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Materials for outdoor curtains and awnings as a solution for improving thermal comfort and mitigating urban heat island

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ABSTRACT

Outdoor modular structures with curtains and awnings may be an effective solution for mitigating Urban Heat Island, in particular for Cooling Dominated Zones (CDZ). The choice of suitable materials for outdoor shadings plays a fundamental role, especially in dense urban areas, because of high solar irradiance, low ventilation and high mean radiant temperature which might reduce the thermo-hygrometric comfort in summer conditions. For that reason, outdoor textiles materials with high solar reflectance upwards and low thermal emittance downwards could represent an effective microclimate mitigation strategy: textiles with low thermal emittance downwards, in particular, contributes to reduce the infrared radiation towards the covered area, which may ensure better thermal comfort conditions. Furthermore, materials with retro-reflective (RR) capabilities could help to reduce the amount of radiation that reaches the urban surfaces, as they reflect the incoming solar radiation mostly towards the incident beam direction. In this context, the present paper is aimed at studying textile materials for outdoor curtains and awnings in terms of their solar, radiative and RR characteristics, in order to improve human thermal comfort conditions under the coverings. For this purpose, a novel, glass fibre-based material for outdoor shading applications was analysed in terms of thermal emittance, spectral reflectance and directional reflectivity. Results of the experimental characterization show that the tested samples present a good global reflectance, while a high thermal emittance value has been observed. Directional reflectivity characterization reveals that all samples present a RR trend for incident light directions near the perpendicular.

Introduction

The unstoppable urbanization and the continuous rise of population that lives in cities (UN DESA 2017), together with a low presence of vegetation and permeable surfaces, contributes to the occurrence of the so-called Urban Heat Island (UHI) phenomenon. UHI consists in higher air temperatures that occur in dense urban environments with respect to the surrounding rural areas (Oke 1995) and it is particularly affected by solar and radiant characteristics of built surfaces, such as building coatings and paving materials. Furthermore, the higher occurrence of Urban Heat Canyon configuration in dense urban environments could create Inter-Building effects, consisting in multiple reflection of the solar radiation within the urban canopy, and thus contributes to exacerbate UHI phenomenon. The higher air and mean radiant temperatures that occur in dense urban areas, along with a lower ventilation, could negatively impact on human outdoor thermal comfort (Frohlich, Gangwisch and Matzarakis 2019). Therefore, built surfaces have a great potential in the mitigation of UHI: solar reflectance

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and thermal emittance capabilities, in fact, could strongly influence urban microclimate, especially in terms of summer air temperature and mean radiant temperature distribution. Several microclimate mitigation strategies aimed at countering UHI phenomenon are already widely known; these techniques involve the application of highly reflective surfaces (i.e. cool roofs and cool pavements), green roofs and vegetation coverage (Pisello et al. 2018) and, finally, of thermochromics (Garshasbi and Santamouris 2019) and retro-reflective materials (Rossi et al. 2014). Cool roofs and pavements consist in the improvement of surface's solar reflectance, while green roofs take advantage of the evapotranspiration provided by greenery. Retro-reflective materials play an important role in counteracting UHI effect especially in Urban Heat Canyon configurations, because they are able to reflect the incoming solar radiation mainly towards the incident direction (Rossi et al. 2015, 2016). In this panorama, the choice of suitable materials for external built surfaces is a fundamental issue for avoiding outdoor thermal discomfort of occupants, especially in dense urban environments.

Motivation

In this context, the present work is aimed at investigating textile material solutions for outdoor curtains and awnings and their possible optimization for improving thermo-hygrometric comfort conditions under the coverings. External built surfaces, as e.g. tensile structures and curtains, in fact, have a great potential in urban microclimate enhancement and UHI mitigation, especially in summer conditions. This is due to solar reflectance (r_i) and emissivity (ξ) properties of outdoor surfaces, which may have an impact on thermal comfort parameters, such as air temperature (T_a) and mean radiant temperature (MRT), as shown in Figure 1a and 1b. For this purpose, the present research is focused on the study of solar, thermal and retro-reflective properties of an innovative glass fibre-based material for outdoor curtains and awnings, in order to propose possible optimized solutions for ensuring better human thermal comfort conditions.

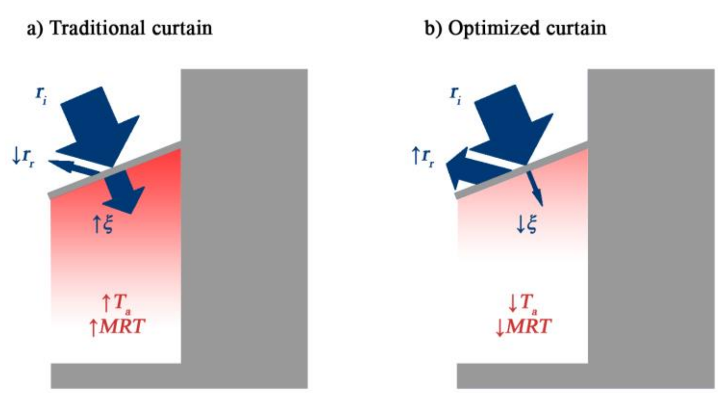

Figure 1: a. *Traditional curtain*, with low external solar reflectance and high emissivity downwards; b. *Optimized curtain*, with high external solar reflectance and low emissivity downwards.

Methodology

A novel, glass fibre-based material was chosen as a modular solution for outdoor curtains and awnings. Panels are yarn-oriented and the glass fibres are covered with resins, which ensure an excellent resistance to fire. Four samples of white glass-fibre material have been investigated in terms of emissivity, spectral and global reflectance and retro-reflective properties. For the assessment of retro-reflective potential, a directional reflectivity characterization has been carried out by means of an innovative experimental equipment.

Description of Samples

As shown in Figure 2, four white glass-fibre samples with a dimension of approximately 20x20 cm have been selected and analysed, as described below:

- *Curve* sample: It consists in a 20 x 20 cm white, glass fibre-based panel, in which yarns follow a curved pattern;
- *Straight* sample: It is a 20 x 20 cm white, glass fibre-based panel, in which yarns follow a straight direction;
- *Smooth Opaque* sample: It consists in a 20 x 20 cm white, glass fibre-based panel, with straight-oriented yarns and a matte finishing;
- *Smooth Bright* sample: It is a 20 x 20 cm white, glass fibre-based panel, with straight-oriented yarns and a bright finishing.

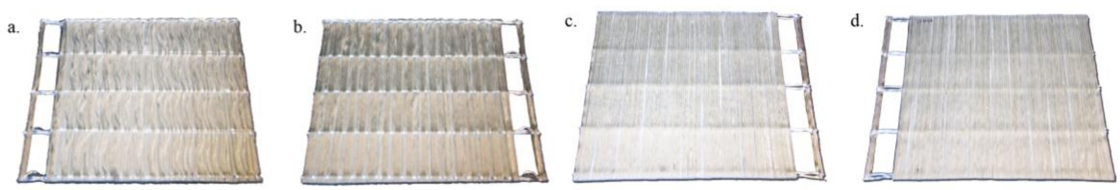

Figure 2: a. *Curve* sample; b. *Straight* sample; c. *Smooth Opaque* sample; d. *Smooth Bright* sample.

The tested glass fibre-based material presents high resistance to fire and high durability, as well as good ageing resistance. In particular, both material's colour and performance do not change when subjected to ageing, UV and weather events. Different experimental analyses have been assessed for all the samples: firstly, emissivity has been measured by means of an emissometer; secondly, solar reflectance has been evaluated for wavelengths from 300 to 2500 nm through the use of a spectrophotometer and, finally, a directional reflectivity characterization of samples have been carried out by using a novel experimental facility.

Emissivity Analysis

A portable differential thermopile emissometer was used in order to measure the hemispherical emittance of the material, in accordance with ASTM C1371 standard test method (ASTM C1371-15). The specific emissivity measurements have been performed by means of an AE1 RD1 Emissometer D&S with Scaling Digital Voltmeter (Devices & Services Co., Dallas, Texas), as shown in Figure 3. Technical features of the abovementioned emissometer are presented in Table 1. The portable emissometer apparatus is composed by a Differential Thermopile Radiant Energy Detector, a Controlled Heater, a Readout Device, a Heat Sink Stage, two Reference Standards (a high-emittance and a low-emittance one, characterized by emissivity values of 0.9 and 0.06, respectively) and, finally, the sample to be tested (ASTM C1371-15).

As the emissivity depends only on the specific material and it does not change with fibre pattern and orientation of yarns, a single 10 cm x 10 cm sample of glass-fibre material was selected for the emissivity measurements. After the calibration of the emissometer, three different measurements have been carried out, because of the non-homogeneity of the tested surface.

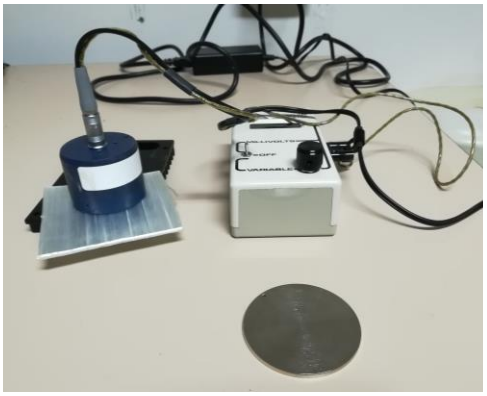

Figure 3: AE1 RD1 Emissometer D&S with Scaling Digital Voltmeter and the tested sample

Table 1: Characteristics of AE1 RD1 Emissometer D&S with Scaling Digital Voltmeter

Repeatability	±0.01 emittance units
Warming up time	30 minutes
Total hemispherical emittance approximation	150 F (65°C)
Sample dimension	2.25 inches (5.7 cm)
Output	2.4 millivolts nominal, with sample emittance of 0.9 and sample temperature of 78 F (25°C)
Linearity	±0.01 units
Time constant	10 seconds
Sample temperature	130 F maximum (54.4°C)
AC Power Adapter	Universal AC adapter, 100-240V, 50-60 Hz, 12 Volts DC

Source: AE1 RD1 Emissometer D&S specification sheet (Devices & Services Co., Dallas, Texas)

Spectrophotometric Analysis

Solar reflectance of glass-fibre samples was determined by using an UV-VIS-NIR Spectrophotometer, model Shimadzu SolidSpec-3700, with a 60 mm integrating sphere (Figure 4), whose technical features are listed in Table 2. The wavelength range of the spectrophotometer varies from 240 to 2600 nm, including UV, VIS and NIR regions.

Figure 4: Shimadzu SolidSpec-3700 Spectrophotometer and one of the tested samples

For the purpose of the work, spectrophotometric measurements have been performed within a wavelength range from 300 to 2500 nm, in accordance with ASTM E903 standard test method (ASTM E903-12). Five measurements have been carried out for each 20 cm x 20 cm glass-fibre sample, as the specimens surface is non-homogeneous, for a total of 20 measures.

Table 2: Characteristics of Shimadzu SolidSpec-3700 Spectrophotometer

Wavelength range	240 nm to 2600 nm
Spectral bandwidth	UV-VIS: 8 steps (0.1 to 8 nm) NIR: 10 steps (0.2 to 32 nm)
Resolution	0.1 nm
Wavelength accuracy	UV-VIS: ±0.2 nm NIR: ±0.8 nm
Wavelength repeatability	UV-VIS: within ±0.08 nm NIR: within ±0.32 nm
Noise	<0.0002 Abs (500 nm, SBW 8 nm) <0.00005 Abs (1500 nm, SBW 8 nm) determined under conditions of RMS value at 0 Abs and 1 second response
Photometric range	-6 to 6 Abs

Source: Shimadzu SolidSpec-3700 Spectrophotometer specification sheet

Directional Reflectivity Characterization

For the investigation of materials' retro-reflective capabilities, traditional in-lab and in-situ analysis, e.g. with a spectrophotometer with integrating sphere, does not correctly describe their angular reflectance distribution, as stated in Rossi et al. (2014). For that reason, a new experimental facility was used in order to assess the angular reflectivity of the four 20 cm x 20 cm glass-fibre samples. The innovative experimental array consists in the following elements:

- An artificial solar source, which is composed by an IP65-rated micro-spotlight in anodized aluminium. A summary of the lamp main technical features is reported in Table 3;
- A semicircular equipment (with a diameter of approximately 0.85 m), to which the artificial solar source is attached, in a way that it is free to move along the curved axis. The sample to be tested is positioned at the centre of the semicircular facility, over a flat and black surface, in order to avoid other light reflected components than the ones provided by the sample. The semicircular frame is provided with a graduate scale each 10 degrees, corresponding to 17 possible positions of the lamp, i.e. at -10°, -20°, -30°, -40°, -50°, -60°, -70°, -80°, 90°, 80°, 70°, 60°, 50°, 40°, 30°, 20°, 10°. A 90° lamp position means incident radiation which is perpendicular to the sample surface. A picture of the entire experimental facility can be seen in Figure 5a.
- A Photo-Radiometer Delta Ohm HD 9221, with an LP 9221/RAD probe for irradiance measurements along the semicircular frame (Figure 5b). Technical features of the Photo-Radiometer and the irradiance probe are listed in Table 3.

For the detection of the directional reflectivity properties, all the four 20 cm x 20 cm glass-fibre samples have been tested, in order to assess a possible correlation between angular reflectivity and surface yarn orientation. For each sample, the lamp has been placed in 9 positions, covering a half of the semicircular frame, i.e. at -10°, -20°, -30°, -40°, -50°, -60°, -70°,

-80°, 90°. It was possible to reduce the number of the lamp positions from 17 to 9 due to the symmetry of the equipment geometry. For each position of the lamp, 17 irradiance measurements have been carried out, by placing the LP 9221/RAD probe each 10 degrees along the semicircular axis, in order to measure the magnitude of the radiation reflected from the sample for each angle from -10° to 10°.

Figure 5: a) Experimental equipment for the directional reflectivity characterization; b) Photo-Radiometer Delta Ohm HD 9221 with an LP 9221/RAD probe

Table 3: Characteristics of the main equipment components

Artificial Solar Source (Lamp)	Power	2W
	Supply Current	500 mA
	Colour Temperature	4200 K
	Luminous Flux	154 lm
	Driver	On/Off (non-dimmable)
Photo-Radiometer Delta Ohm HD 9221	Spectral range	450 nm to 950 nm
	Measurement range	1 $\mu W/cm^2$ to 200 mW/cm^2
	Probe precision	±4%
	Linearity	±1%
	Resolution	≤ 200 = 0.1; ≥ 200 = 1
	Stability	0.15%

Source: Artificial Solar Source and Photo-Radiometer Delta Ohm HD 9221 specification sheets

Results and Discussion

Emissivity Analysis

Emissivity measurements for the 10 cm x 10 cm glass-fibre sample are reported in Table 4. Results show slightly high emissivity values, with an average of about 0.79. High emissivity surfaces for outdoors could result in higher air temperature and mean radiant temperature in the surroundings, leading to worse thermal comfort conditions, especially in hot summer days. In the way of ensuring better outdoor thermal comfort conditions under the curtains, a possible optimization of the tested material could involve the addition of a low-emittance layer on the internal side of the curtain, in order to minimize the infrared radiation downward.

Table 4: Emissivity measurements results

Measure n.	Emissivity
1	0.78
2	0.80
3	0.78
Average	0.787

Spectrophotometric Analysis

As previously described, five measurements have been collected for each 20 cm x 20 cm glass-fibre sample, because of the non-homogeneity of the material surface. Averaged results for each sample are reported in Figure 6 in terms of spectral reflectance over the whole wavelength range, from 300 to 2500 nm. Results show that the *Smooth Bright* and the *Smooth Opaque* samples present a very similar behaviour in terms of spectral reflectance over the whole wavelength range; however, the *Smooth Opaque* sample has a slightly higher reflectance than the *Smooth Bright* one within the NIR region, for wavelengths that range from 2240 to 2500 nm. The *Straight* sample has the worst performance from 300 to 1700 nm, while the *Curve* sample present the lowest spectral reflectance for wavelengths above 1700 nm. Global reflectance has been determined for each sample and the specific values are reported in Table 5. *Smooth Bright* sample has the highest global reflectance, of about 67.7%, while the *Straight* sample shows the worst performance, with a global reflectance value of 65.17%.

Table 5: Global Reflectance of samples

Sample	Global Reflectance [%]
Curve	65.90
Straight	65.17
Smooth Opaque	67.43
Smooth Bright	67.67

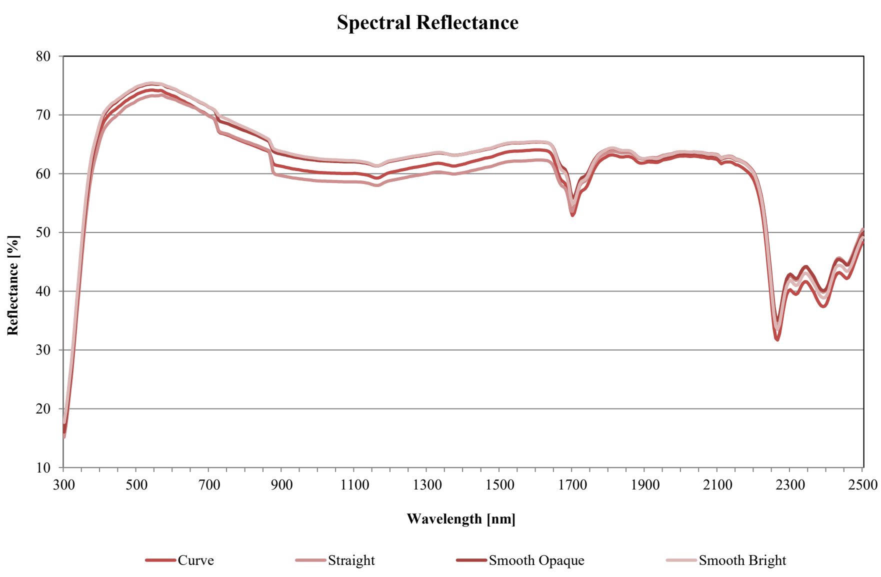

Figure 6: Spectral Reflectance of samples from 300 to 2500 nm

Directional Reflectivity Characterization

The most representative results of the directional reflectivity characterization are shown, for instance, in graphs of Figure 7 for *Smooth Bright* sample. The red arrow represents the direction of the incident radiation (i.e. the position of the artificial solar source along the semicircular facility) for each set of measures. Findings show that for incident beam directions near the perpendicular (i.e. from 90° to ±60°), all the tested samples reveal a retro-reflective tendency, coupled with a slightly diffusive behaviour. As the incident beam direction moves towards the horizontal, i.e. for angles from ±50° to ±10°, a specular tendency progressively occurs for all the samples.

Furthermore, it is noticeable that the major RR tendency for incident beam directions near the perpendicular constitutes an important issue for UHI mitigation, especially in summer during the central hours of the day, i.e. when the sun is in vertical position with respect to the horizontal surfaces. For that reason, textile materials for outdoor horizontal curtains with RR tendency for high angles (i.e. near 90°) are to be preferred, because they could avoid multiple reflections, also ensuring the reduction of the radiation trapped within the Urban Canyon.

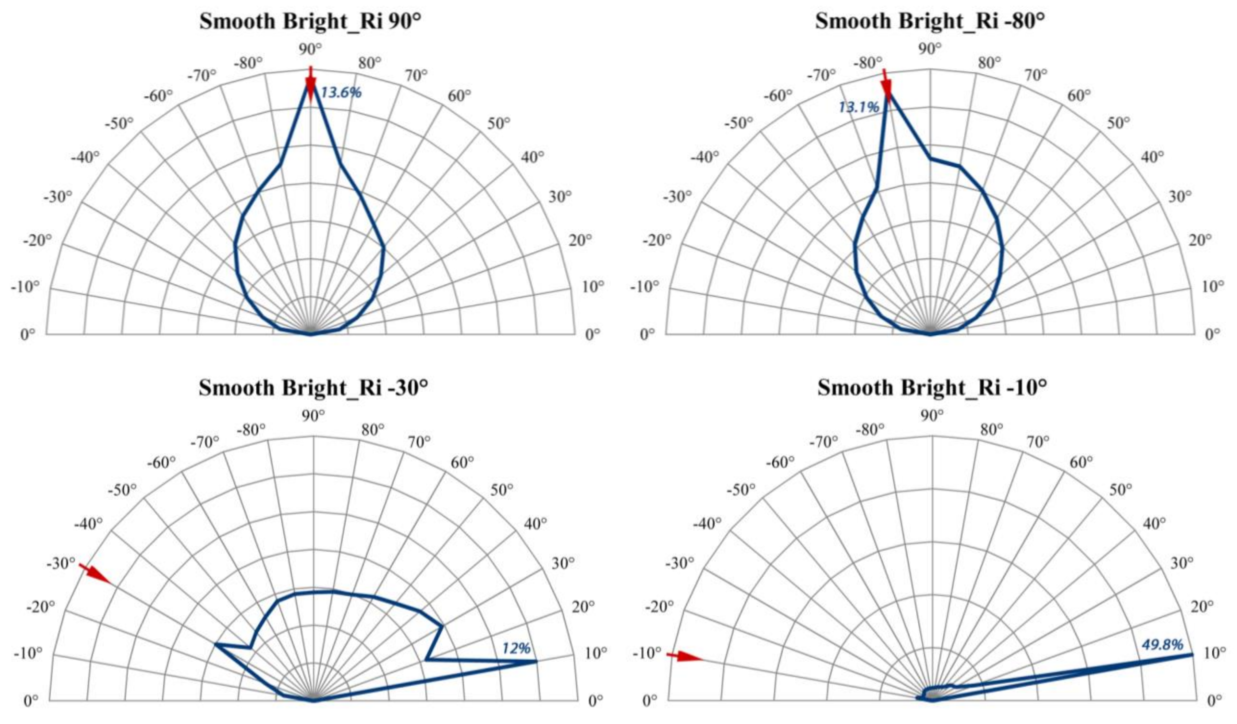

Figure 7: Directional Reflectivity characterization for *Smooth Bright* sample, for incident beam directions of 90°, -80°, -30°, -10°

Conclusions and Further Developments

In this work, a novel, glass fibre-based material for outdoor shading applications has been investigated in terms of thermal emittance, solar reflectance and directional reflectivity properties. Results of the experimental campaign show that the considered material presents high values of emissivity, while a good global reflectance has been detected. Furthermore, the directional characterization of the material revealed that all the samples have a retro-reflective tendency for incident beam directions near the perpendicular. In a next step of the research, optimized solutions will be proposed, with higher solar reflectance on the external side of the curtain and lower infrared emissivity towards the covered area. In this way, the proposed advanced covering solutions could positively affect urban microclimate, by contributing to the mitigation of urban heat island and therefore by reducing outdoor discomfort, especially in summer conditions.

Acknowledgments

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References

ASTM C1371-15, Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM E903-12, Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres, ASTM International, West Conshohocken, PA, 2012, www.astm.org

Frohlich, D., M. Gangwisch, A. Matzarakis. 2019. "Effect of radiation and wind on thermal comfort in urban environments – Application of the RayMan and SkyHelios model" *Urban Climate* 27: 1-7.

Garshasbi, S., M. Santamouris. 2019. "Using advanced thermochromic technologies in the built environment: Recent development and potential to decrease the energy consumption and fight urban overheating" *Solar Energy Materials and Solar Cells* 191: 21-32.

Oke, T.R. 1995. "The Heat Island of the Urban Boundary Layer: Characteristics, Causes and Effects". In: Cermak J.E., Davenport A.G., Plate E.J., Viegas D.X. (eds) Wind Climate in Cities. NATO ASI Series (Series E: Applied Sciences), vol 277. Springer, Dordrecht

Pisello, A.L., M. Saliari, K. Vasilakopoulou, S. Hadad, M. Santamouris. 2018. "Facing the urban overheating: Recent developments. Mitigation potential and sensitivity of the main technologies." *WIREs Energy and Environment* 7: e294. https://doi.org/10.1002/wene.294

Rossi, F., A.L. Pisello, A. Nicolini, M. Filipponi, M. Palombo. 2014. "Analysis of retro-reflective surfaces for urban heat island mitigation: A new analytical model" *Applied Energy* 114: 621-631.

Rossi, F., B. Castellani, A. Presciutti, E. Morini, M. Filipponi, A. Nicolini, M. Santamouris. 2015. "Retroreflective façades for urban heat island mitigation: Experimental investigation and energy evaluations" *Applied Energy* 145: 8-20.

Rossi, F., B. Castellani, A. Presciutti, E. Morini, E. Anderini, M. Filipponi, A. Nicolini. 2016. "Experimental evaluation of urban heat island mitigation potential of retro-reflective pavement in urban canyons" *Energy and Buildings* 126: 340-352.

UN DESA (United Nations, Department of Economic and Social Affairs), Population Division (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables.* Working Paper No. ESA/P/WP/248.