – 0.95)



Weighting spectra to determine solar reflectance

- ASTM E 1980-01 (now withdrawn) specified ASTM E 891 "Terrestrial Direct Normal Solar Irradiance, AM 1.5"

- ASTM E 1980-11 (currently valid) specifies ASTM G 173 "Tables for Reference Solar Spectral Irradiance: Direct Normal and Hemispherical on 37° Tilted Surface" without indicating which Table



Effect of different solar weighting spectra

- effect greatest for coloured materials (not spectrally "flat")

  $\Delta Rnh_{sol} < 0.018$

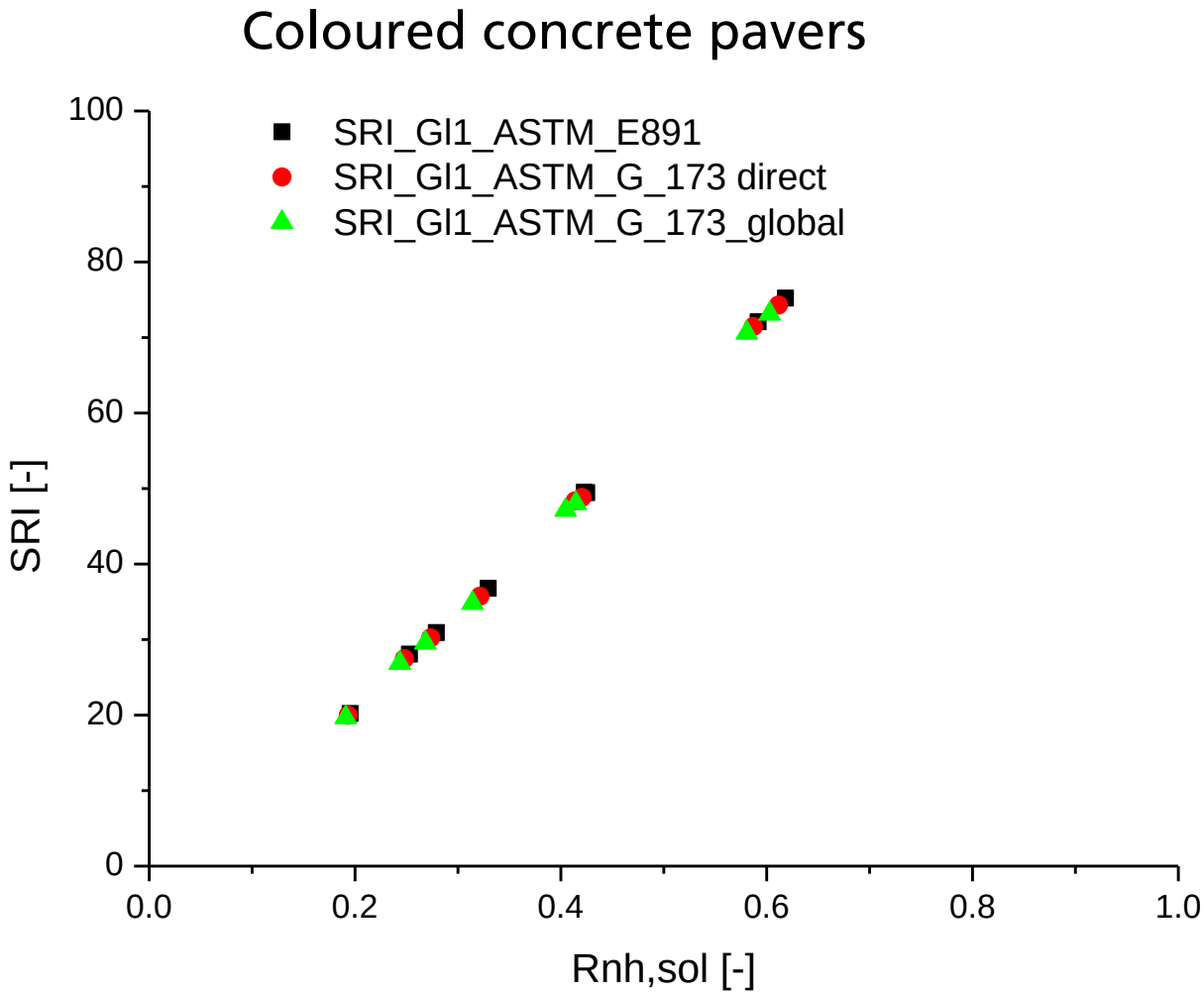
  -> $\Delta SRI < 2.4$

- effect still evident for white/grey/black materials (spectrally "flat" in visible range)

  $\Delta Rnh_{sol} < 0.009$

  -> $\Delta SRI < 1.3$

All following SRI values are evaluated with ASTM G 173 direct.



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Dependence of SRI on solar reflectance Rnh

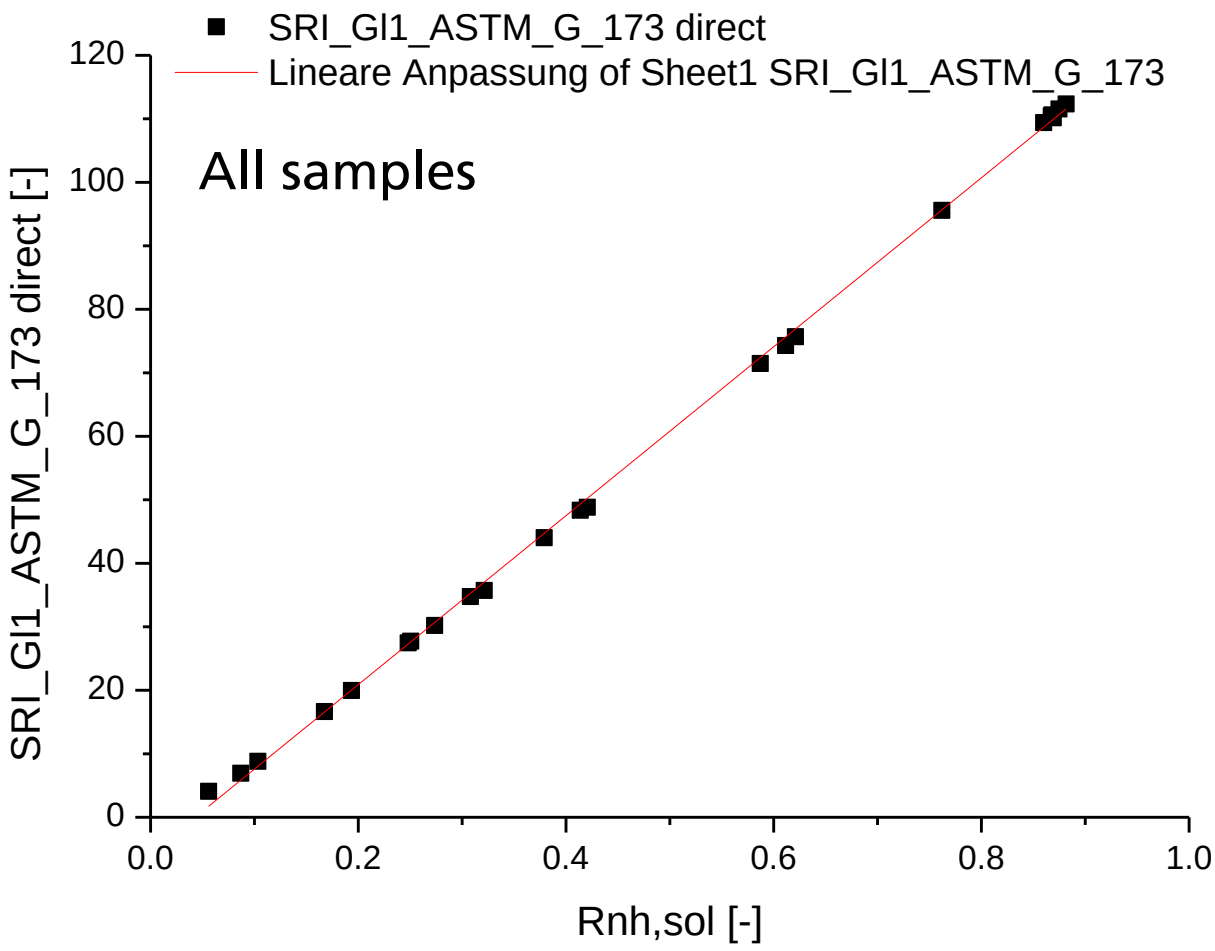
for concrete pavers, white coatings and bitumen with gravel

- well described by a linear fit as expected for the limited range of thermal emissivity sampled here (0.92 – 0.97)

Result of linear fit:

$SRI = -5.71 + 133.0 * Rnh_{sol}$

$R^2 = 0.999$



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Correlation of SRI with visible reflectance Rnh

for concrete pavers, white coatings and bitumen with gravel

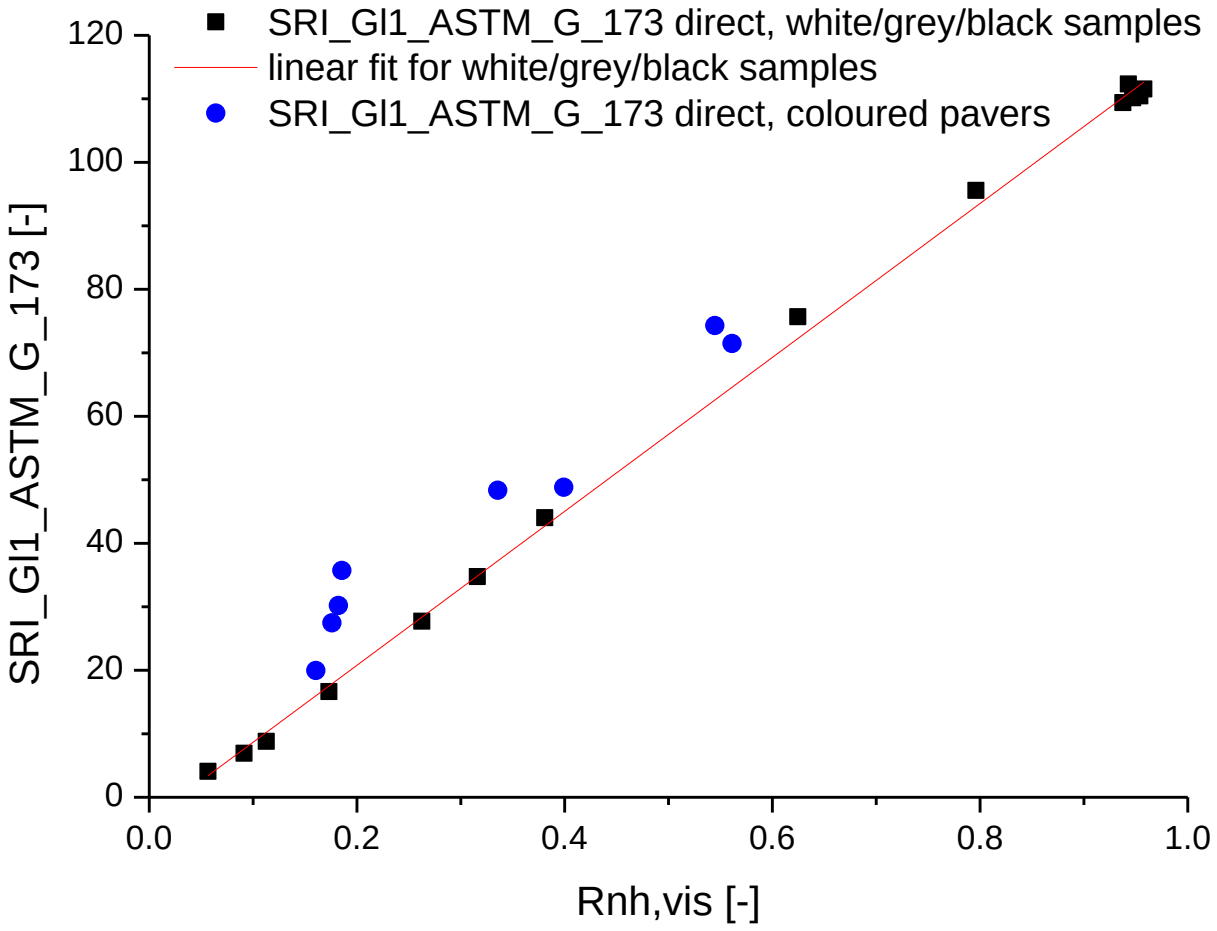
- white/grey/black samples well described by a linear fit for the limited range of thermal emissivity sampled here (0.92 – 0.97)

Result of linear fit:

$SRI = -3.45 + 121.2 * Rnh_{vis}$

$R^2 = 0.999$

Coloured pavers deviate markedly toward higher SRI values.



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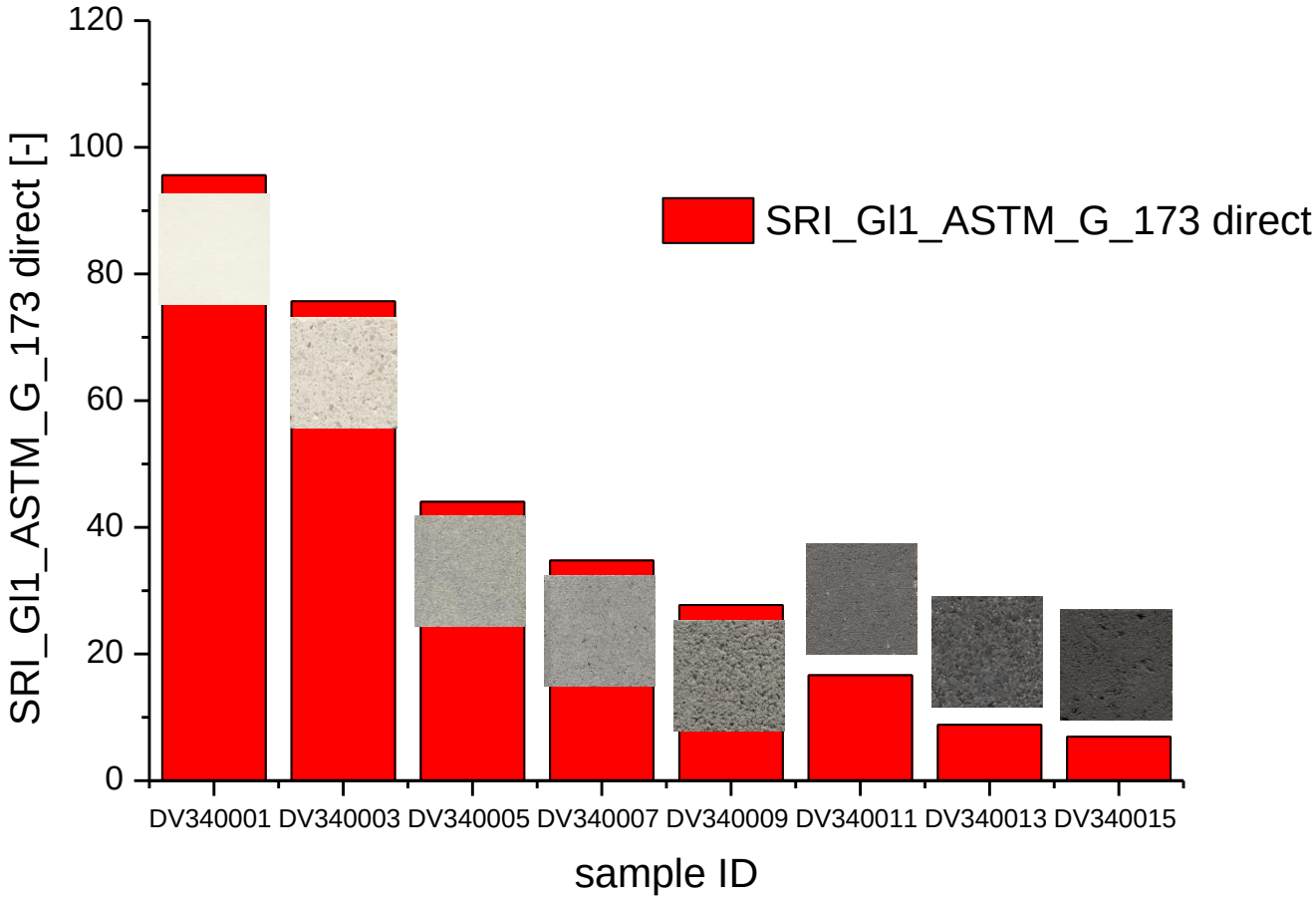
SRI values and visual appearance

of white / grey / black concrete pavers

- qualitative gradation of "darkness" corresponds to order of SRI values

- white coatings and paints with SRI values > 100 (not illustrated here) appear "whiter than white"



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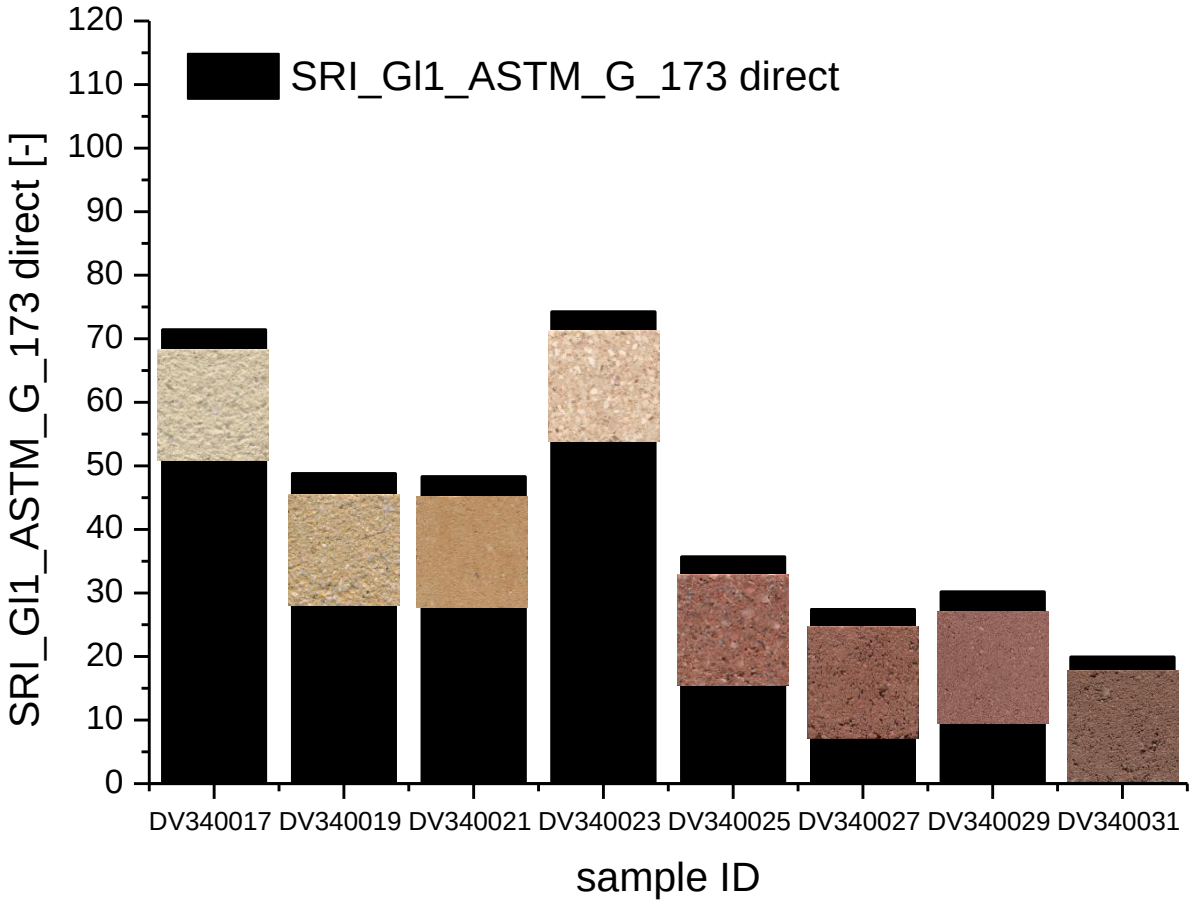
SRI values and visual appearance of coloured concrete pavers

- qualitative impression of "darkness" of coloured samples is not a good indicator to SRI value due to spectrally selective absorption in visible range
– cf. graph of SRI versus Rnh_{vis} values



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Summary

- Although the solar reflectance index depends on both the solar reflectance and the thermal emissivity, it is more sensitive to variations in the solar reflectance.
- The solar spectrum used to determine the solar reflectance should be specified when SRI values are reported.
- The visual impression of "darkness" is a good qualitative guide for ranking the SRI values of the white/grey/black roofing and paving materials presented, but not for coloured materials.

Thank you for your attention!

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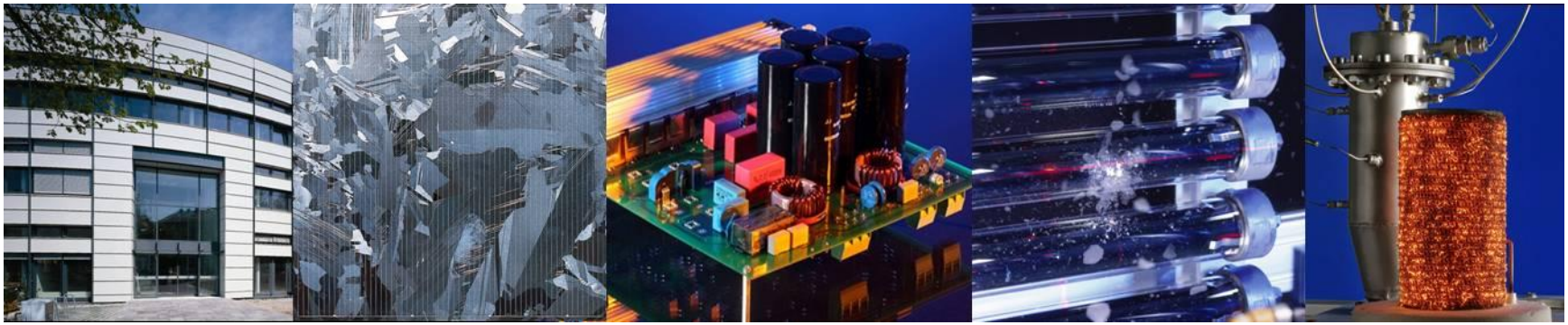

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