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Experimental analysis of the effects of three cool roofing materials on thermal radiation

三种冷却屋顶材料对城市热辐射影响的实验分析

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Outline

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1.Introduction

Urban heat island (UHI) effect exists in most large cities and the caused negative impacts have attracted widespread attention from scholars.

- The UHI effect is caused primary by the widespread presence of dark surfaces in cities



Thus, the use of light-colored, high-albedo cooling materials to cover dark-colored urban facilities decreases both urban surface temperatures and the energy required to cool buildings by decreasing the amount of heat storage

Introduction

Cool roofing materials can be broadly divided into light-colored coatings (mainly white paint), single-membrane materials, and ceramic products

- Numerous experimental studies in Europe and the United States have shown that white paint is easy and inexpensive to use and can rapidly increase the albedo of a roof under different climatic conditions in different regions. Although membranes are costly, they degrade slowly and reduce roof surface temperatures effectively.
- Most Chinese studies on cool roofing materials have involved numerical simulations. Few experiments have been conducted on the thermal radiation effects of high-albedo roof materials in China; thus, the cooling efficacy and roof material aging patterns remain unknown.

- (1) Which material offers better cooling performance.
- (2) How the different materials age amidst high atmospheric aerosol concentrations in China.

2.Methods

- Study site and selected materials

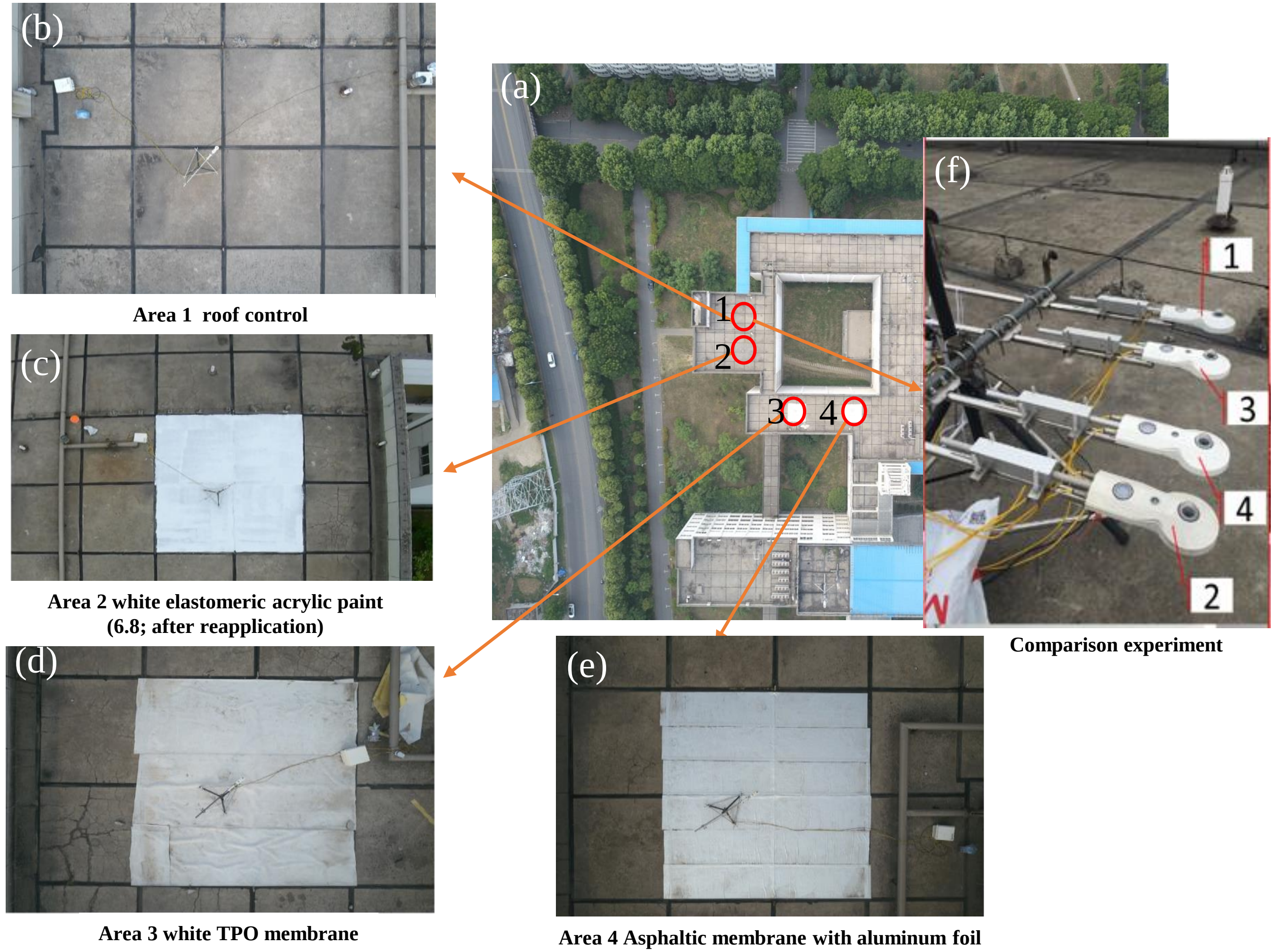


Figure 1. (a) Overhead view of the monitoring site, including the (b) roof control area, (c) area with the reapplied white elastomeric acrylic coating, (d) area with the white TPO membrane, and (e) area with the aluminum foil- and asphalt-based (SBS) membrane. (f) Instrument comparison experimental setup.

Table 1. Information on the three materials examined in this study.

Material type	Material image	Manufacturer, product usage, and [price]	Advantages
Area 2: white elastomeric acrylic coating (Ac)		Libang, 1 mm thick, 18 kg, [2.36 USD kg^{-1}]	Resistant to cracking, high temperatures, and water
Area 3: white TPO membrane (TPO)		Hongchang Waterproof Material Co., Ltd., 1 mm thick, 30 m^2, [18.88 USD m^{-2}]	Weather-resistant, weldable, novel cool roofing and waterproof membrane materials, high tensile strength, long service life
Area 4: aluminum foil-covered asphalt-based (SBS) membrane (AA)		Laishide, 30 m^2, [3.14 USD m^{-2}]	Waterproof, insulating, convenient installation, inexpensive, resists deformation, puncture resistant

*Ac and AA denote the white elastomeric acrylic coating and aluminum foil covered and asphalt-based (SBS) membrane in the chart below but are not used as abbreviations for these materials in the text.

• Instrumentation and instrument comparison experiment

- The radiation levels at the experimental site were measured using four net radiation sensors (model CNR4, Kipp & Zonen B.V., The Netherlands).

- A 3-day instrument comparison experiment was performed (March 13 to March 15).

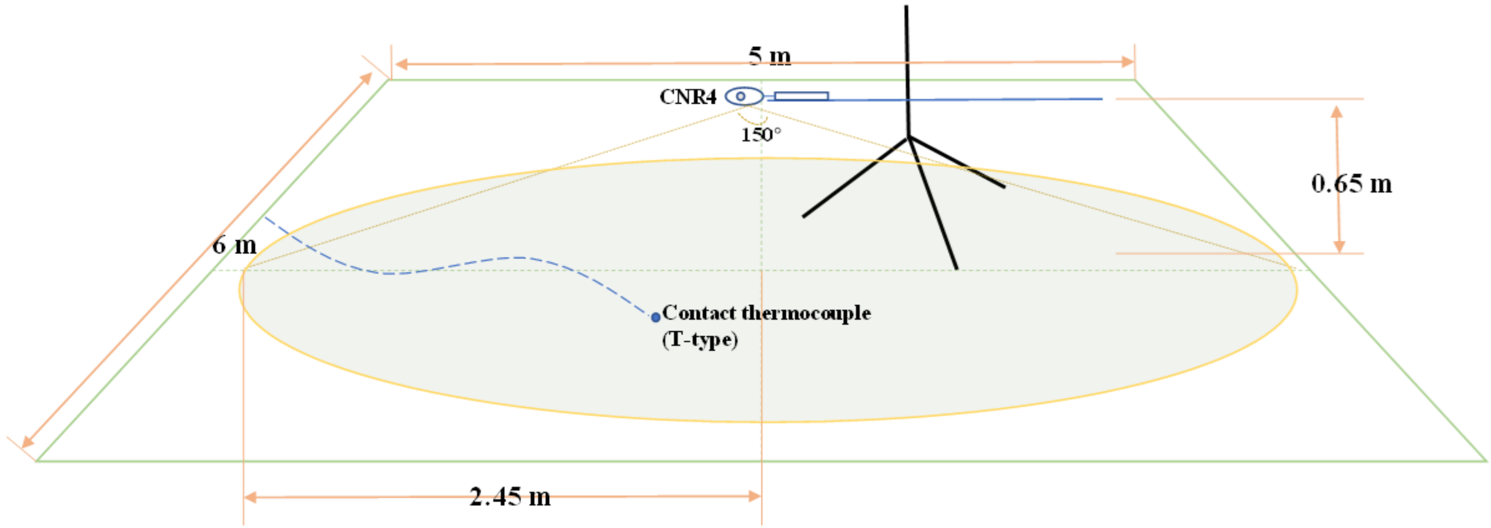


Figure 2. Instrument configuration in the experiment area (the shaded area denotes the monitoring range of the CNR4).

- 0.127 mm T-type thermocouples were used to determined for each material based on Stephen Boltzmann's law. Roof, 0.9483; white elastomeric acrylic paint, 0.8188; white TPO membrane, 0.9009; and aluminum foil-covered and asphalt-based (SBS) membrane, 0.8393.

3.Results

- 3.1 Surface temperature performance of the three cool roofing materials

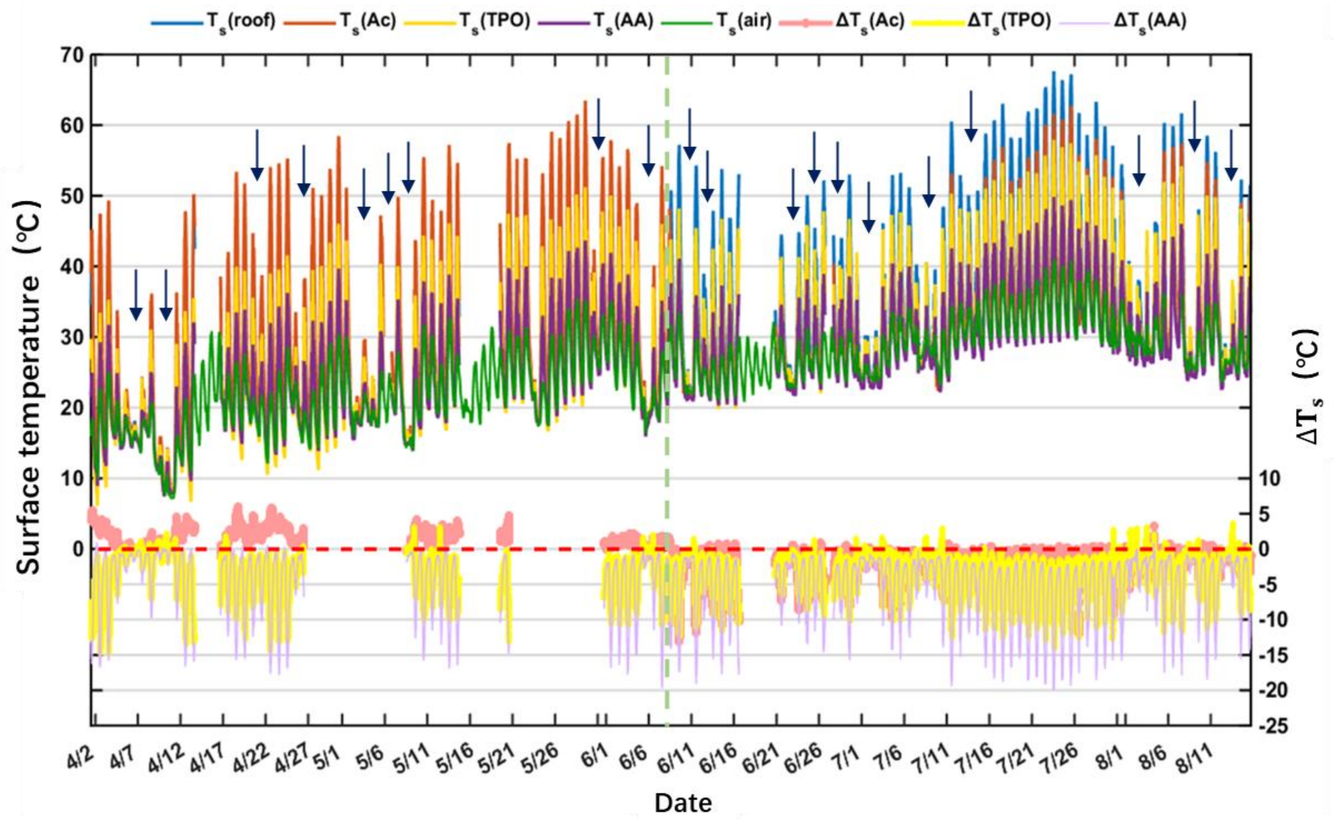


Figure 4. Surface temperatures in the four experimental areas, air temperatures (measured 2 m from the roof surface) and cooling temperatures for the three materials; the dotted line denotes the day that the white coating was reapplied and the arrows denote the occurrence of overcast and rainy days. The graph spans April 1-August 15.

Table 2. Air temperatures (measured 2 m from the roof surface) for each month, the monthly average surface temperatures in the four areas, and the corresponding cooling temperatures.

Temp (°C) / Time	Avg. 2 m T_{air}	Avg. T_s (Roof)	ΔT_s (Ac)	ΔT_s (TPO)	ΔT_s (AA)
April	18.53	21.92	1.16	-2.80	-3.74
May	23.60	28.76	1.01	-2.61	-4.57
June	25.60	30.94	-2.97	-2.63	-4.75
July	31.45	37.65	-2.37	-3.08	-5.45
August	28.64	33.39	-1.43	-1.98	-4.03

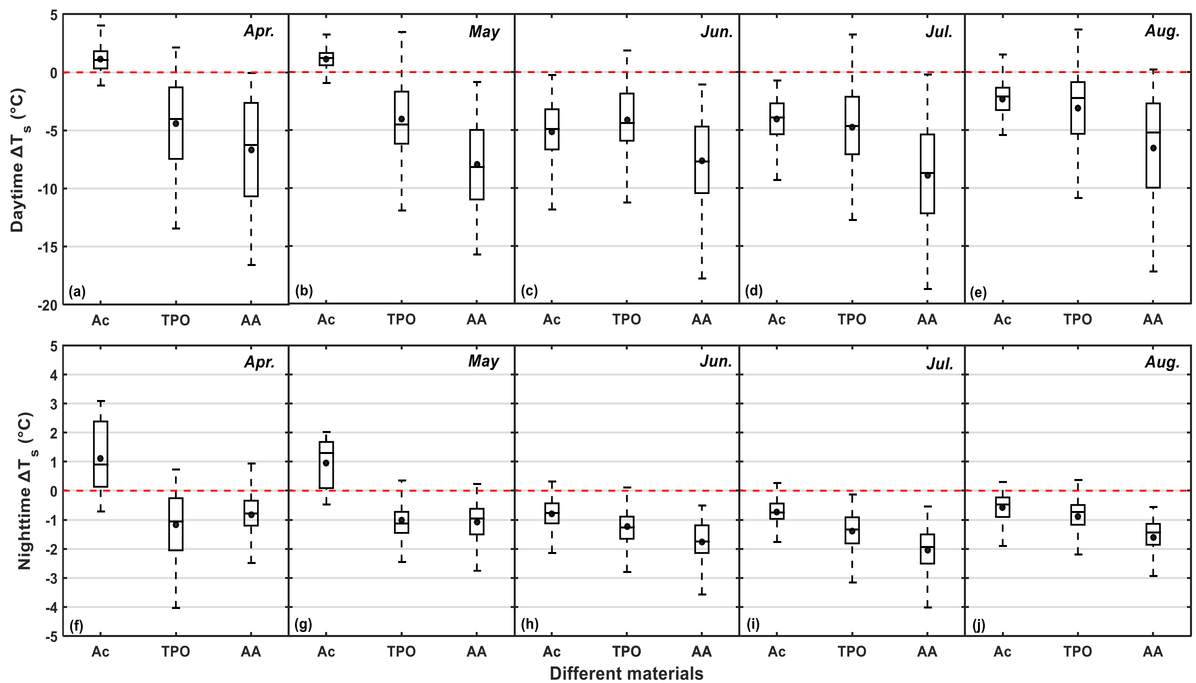


Figure 5. Boxplots of daytime (6:00 -17:00) and nighttime (20:00-3:00) surface temperatures measured during the experimental period (April 1 -August 15); the black dots shown in each box denote the monthly average cooling temperature.

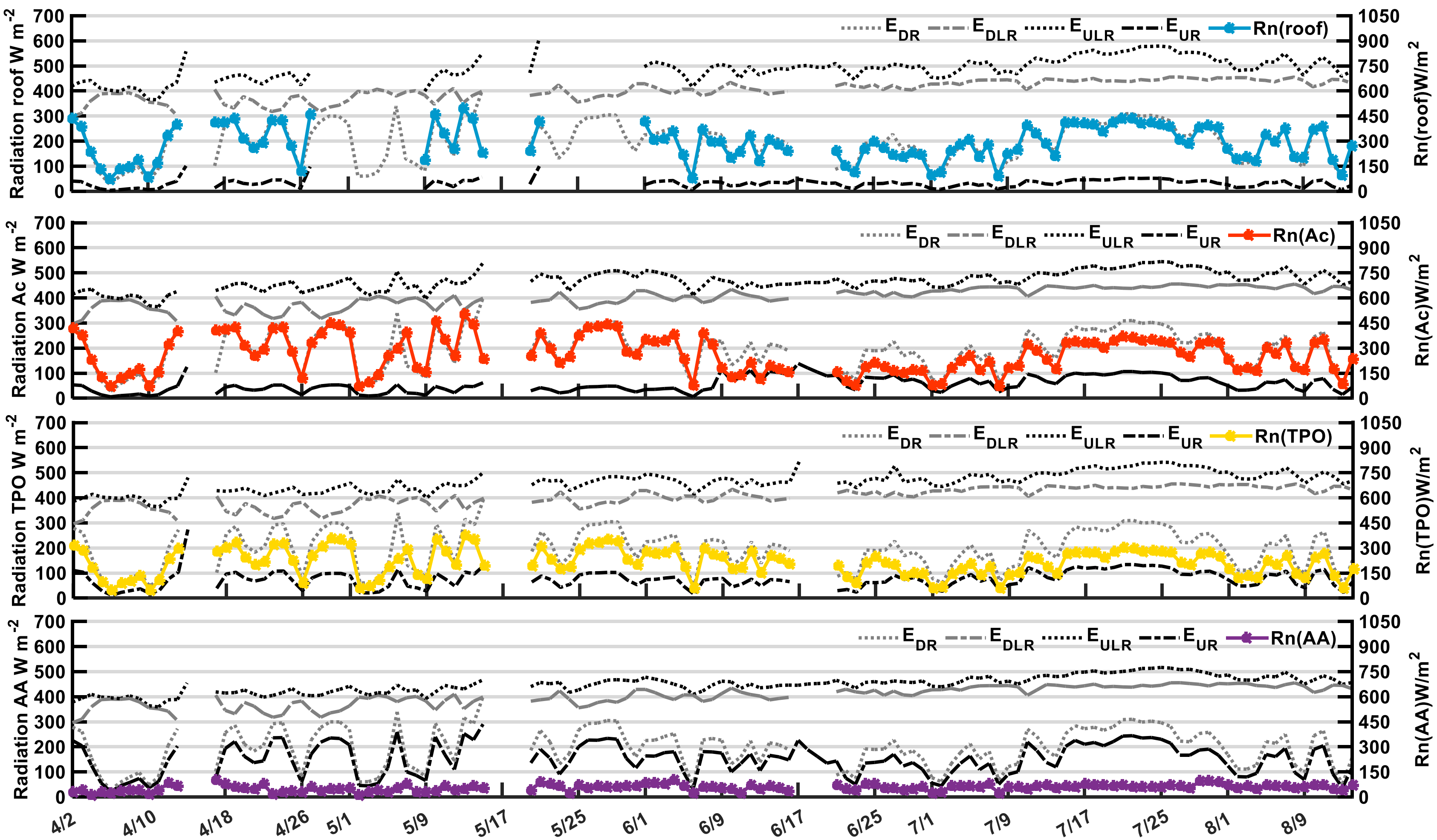


Figure 6. Daily average changes in radiation and net radiation flux observed in the four experimental areas.

- 3.2 Albedo performance of the three cool roofing materials

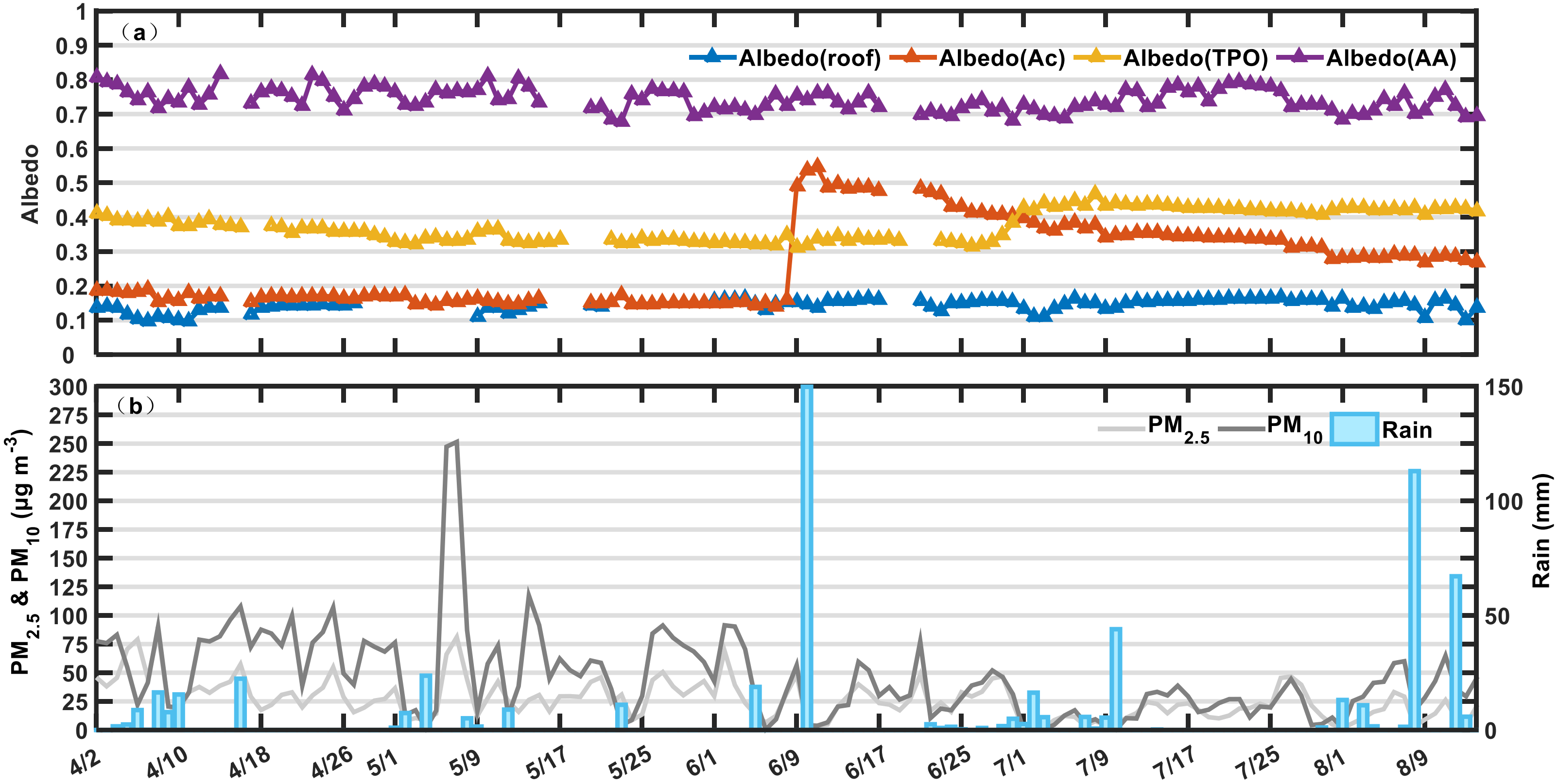


Figure 7. Albedo, $PM_{2.5}$, and PM_{10} levels and daily average rainfall observed in the four experimental areas (April 1-August 15).

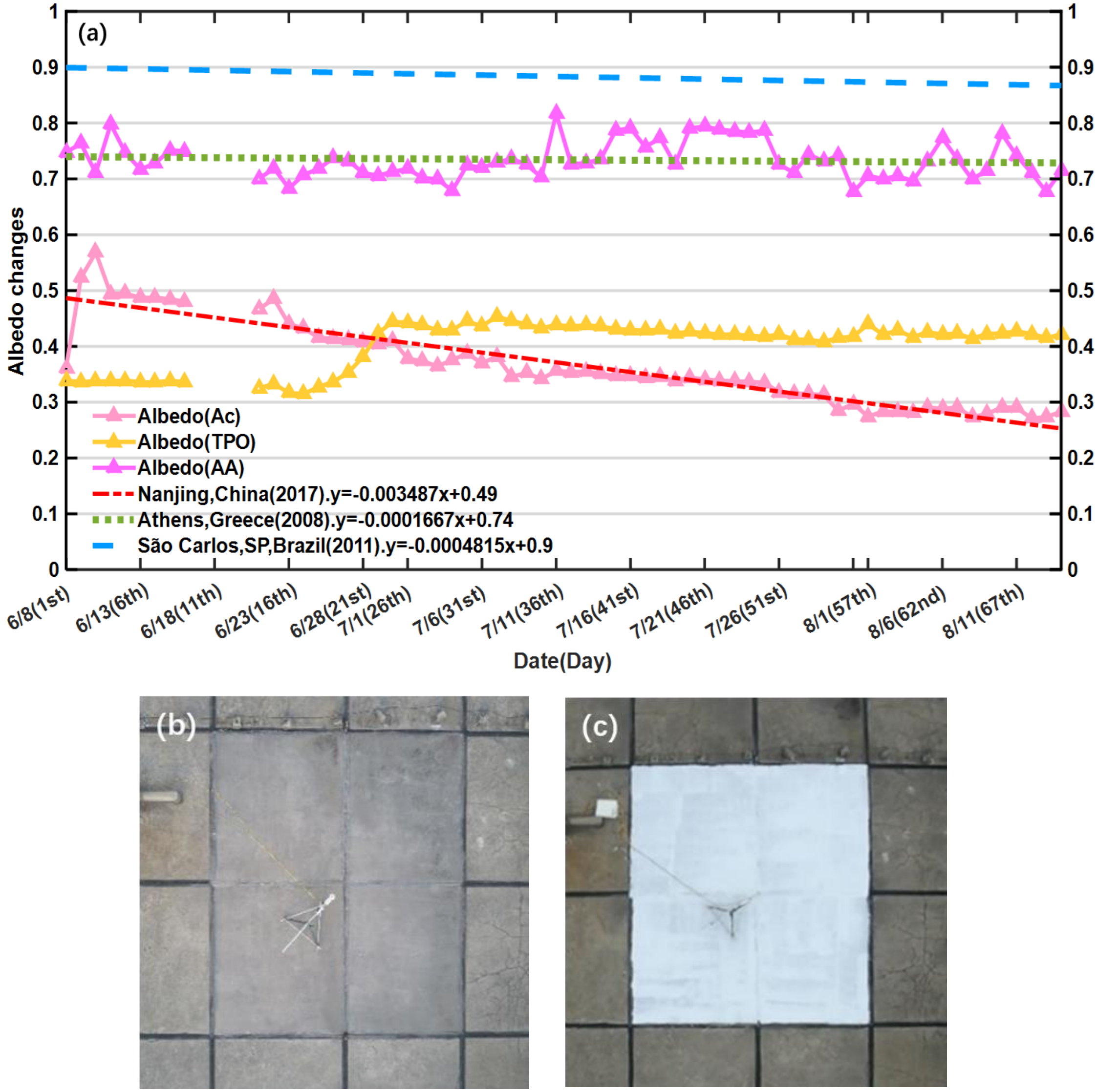


Figure 8. (a) Average albedo of the white acrylic elastic coating, white TPO membrane, and aluminum foil covered asphalt-based (SBS) membrane during the study period and linear regressions of the changes in albedo for white coatings observed over 68 days in Nanjing , Athens, and San Carlos (right axis; the numbers shown in parentheses on the abscissa denote days used in the linear fit; the year shown after the country name in the legend denotes the start time of the experiments). Overhead views of the surface (b) bef ore and (c) after the application of a white acrylic coating.

Table 3. Cool roofing material experiments conducted in different climates and countries.

Study site	Time	Climate	Materials used	Initial albedo	Thermal performance
Nevada, USA [25]	June to October, 2000	Desert climate	White coating	0.72	Albedo increased from 0.26 to 0.72
Phoenix, Arizona, USA [49]	1August 13 to September 19, 2008	Subtropical continental desert arid climate	White marble	0	
School building, Athens, Greece [24]	1May 15 to September 30, 2009	MMediterranean climate	White elastomeric coating	0	
University of Perugia, Italy [48]	December, 2013 to July, 2014	Mediterranean climate	Five types of membranes	0 0 0 0 0	
California, USA [47]	8August 8 to September 30, 2002	Mediterranean climate	White elastomeric coating; PVC single-ply membrane; white elastomeric coating	--	
New York, USA [26]	Summer 2008 to Summer 2011	Temperate continental climate	White acrylic elastomeric coating; EPDM membrane; TPO membrane	0.65; 0.64; --	Daily average daily temperatures of white paint decreased by 6.6 °C, and albedo declined from 0.65 to 0.35 within one year; EPDM featured an albedo of 0.64 persisting for three y and an average summer daily temperature decrease of 5.1 °C; the TPO film did not change significant for four years, and the average daily decrease in summer was 3.3 °C.
Hyderabad, India [51]	January to December, 2010	Tropical monsoon	Black and white coatings	0.7	The white paint increased the surfac temperatures by 13.5°C while the bl coating increased temperatures by 16.6°C.
Northern Florida, United States [50]	August 19 to September 10, 1996	Subtropical monsoon	White acrylic roof coating	0.75	Roof surface reflectivity was increa from 29% to 75%.
Nanjing University of Information Technology	April 1 to August 15, 2017	Subtropical monsoon climate	White acrylic elastic coating, white TPO film, aluminum foil covered and asphalt-based (SBS) membrane	0.55; 0.43; 0.8	Average summer temperature decre of 4.74 °C for an aluminum foil-asp waterproof membrane, with a maximum temperature decrease of 20.07 °C. Average summer tempera decrease of 2.56°C for a white TPO membrane, with a minimum temperature of 13.98 °C. Average summer temperature decrease of 2.26 °C for a fresh coat of white acr

Conclusions

- The aluminum foil asphalt-based membrane delivers the strongest cooling effect, producing an average albedo of 0.75 and a minimum surface temperature of 20.07 °C under high-temperature conditions during summer; the average cooling during April-August measured 4.74 °C. This material can be easily adapted to address the heavy particulate pollution and increased rainfall in spring and summer in Nanjing and exhibits stable cooling performance.

- White TPO membranes are better able than white acrylic elastic paint to adapt to particle effects, undergoing a “self-cleaning” process during the plum rain season in the middle and lower reaches of the Yangtze River; TPO membranes also boast a longer life span and stronger cooling effect, producing an average summer temperature decrease of 2.56 °C.

- White acrylic elastic coatings deteriorate rapidly due to the large volumes of particulate matter found in urban areas in China. The cooling effect of this material lasts for only three months; therefore, it may not be suitable for use in Chinese cities.

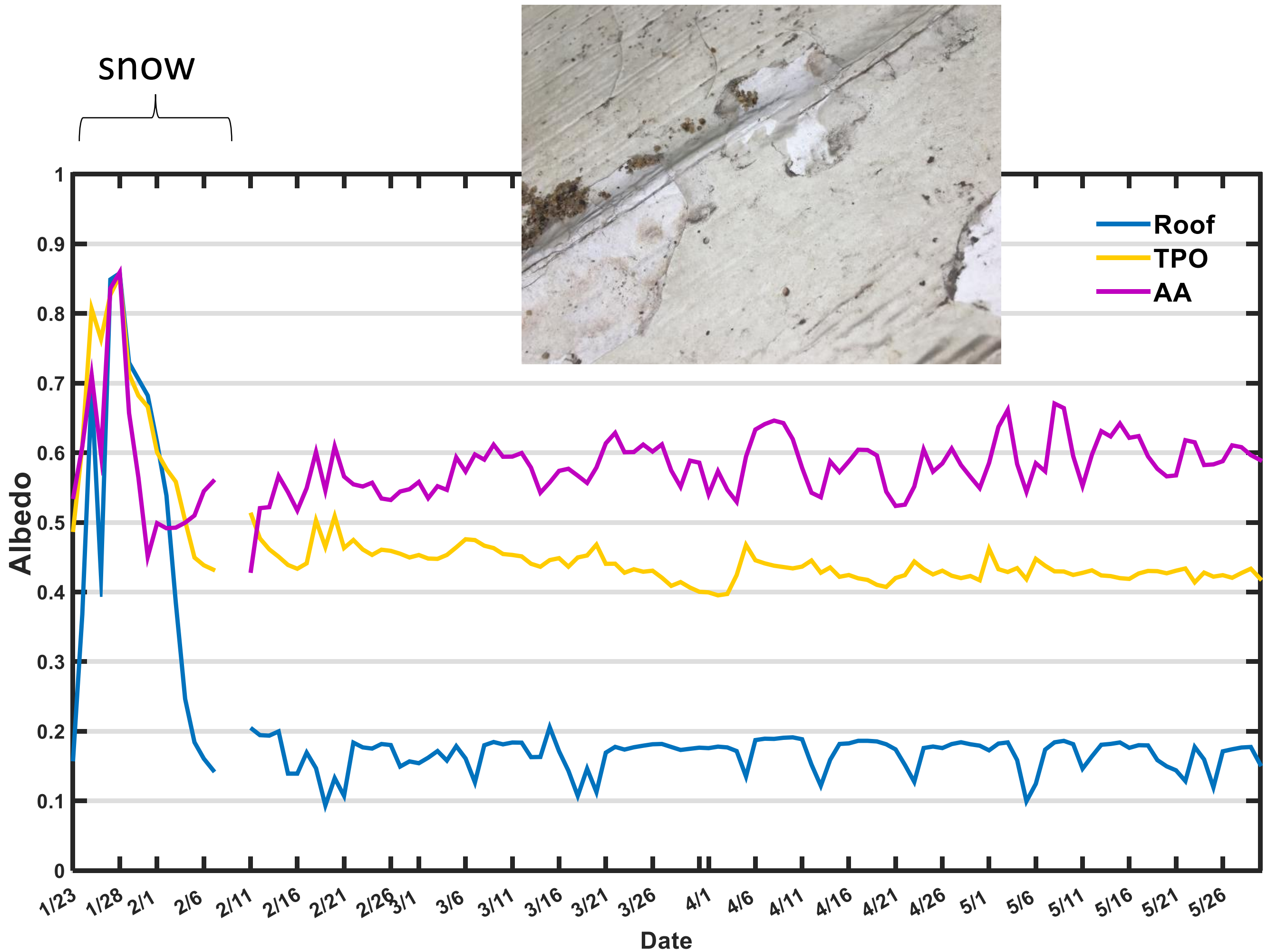
Inadequacies and next steps

- Because only three relatively basic roof cooling materials (without improvements) were studied, our data are rather limited in comparison to the plethora of available materials. The heat energy load reductions resulting from cooling in summer must also be determined in future studies, along with the effects of using cool roofing materials in winter.

- Collect the long-term performing data of white thermoplastic polyolefin (TPO) membrane and aluminum foil cover with an asphalt-based (Styrene Butadiene Styrene block polymer, SBS) membrane.(2018.1.23-2019.1)

- Town energy balance (TEBV2.4406) model is a physics-based single-layer urban canopy scheme that can input single-point data to study urban climate on a microscale.

Current results



- Thank you for your suggestions!