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Research Highlight

Radiation cooling textiles countering urban heat islands

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In recent years, researchers have paid increasing attention to the use of radiation cooling textiles for maintaining human thermal comfort. Radiation cooling can achieve effective cooling without energy consumption by emitting heat into cold outer space through an atmospheric transparent window (ATW, 8–13 μm) while reflecting solar irradiance in the solar region (0.3–2.5 μm) [1]. For example, Zeng et al. [2] reported a layered morphology radiation-cooled textile composed of TiO_2/polylactic acid and polytetrafluoroethylene. This design offers optimal mechanical strength, waterproofing and breathability, while enabling spectral modulation within the 0.3–2.5 μm wavelength range and ensuring efficient radiative cooling. Yang et al. [3] developed a SiO_2 microsphere-modified fabric film with shish-kebab structure. This fabric film exhibits high emissivity within the atmospheric window and strong reflectivity to solar radiation, resulting in exceptional cooling properties for both indoor and outdoor applications. A key concern is that these radiation cooling textiles are typically applied horizontally, where they demonstrate effective cooling in sunny, unobstructed environments. However, their effectiveness may be limited in more complex real-world applications.

Since most textiles are used vertically, such as when a person is standing (Fig. 1a, b), they are more likely to absorb heat—up to 50%—from man-made structures like walls and ground. At present, with the urban heat island effect intensifying, this part of heightened heat has increased its impact on the human body, creating significant challenges in maintaining the effectiveness and thermal comfort of cooling textiles. The urban heat island effect is caused by heavy urbanization, which has led to the replacement of natural surfaces with numerous buildings, roads, and other man-made structures, resulting in increased heat absorption in urban areas [4]. Furthermore, urban building materials like concrete and asphalt have high heat absorption and low reflectivity, causing them to absorb significant heat during the day and rapidly increase in temperature [5,6]. This exacerbates the urban heat island effect, resulting in extreme temperature that adversely affect human thermal comfort and can lead to heat-related illnesses, including neurological and respiratory conditions [7,8]. The above highlights the urgency of exploring countermeasures to counter the impacts of the urban heat island on the human body.

Developing spectrally selective textiles with high emissivity in the ATW range and high reflectivity outside of it is an effective strategy for combating urban heat islands. However, most natural and synthetic textiles exhibit numerous chemical bonding vibrations in the non-ATW region, such as –OH (3100 to 3600 cm^{-1}) in cotton and –CONH- (1520 to 1720 cm^{-1}) in silk. In contrast, polymethylpentene (PMP) contains only C–C (942 to 1066 cm^{-1}), $–CH_2$ (1168 to 1241 cm^{-1}), –CH (848 to 871 cm^{-1}), and $–CH_3$ (931 cm^{-1}, 1103 to 1150 cm^{-1}) bonds. Thus, it shows great potential as a selective emitter with high absorption exclusively within the ATW range. Taking this into account, Wu et al. [9] recently developed a spectrally selective hierarchical fabric (SSHF) for the mid-infrared range (MIR) using electrostatic spinning technology. This fabric reduces heat absorption by the human body from buildings and hot floors, offering enhanced cooling in urban areas.

SSHF consists of PMP micro/nanofibers, silver nanowires (AgNWs), and wool fabrics (Fig. 1c). The upper layer, made of PMP, is an effective selective emitter with a spectrally selective ratio (the ratio of average ATW emissivity to non-ATW emissivity) of up to 2.34. It exhibits high emissivity solely in the ATW band, without absorbing or reflecting in other bands. The middle layer, composed of AgNWs, enhances the fabric's reflectivity in the whole MIR, preventing infrared transmission from reaching the body, as also demonstrated by Feng et al. [10]. The lower layer uses wool as a broadband emitter, further directing heat radiation from human skin outward through the AgNWs layer. This multi-layered structure minimizes heat absorption from the environment, improving human thermal comfort. Calculations reveal that the cooling power of broadband textiles, such as cotton, silk, and polyester fabrics, is better under lower solar radiation. As solar radiation increases up to 480 W m^{-2}, SSHF effectively blocks ground thermal radiation, exhibiting more superior cooling power (Fig, 1d).

Fibers prepared by electrospinning are known for their small diameter and exceptionally high specific surface area [11]. A scalable electrostatic spinning technique was used to fabricate PMP polymers into uniform micro/nano fibers with abundant porous structures. Fiber size significantly impacts the optical properties of fabrics. Therefore, to ensure high emissivity and effective scattering in SSHF, fiber size has been studied in depth. Spinning parameters are closely linked to fiber size, with polymer concen-

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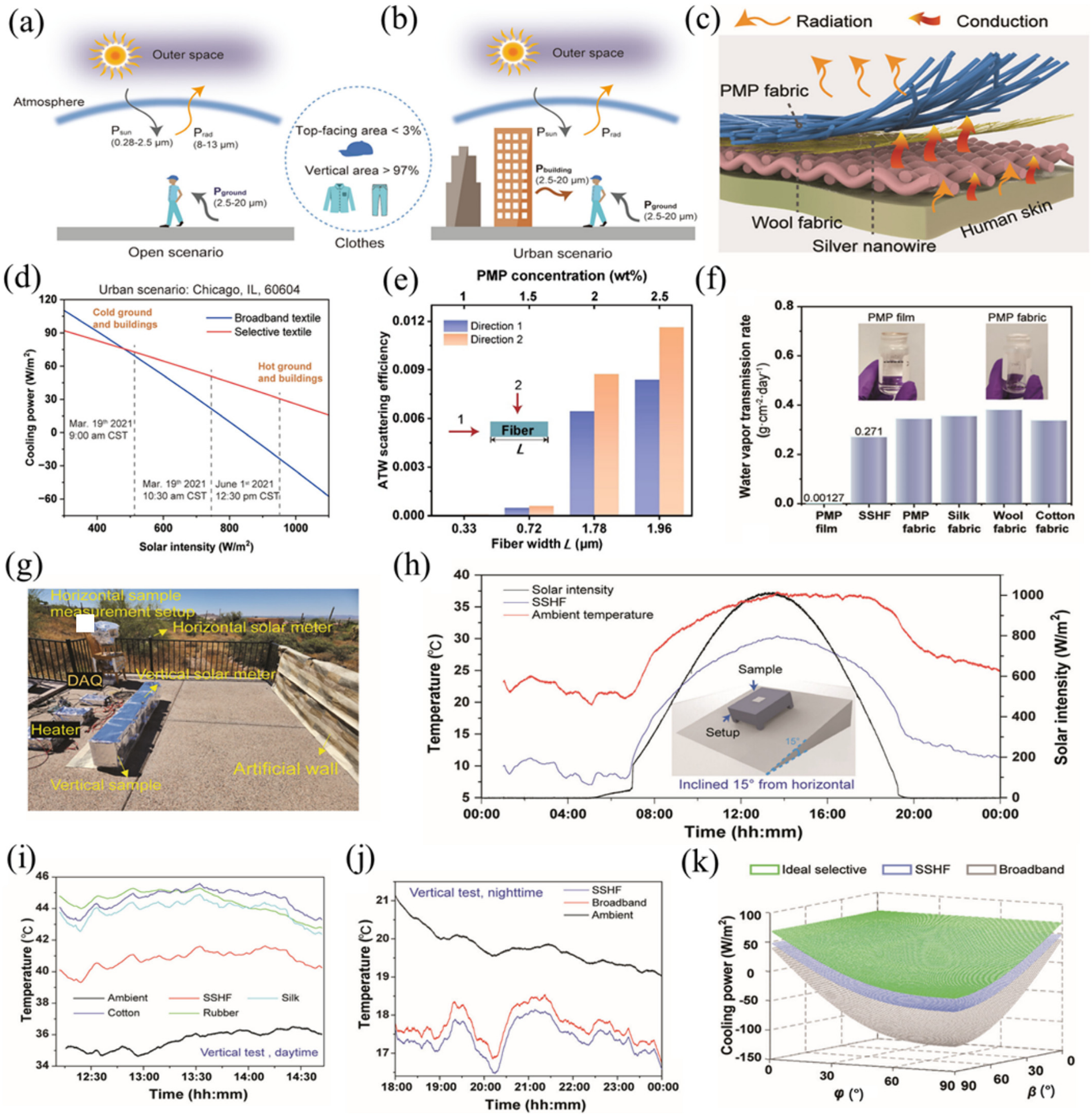

Fig. 1. (Color online) (a) Schematic of the wearable fabric in the open scenario and (b) urban scenario. (c) Schematic of layered structure of SSHF textile. (d) Cooling power of vertically oriented broadband and selective textiles in an urban scenario. (e) Scattering efficiency of PMP fabrics along different incidence directions. (f) Air permeability test of different samples. (g) Photograph of outdoor measurement experimental setup. (h) Schematic diagram of the measurement setup inclined at 15° to the ground plane and sample temperature curve. (i) Temperature profiles of different samples in vertical orientation during daytime. (j) Comparison of SSHF and broadband transmitter placed vertically at nighttime. (k) Simulation results of the ideal cooling power of SSHF vs. broadband transmitter. Reprinted with permission from Ref. [9], Copyright © 2024, AAAS.

tration being a major determinant [12]. Experiments have demonstrated that reducing the solution concentration substantially decreases the resulting fiber size. Finite element simulation analysis reveals that fibers with smaller cross-sections lead to lower scattering efficiency (Fig. 1e). Simultaneously, an increase in thickness positively affects the fabric, enhancing both reflectance and emissivity. In practice, considering both cooling performance and economic benefits, a polymer concentration of 2 wt% and a thickness of 292 μm are more appropriate.

To ensure the fabric meets wearing requirements for the human body, factors such as abrasion resistance and air permeability are critical. Fig. 1f shows that PMP fabric, with superior pore structure, exhibits excellent water vapor permeability compared to PMP film produced by the casting. The rough surface of the micro/nano fiber network results in a contact angle of 135°, providing self-cleaning properties for SSHF. Additionally, after undergoing tensile-release and washing tests, SSHF shows minimal changes in reflectivity and emissivity, indicating good durability.

Fig. 1g illustrates the setup for the SSHF's outdoor cooling performance test, showing temperature monitoring of samples in both horizontal and vertical orientations. In the horizontal test (Fig. 1h), the SSHF consistently maintained temperature below the ambient level. It achieved an average temperature reduction of 12.6 °C at night. Even during peak daytime solar irradiation, SSHF remained approximately 6.2 °C cooler than the ambient temperature. In the vertical test, SSHF was subjected to thermal radiation from the ground and cardboard (simulating a man-made building) in addition to solar irradiation. Despite these conditions, SSHF exhibited lower temperatures compared to commercial textile materials (Fig. 1i). At night, the cooling capacity of selective emitter was slightly higher than that of broadband emitter (Fig. 1j) because the former was more effective at blocking thermal radiation from the ground. Additionally, to simulate the cooling performance of SSHF in an urban scenario, a 3D theoretical model has been constructed, as shown in Fig. 1k. At a solar intensity of 850 W m^{-2}, SSHF consistently demonstrated superior cooling performance compared to broadband emitters. This advantage will become increasingly pronounced with higher densities of urban structures.

In summary, a layered cooling fabric designed to counter urban heat islands has been introduced, demonstrating excellent breathability and abrasion resistance. The fabric utilizes the selective emission of PMP, the high reflectivity of AgNWs and the broadband emission of wool to achieve optimal cooling performance. When positioned perpendicular to the ground, SSHF is 2.3 °C cooler than a broadband radiator. When oriented nearly horizontal, it is 6.2 °C cooler than the ambient temperature, demonstrating its superior outdoor cooling capability. The fabric can be adapted to various broadband emitter substrates, thereby broadening its range of applications. However, SSHF has limitations, such as the use of advanced materials and preparation processes that may drive up costs, and the long-term durability of the samples under real-world conditions remains uncertain. These factors could pose challenges for the product's practical application. Given this, future research should focus on reducing costs and evaluating the stability of the material in diverse environments. Overall, this work fills the research gap concerning the impact of the urban heat island effect on radiation cooling and proposes a practical strategy to mitigate heat radiation from the ground and buildings. It enriches the theoretical foundation of cooling fabric research and offers a more comprehensive reference for future studies.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] Huang M, Yang M, Guo X, et al. Scalable multifunctional radiation cooling materials. Prog Mater Sci 2023;137:101144.

[2] Zeng S, Pian S, Su M, et al. Hierarchical-morphology metafabric for scalable passive daytime radiation cooling. Science 2021;373:692–6.

[3] Yang R, Xie F, Li Y, et al. Advancing thermal comfort: an innovative SiO_2 microsphere-decorated shish-kebab film composite for enhanced personal cooling. Adv Nano 2024;1:86–93.

[4] Hong C, Wang Y, Gu Z, et al. Cool facades to mitigate urban heat island effects. Indoor Built Environ 2022;31:2373–7.

[5] Zhu S, Mai X. A review of using reflective pavement materials as mitigation tactics to counter the effects of urban heat island. Adv Compos Hybrid Mater 2019;2:381–8.

[6] Levermore GJ, Parkinson JB, Laycock PJ, et al. The urban heat island in manchester 1996–2011. Build Serv Eng Res T 2014;36:343–56.

[7] Roxon J, Ulm FJ, Pellenq RJM. Urban heat island impact on state residential energy cost and CO_2 emissions in the United States. Urban Clim 2020;31:100546.

[8] Wu J, Hu R, Zeng S, et al. Flexible and robust biomaterial microstructured colored textiles for personal thermoregulation. ACS Appl Mater Inter 2020;12:19015–22.

[9] Wu R, Sui C, Chen T, et al. Spectrally engineered textile for radiation cooling against urban heat islands. Science 2024;384:1203–12.

[10] Feng S, Yao L, Chen X, et al. Dual-asymmetrically selective interfaces-enhanced poly(lactic acid)-based nanofabric with sweat management and switchable radiation cooling and thermal insulation. J Colloid Inter Sci 2023;648:117–28.

[11] Ji D, Lin Y, Guo X, et al. Electrospinning of nanofibres. Nat Rev Methods Primers 2024;4:1.

[12] Han T, Zhou Z, Du Y, et al. Advances in radiation sky cooling based on the promising electrospinning. Renew Sust Energ Rev 2024;200:114533.

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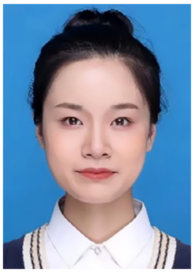

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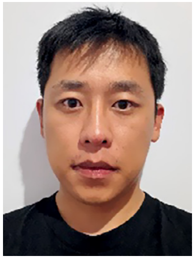

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