Electronic Supplementary Material (ESI) for Materials Horizons.

Supporting information to:

Controllable-morphology polymer blend photonic metafoam for radiative cooling

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Supplementary Text

1. Simulation model

1.1. Radiative characteristics of single air pores embedded in porous metafoam

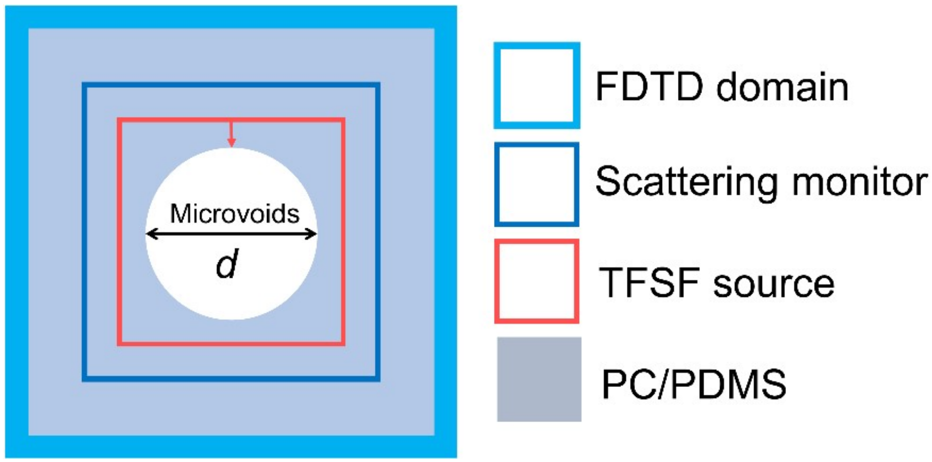

Figure S1. Microvoids structure used for the FDTD simulation.

1.2. Heat transfer model analysis of the structure

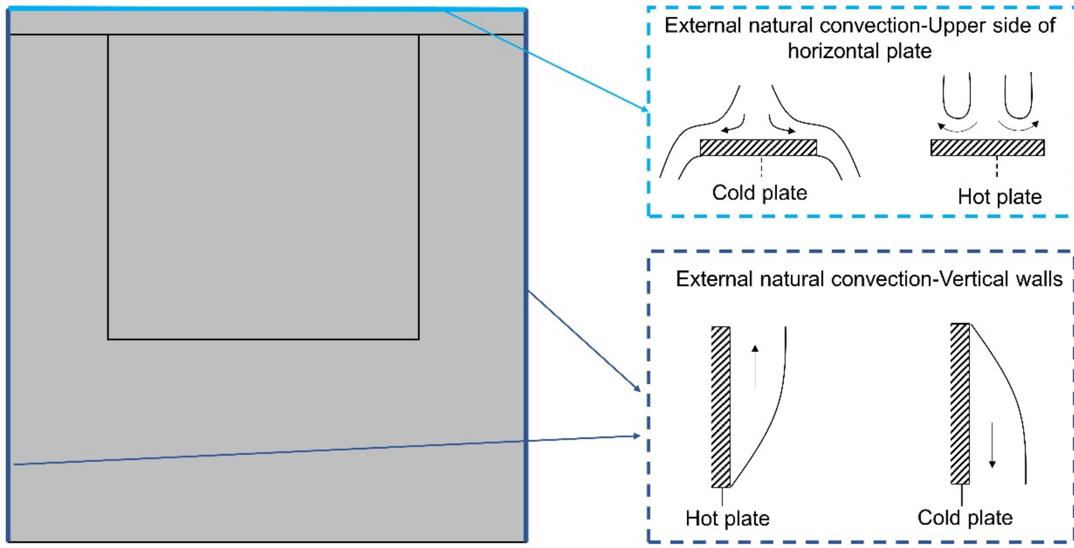

Figure S2. COMSOL simulation of the radiative cooler in natural convection of air.

1.3. Building energy-saving simulation by EnergyPlus

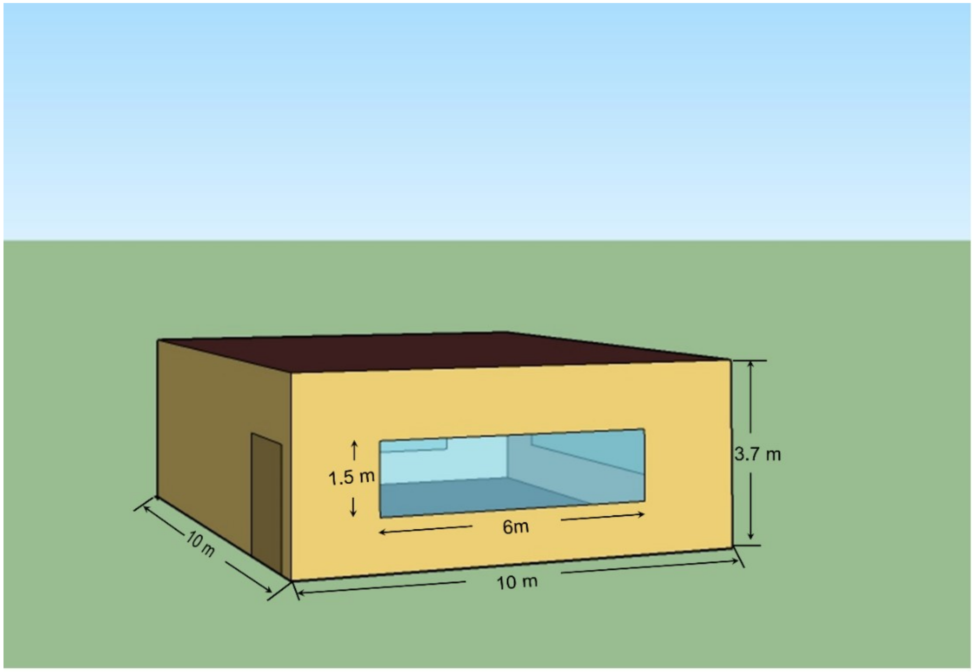

Figure S3. Schematic of a simplified residential house with 10 m×10 m×3.7 m for EnergyPlus simulation.

Table S1. Thermo-fluid properties used in the energy consumption simulation

Property	Value
Sample thickness (mm)	5
Thermal absorptance	0.91
Solar absorptance	0.03
Specific heat ($J \cdot kg^{-1} \cdot K^{-1}$)	830
Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	0.046
Density ($g \cdot cm^{-3}$)	0.216

2. Calculation of cooling power

According to the law of Kirchhoff, the emissivity of an arbitrary body is equal to its absorptivity in thermodynamic equilibrium. So Emissivity (ε(λ)) was calculated by ε(λ)=1- R (λ)- T(λ).[1] The average solar reflectance ($\bar{R}_{solar}$) is defined as:[2]

$$\bar{R}_{solar} = \frac{\int_{0.3\ \mu m}^{2.5\ \mu m} I_{solar}(\lambda) \cdot R_{solar}(\lambda) d\lambda}{\int_{0.3\ \mu m}^{2.5\ \mu m} I_{solar}(\lambda) d\lambda} \tag{1}$$

Where λ is the wavelength of the sunlight in the range of 0.3-2.5 μm, $I_{solar}(\lambda)$ is ASTM G173-03 Global solar intensity spectrum (AM1.5), and $R_{solar}(\lambda)$ is spectral reflectivity of the material. The average emittance ($\bar{\varepsilon}_{ATW}$) in the atmospheric transmittance window is defined as:

$$\bar{\varepsilon}_{ATW} = \frac{\int_{8\ \mu m}^{13\ \mu m} I_{BB}(\lambda) \cdot \varepsilon_{ATW}(\lambda) d\lambda}{\int_{8\ \mu m}^{13\ \mu m} I_{BB}(\lambda) d\lambda} \tag{2}$$

Where $\varepsilon_{ATW}(\lambda)$ represents spectral thermal emittance of the surface in the range from 8 μm to 13 μm. $I_{BB}(\lambda)$ represents the radiant intensity emitted by a blackbody at a temperature of T, and it can be calculated by the following equation:

$$I_{BB}(T,\lambda) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda K_B T}} - 1} \tag{3}$$

Where h is Planck's constant, K_B is the Boltzmann constant, and c is the speed of light.

The daytime cooling power of radiative cooler is calculated by the following equation:

$$P_{cooling} = P_{rad}(T) - P_{sun} - P_{atm}(T_{amb}) - P_{non-rad} \quad (4)$$

Where P_{rad} (T) represents the power radiated out by the radiative cooler at temperature T, which can be defined as:

$$P_{rad}(T) = 2\pi \int_{0}^{\frac{\pi}{2}} d\theta sin\theta cos\theta \int_{2.5\ \mu m}^{25\ \mu m} I_{BB}(T, \lambda)\varepsilon(\lambda,\theta)d\lambda \quad (5)$$

$I_{BB}(T, \lambda)$ is calculated by eq.(3), and $\varepsilon(\lambda, \theta)$ is the spectral and angular emissivity of the cooler. Atmospheric thermal radiation absorbed by the radiative cooler can be calculated as follows:

$$P_{atm}(T_{amb}) = 2\pi \int_{0}^{\frac{\pi}{2}} d\theta sin\theta cos\theta \int_{2.5\ \mu m}^{25\ \mu m} I_{BB}(T, \lambda)\varepsilon(\lambda,\theta)\varepsilon_{atm}(\lambda,\theta)d\lambda \quad (6)$$

$\varepsilon_{atm}(\lambda, \theta)$ is the spectral and angular emissivity of the atmosphere, which can be defined as $\varepsilon_{atm}(\lambda, \theta) = 1 - t(\lambda)^{1/\cos\theta}$. Here $t(\lambda)$ is the atmospheric transmittance in the zenith direction, which can be obtained by MODTRAN of Mid-Latitude Summer Atmosphere Model (MODTRAN® (spectral.com)).[3,4]

The solar irradiance absorbed by cooler (P_{sun}) and the non-radiative power lost ($P_{non\text{-}rad}$) due to convection and conduction is defined as:

$$P_{sun} = \int_{0.3\ \mu m}^{2.5\ \mu m} I_{solar}(\lambda)\varepsilon(\lambda,0)d\lambda \quad (7)$$

$$P_{non-rad} = h_c(T_{amb} - T) \quad (8)$$

Where h_c is the coefficient of the non-radiative heat.

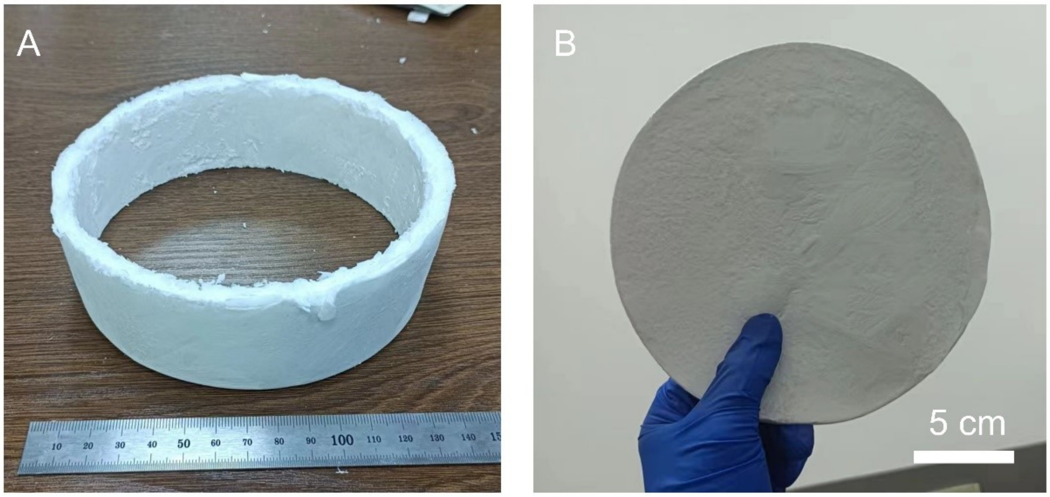

Figure S4. Metafoams with three-dimensional curved shape (A) and larger size (B).

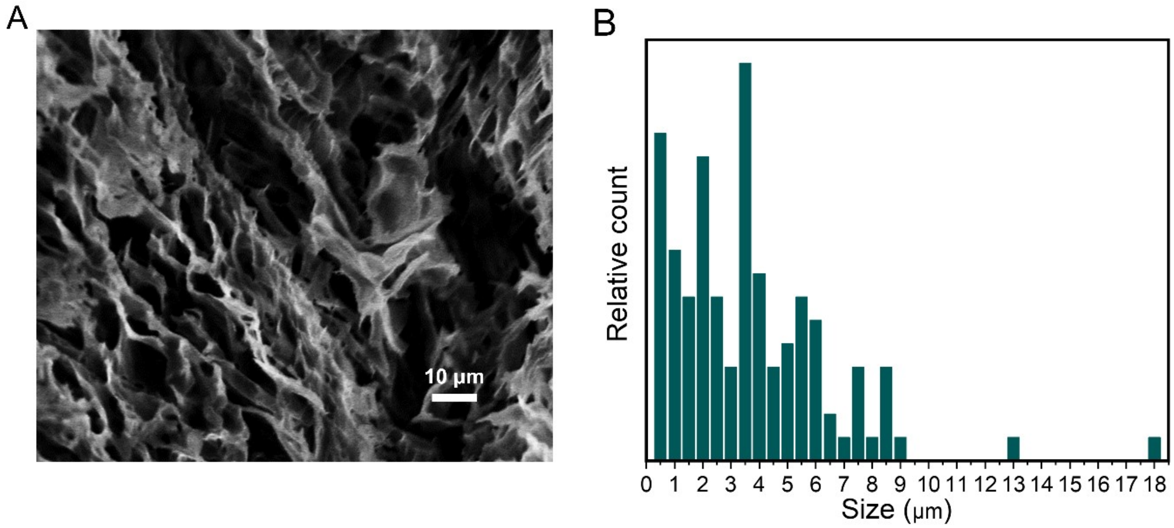

Figure S5. (**A**) SEM, and (**B**) pore size distribution of metafoam.

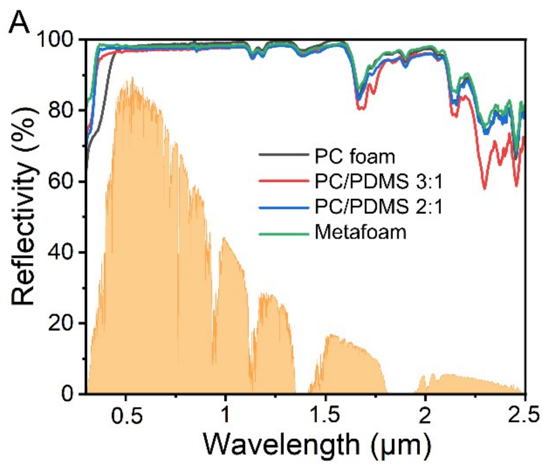

Figure S6. The reflectivity (**A**) in the solar wavelength and thermal emissivity (**B**) in the MIR wavelength of PC foam and polymer blended foam with different PDMS ratios. The ratio of PC and PDMS in metafoam is 1:1.

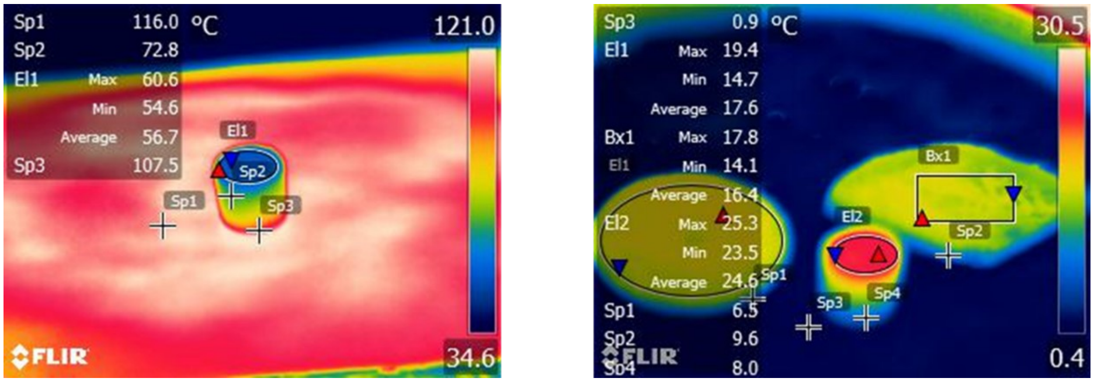

Figure S7. Thermal insulation performance of metafoam. The heated stage on the left is set to 120°C, while the ice-water combination on the right is 0°C. The thicker metafoam is, the bigger temperature differential between the two sides of the metafoam.

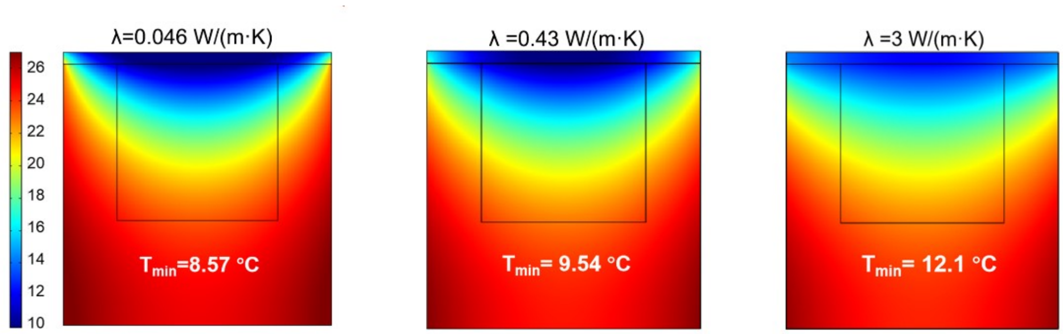

Figure S8. Simulation of the radiative cooling performance for the tested materials with different thermal conductivities. The radiative cooler's thermal conductivity gradually rises from left to right, while the other parameters stay constant.

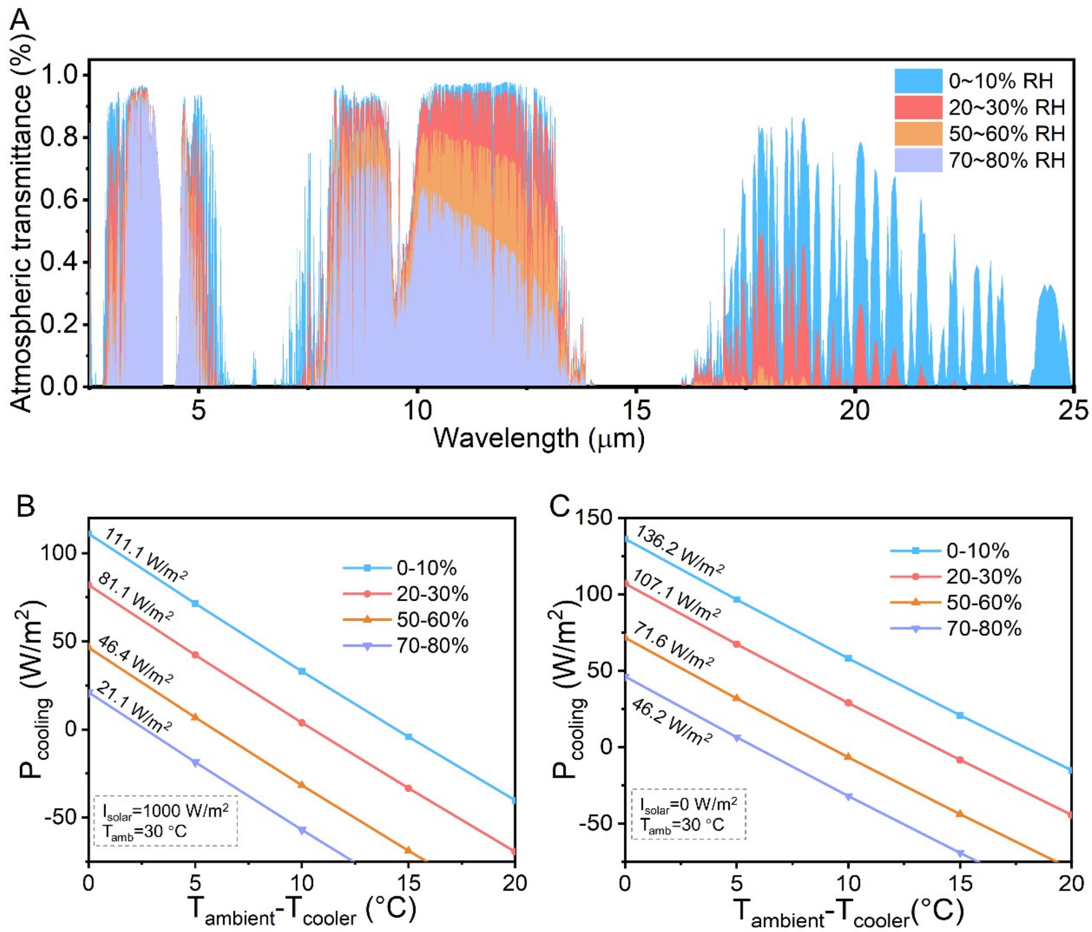

Figure S9. (**A**) The atmosphere transmittance with varied relative humidity, calculated cooling power of metafoam with different RH during the daytime (**B**), and during the nighttime (**C**), where value of 3 W/(m^2·K) for h_c are used in the calculation.

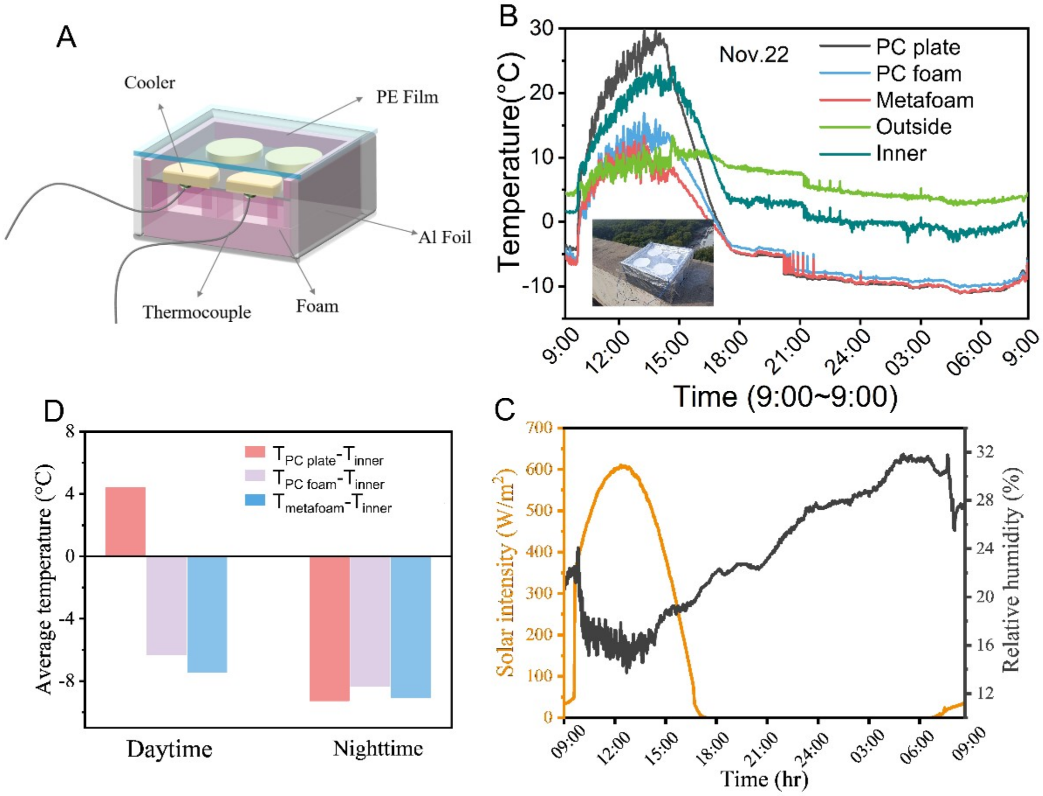

Figure S10. (**A**) Schematic of the experimental setup. (**B**) Temperature curves of PC plate, PC foam, metafoam, indoor and outdoor air, inset is the photo of the experimental setup. (**C**) The solar intensity and relative humidity during testing. (**D**) the average temperature difference in the daytime and nighttime.

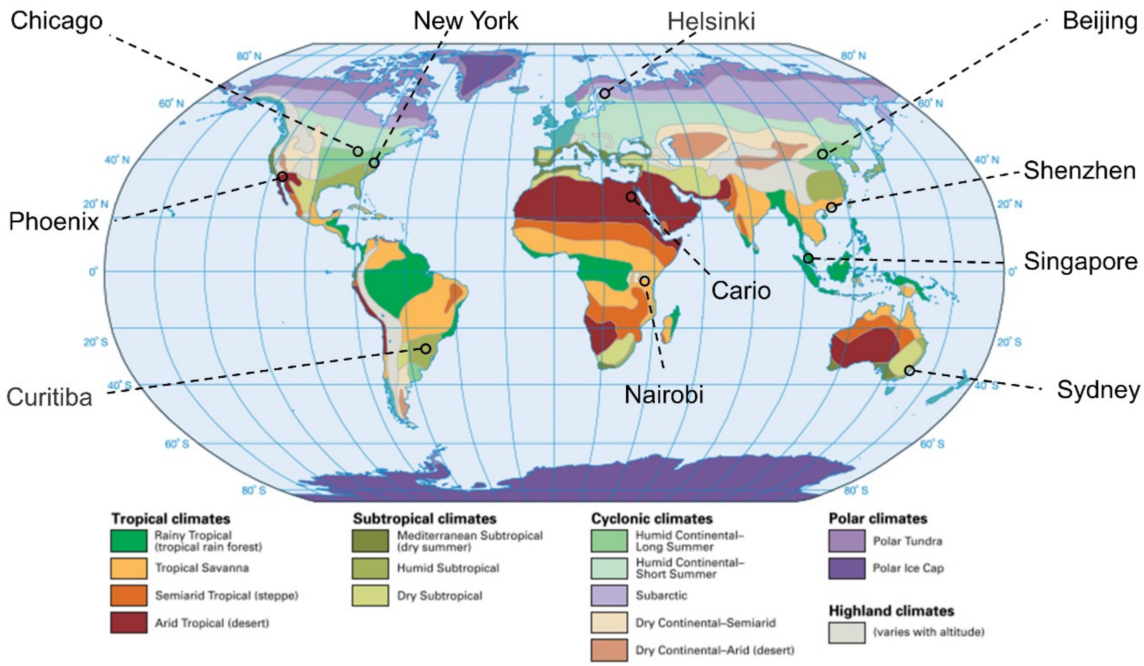

Figure S11. Map of the locations of eleven cities in different climate zones around the world.

References

[1] T. Wang, Y. Wu, L. Shi, X. Hu, M. Chen, L. Wu, A structural polymer for highly efficient all-day passive radiative cooling, Nat. Commun. 12 (2021) s41467.

[2] M. Chen, D. Pang, J. Mandal, X. Chen, H. Yan, Y. He, N. Yu, Y. Yang, Designing Mesoporous Photonic Structures for High-Performance Passive Daytime Radiative Cooling, Nano Lett. 21 (2021) 1412-1418.

[3] C. Liu, Y. Wu, B. Wang, C. Y. Zhao, H. Bao, Effect of atmospheric water vapor on radiative cooling performance of different surfaces, Sol Energy 183 (2019) 218-225.

[4] J. Huang, M. Li, D. Fan, Core-shell particles for devising high-performance full-day radiative cooling paint, Appl. Mater. Today 25 (2021) 101209.