Supporting Information

Low-cost and Transparent Cooling Films with Solar Selective Nanoparticles for Building Energy Saving

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Note S1. Energy Consumption Simulation Details

To demonstrate the applicability of solar selection film in different regions and different types of buildings, we simulated the energy consumption of air conditioning in two types of buildings in seven climatic zones. The simulation compared the annual energy savings of the air conditioning system before and after the application of solar selective films in the building. Solar selective films were set on the outer surface of the building window, which was implemented in the software by setting semi-transparent films on windows outer surface. Parameters of the semi-transparent films were set according to spectral data of the solar selective films (See **Figure 3e** for details). In addition, in view of the fact that the back-to-the-sun windows are less exposed to the sun, according to the actual need of the solar selective films, we set the solar selection films on roof windows and all external windows except north windows in the Northern Hemisphere or south windows in the Southern Hemisphere.

The two buildings are typical office buildings with different number of floors and window-wall ratio, and the remaining building parameters are the same. Of these, the normal building is a 5-story building with 50% window-wall ratio, and the glass-curtain building is a 20-storey building with 90% window-wall ratio (**Table S5**). Considering the occupancy time and human comfort requirements of typical office buildings, we calculate the annual energy consumption of air conditioners at 8:30 ~ 17:30 during the weekdays. Among these, air conditioning systems are used to maintain indoor temperatures between 20 ~ 25 °C. In detail, when the indoor temperature is above 25 °C or below 20 °C, the air conditioning systems turn on the cooling or heating modes respectively. When the indoor temperature is between 20 ~ 25 °C, the air conditioning systems are turned off.

Supplementary Tables

Table S1. Spectroscopic properties of solar selective radiative cooled films to date

Peak transmittance of	Near-infrared barrier	Mid-infrared	References

VIS (%)	rate (%)	emissivity (%)	
80	20	95	1
77	43	91	2
60	51	55.6	3
15	75	-	4
91.3	10	93.7	5
72.8	15	92.4	6
68	75.9	-	7
80	42.9	-	8
53	40.2	-	8
90	33.7	90	9
75	73.8	90.7	10
80.5	71.7	94.8	11
65	73.6	94.3	12
89	40.7	-	13
75	32.5	95	14

Table S2. Spectrum of solar selective films with different $Cs_{0.33}WO_3$ concentrations and different thickens

$Cs_{0.33}WO_3$ concentration (%)	Film thickness (μm)	Average transmittance of VIS (%)	Peak transmittance of VIS (%)	Blocking rate of NIR (%)	Blocking rate of UV (%)
0.5	35	90.	94.9	31.9	38.6
	50	81.7	87.3	45.8	55.4
	65	74.3	81.7	58	68
	75	76.6	83.5	54.9	65.2
	100	79.8	89.4	59.7	72.7
	125	73.5	84.1	69.6	80.9
0.75	35	74.4	83.6	44.1	71.7

	50	59.7	70.2	54.4	83.8
	65	64.8	78.5	64.1	84.7
	75	65.5	78.8	74.7	86.3
	100	63.7	78.0	78.0	88.1
	125	57.8	70.7	83.3	92.3
1	35	64.9	74.6	68.3	81.4
	50	51.8	62.8	79.9	90.1
	65	59.2	69.7	76.6	86.4
	75	54	66.7	78.1	91.7
	100	55.3	68.5	81.6	91.8
	125	46.9	60.5	87.7	95.4
1.25	35	65	76.4	74.4	82
	50	56.5	65.6	85.1	88.8
	65	47.9	58.7	90.3	93.9
	75	53.4	55.9	92.1	90.9
	100	51.4	45.4	95.7	94.2
	125	37	54	92.5	97.3
1.5	35	65.5	75.6	70.6	84.7
	50	52.8	68.1	78.3	92.9
	65	45.7	60.3	87.5	96
	75	42.7	65.3	83.7	96.7
	100	32.4	65.1	87.2	99
	125	41.2	49.4	92.8	99

Table S3. Elemental content in different zones characterized by SEM and EDS

Zone	Element	weight percentage （wt, %)	atomic percentage (at,%)
Zone 1	C	68.79	76.46
	O	17.2	14.36

	F	12.96	9.11
	Cs	0	0
	W	1.05	0.08
	C	52.14	74.19
	O	6.11	6.53
Zone 2	F	18.84	16.95
	Cs	5.62	0.72
	W	17.28	1.61

Table S4. Spectral characteristics of the solar selective film and the commercial film

Peak of visible transmittance (%)	Average transmittance of VIS (%)	Peak transmittance of VIS (%)	Blocking rate of NIR (%)	Blocking rate of UV (%)	Mid-infrared emissivity (%)
Solar selective film	63.7	78.0	78.0	88.1	92.2
Commercial film	72.1	85.7	8.1	99.9	85.0

Table S5. Basic building parameters in energy consumption analysis.

Parameter	Normal building	Glass-curtain building
Number of floors	5	20
Window-wall ratio of the exterior window	50%	90%
Type of building	Office building	
Covers an area	50*50 m	
Type of glass	Double glazing unit (6-12A-6)	
Window wall ratio of the inner window	30%	
The Windows and walls on the roof	25%	

Personnel density	0.125 persons/m^2
Fresh air volume	30 m^3/(h·person)
Lamp power	6.7 W/m^2
Equipment power	10 W/m^2
Room temperature setting range	20~25 ℃
Air conditioner opening period	Weekdays: 8:30~17:30
COP of air conditioner	3
Application of solar selective film	External walls and roof Windows (except north in the Northern Hemisphere or south in the Southern Hemisphere)

Table S6. Cost calculation of solar selective film.

Material	Dosage (g/m^2)	Price ($/kg)	Cost ($/m^2)
Ethyl alcohol	4.5	8.00	0.036
Xylene	4.5	16.56	0.075
FEVE fluorocarbon resin	120	6.69	0.803
$Cs_{0.33}WO_3$ nanoparticles	0.9	414.00	0.373
PVP dispersant	0.09	19.32	0.002
Curing agent	12	18.77	0.225
Thickening agent	0.6	7.45	0.004
Total	-	-	1.52

Note： The usage amount and price of each material are listed in the following tables. All the prices are based on the Alibaba platform

Table S7. Comparing the spectral properties and costs of solar selective film in our work with other studies

Reference	Cost ($/m^2)	Transparency (%)	Near infrared barrier rate (%)	Mid infrared emission (%)

Our Work	1.52	78	78	92.2
[3]	48.3	69.6	50.9	74.5
[10]	4.5	77.5	73.8	90.7
[15]	3.7	83.3	67.7	89.9

Supplementary Figures

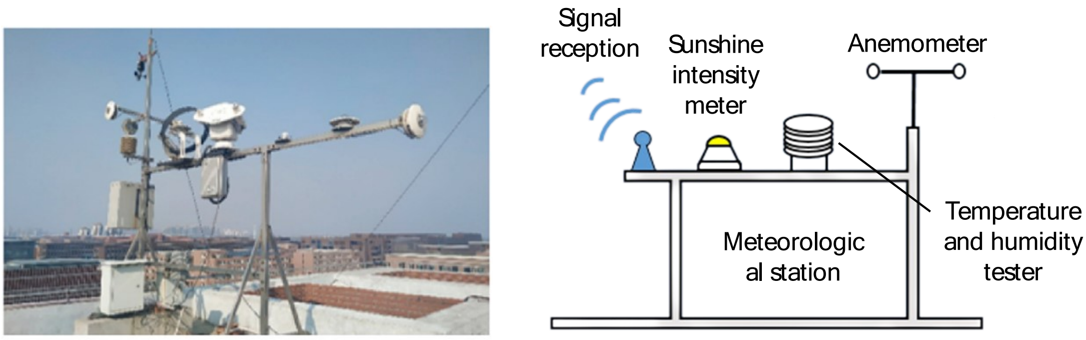


Figure S1. Photos and diagrams of meteorological station.

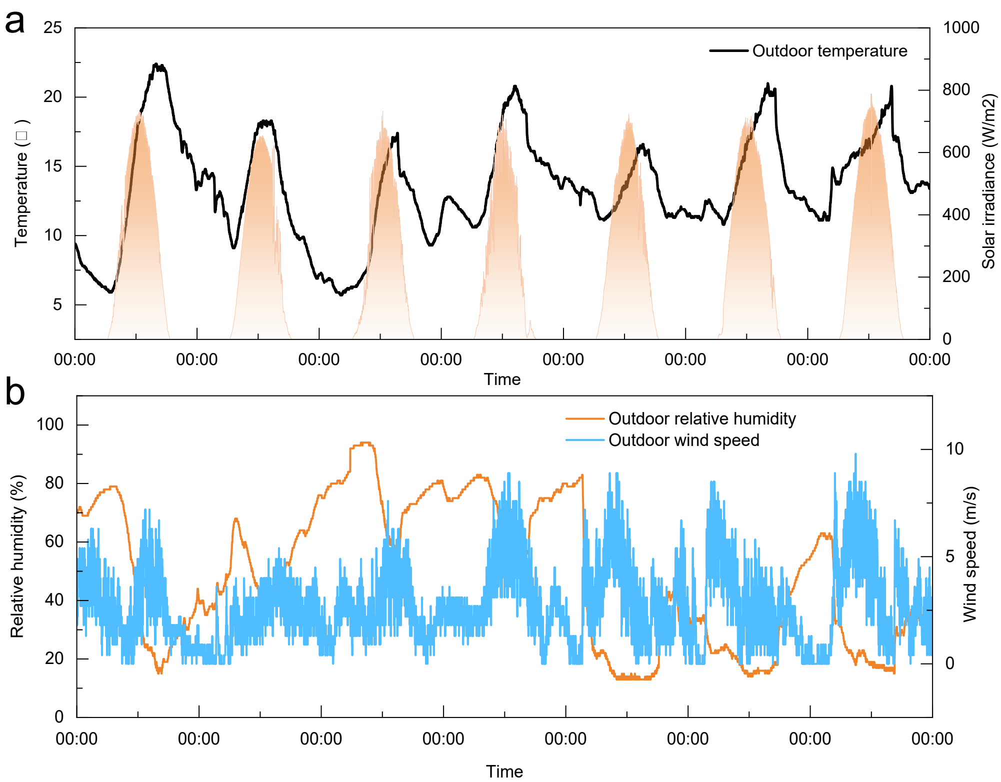


Figure S2. Meteorological parameters during the summer experiment. **(a)** Solar irradiance and outdoor ambient temperature in summer. **(b)** Outdoor relative humidity and wind speed in summer.

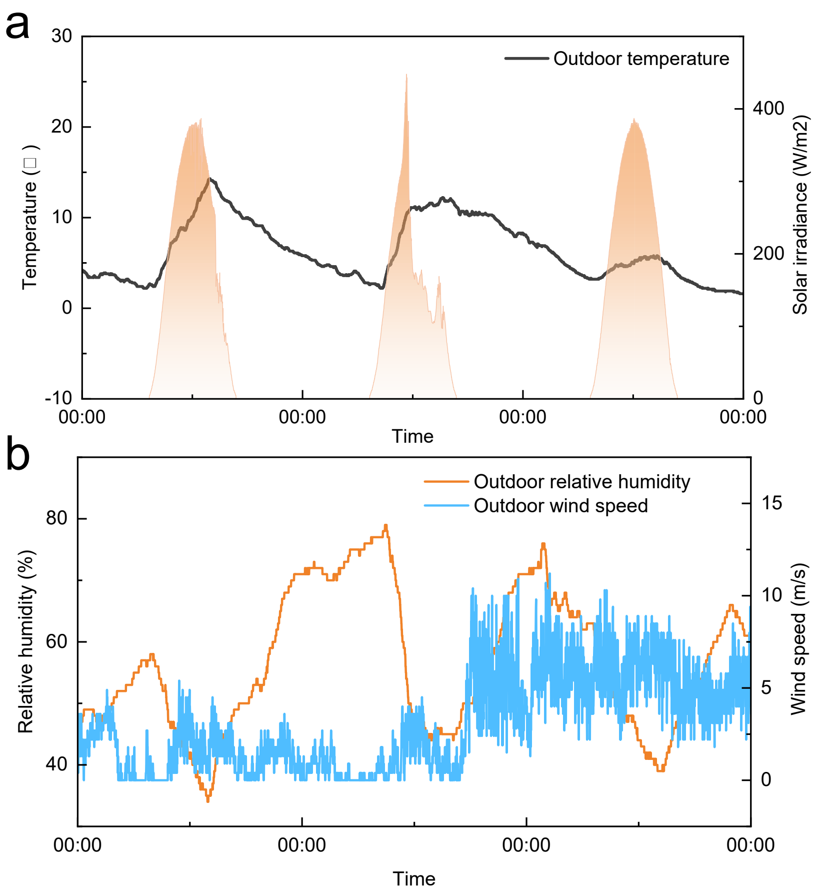


Figure S3. Meteorological parameters during the winter experiment.**(a)** Solar irradiance and outdoor ambient temperature in winter. **(b)** Outdoor relative humidity and wind speed in winter.

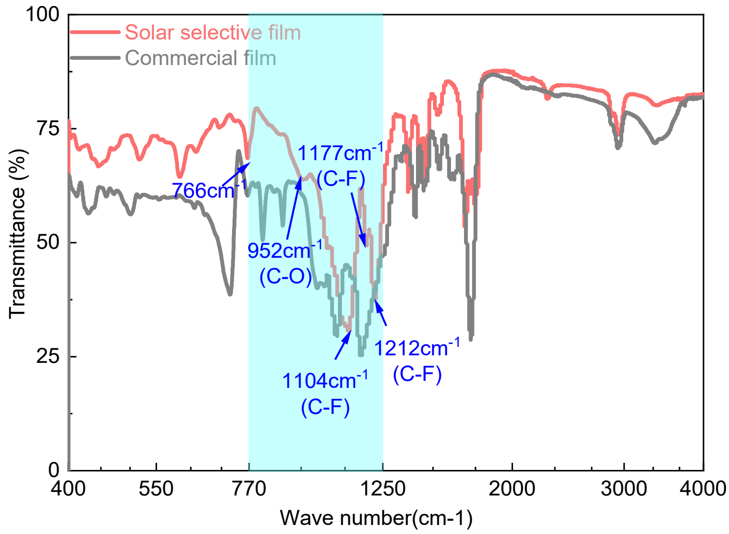


Figure S4. Fourier transform infrared spectrum information of solar selective film and commercial film.

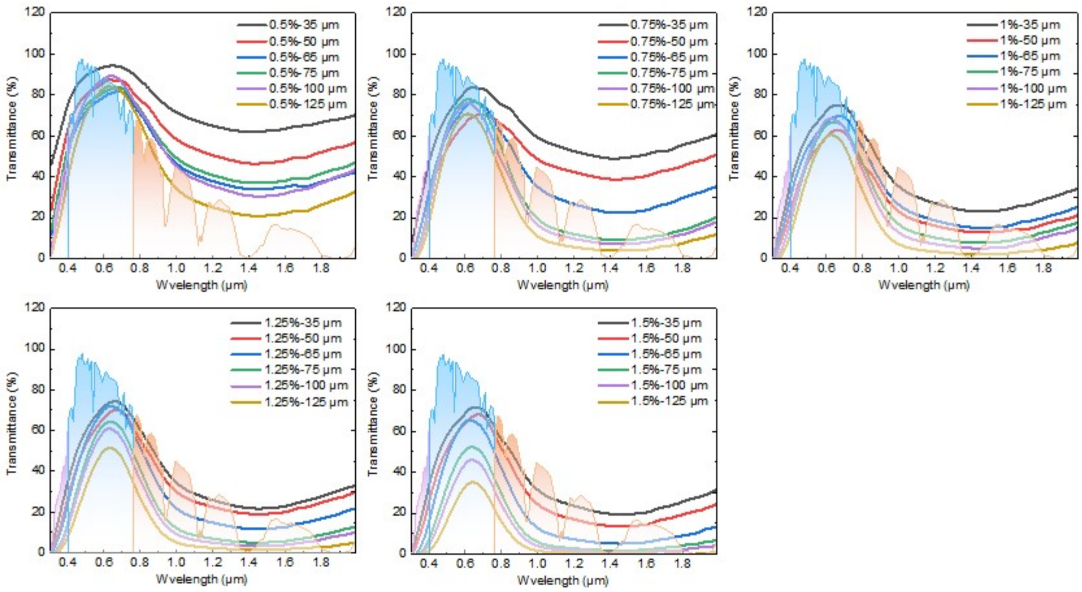


Figure S5. Spectral properties of thin films with different cesium tungstate concentration and different thickness

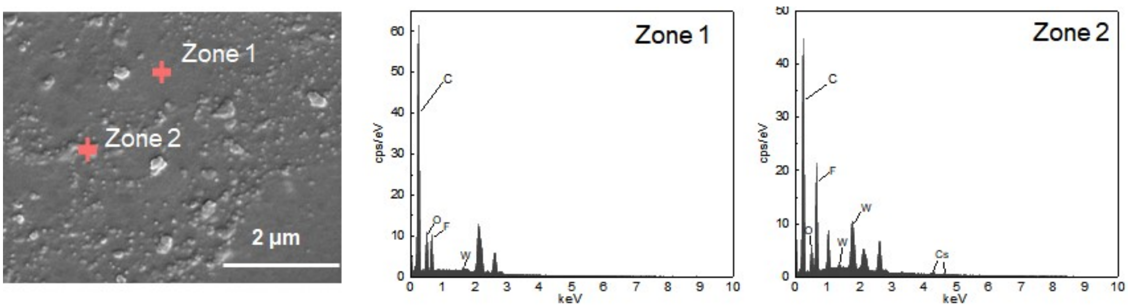


Figure S6. SEM and EDS information of solar selective film.

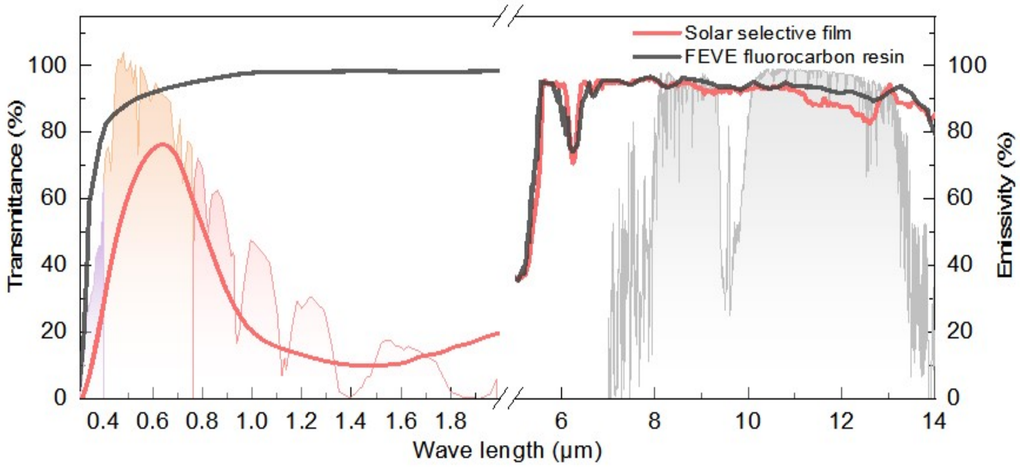


Figure S7. Comparison of spectral properties of FEVE resin and solar selective film.

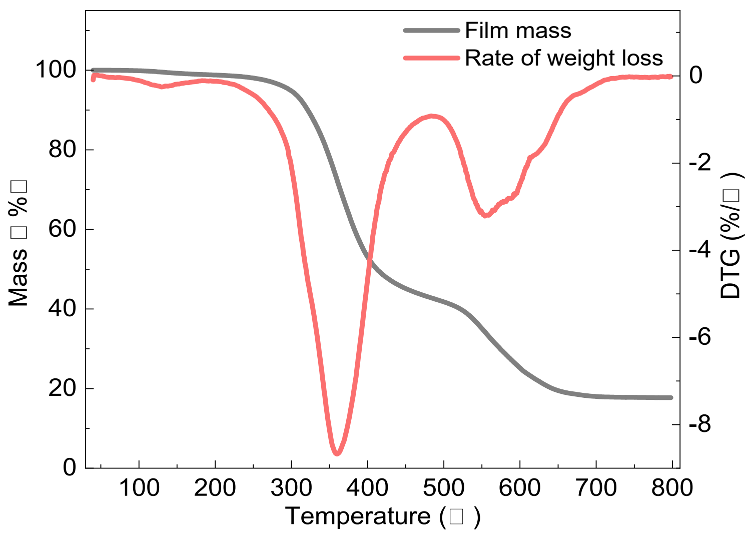


Figure S8. Thermogravimetric analysis of solar selective film.

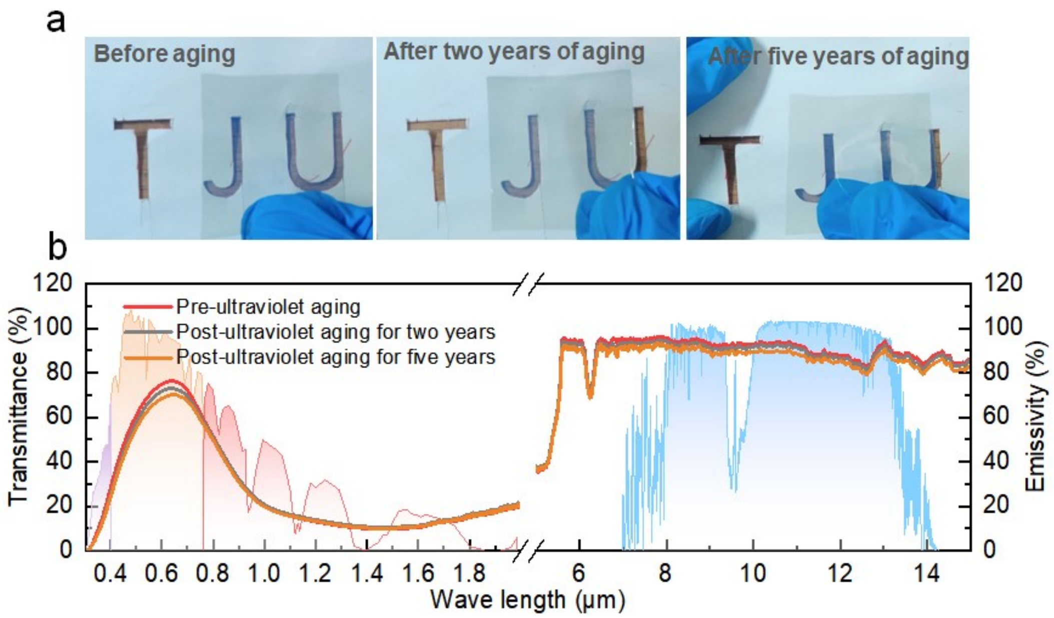


Figure S9. Comparison of solar selective film before and after ultraviolet aging. **(a)** Appearance of the film before and after ultraviolet aging. **(b)** Spectra of film before and after ultraviolet aging.

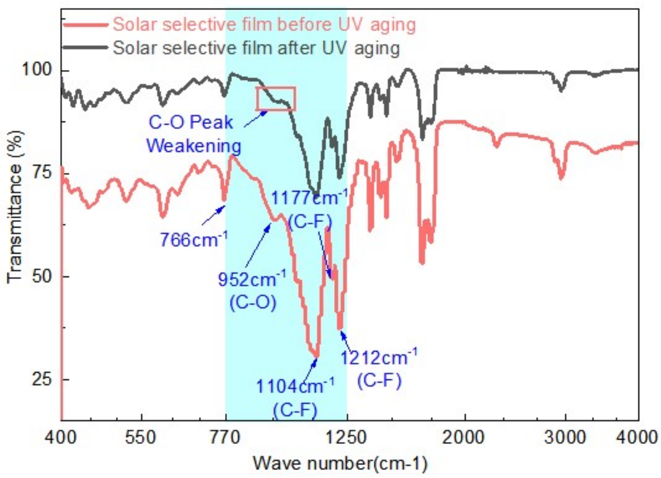


Figure S10. FTIR information of solar selective film before and after UV aging of 5 years

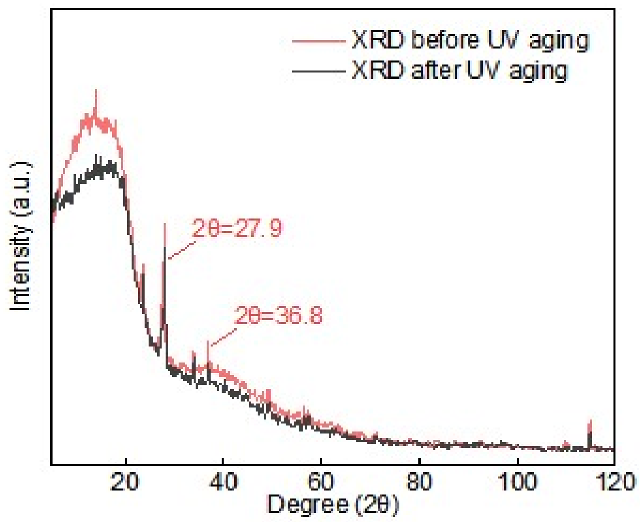


Figure S11. XRD information of solar selective film before and after UV aging of 5 years.

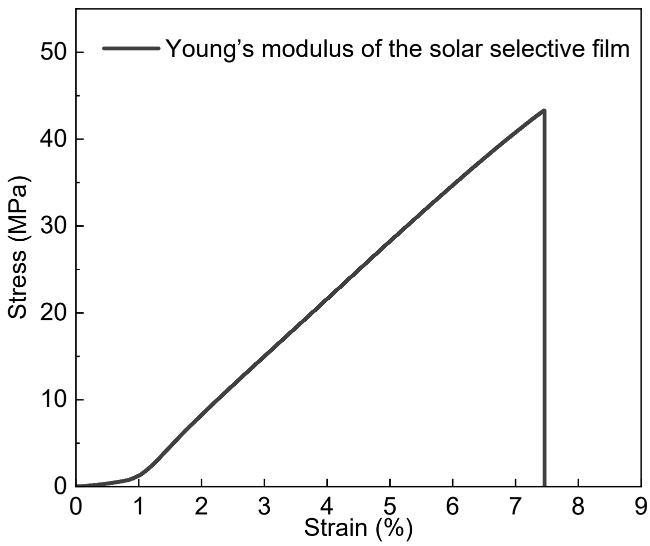


Figure S12. Young's modulus of the solar selective film

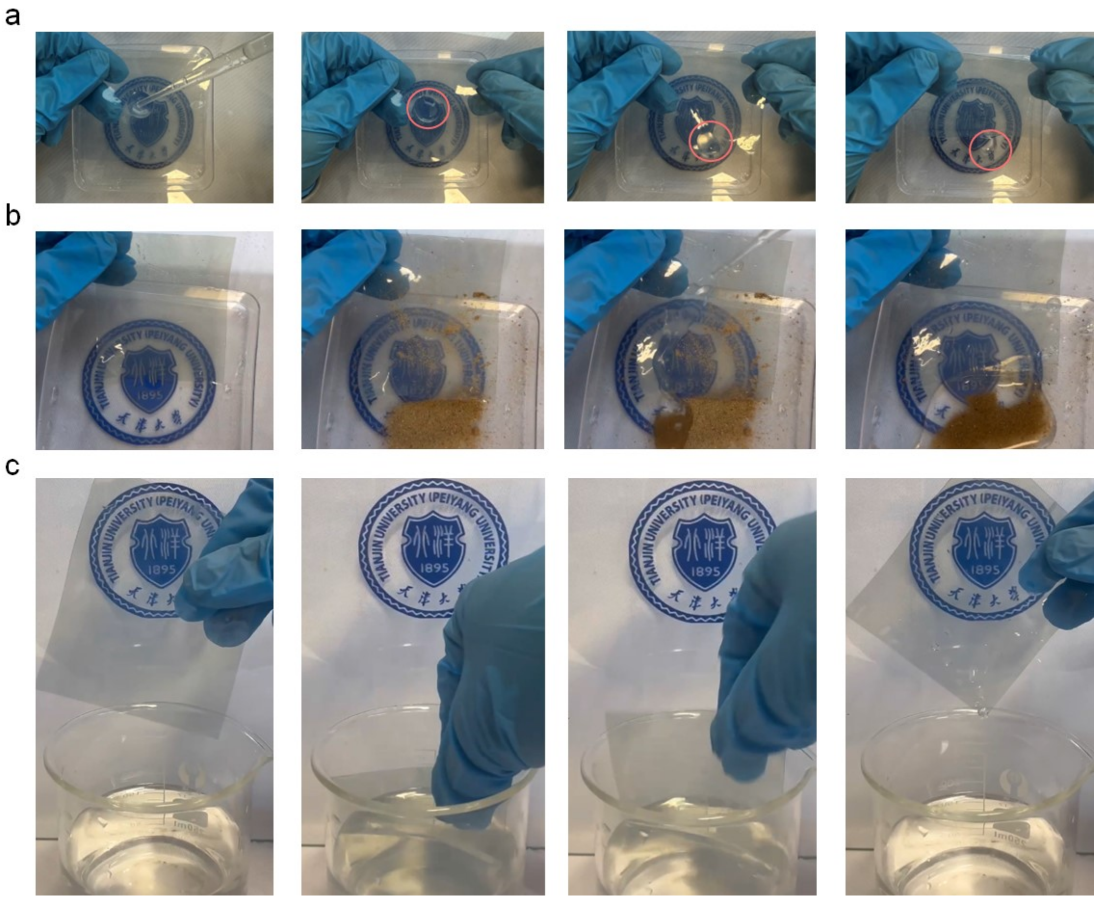
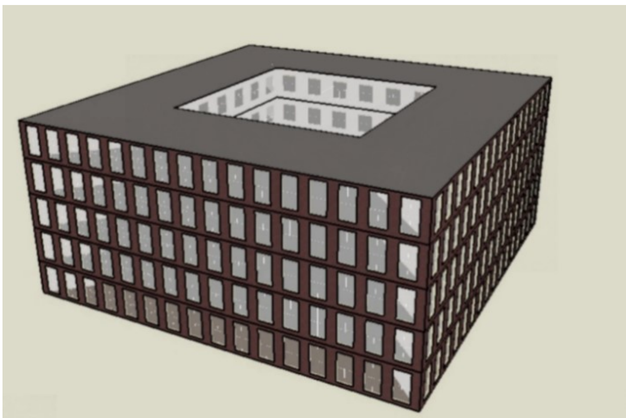


Figure S13. The water resistance and cleanability of the solar selective film



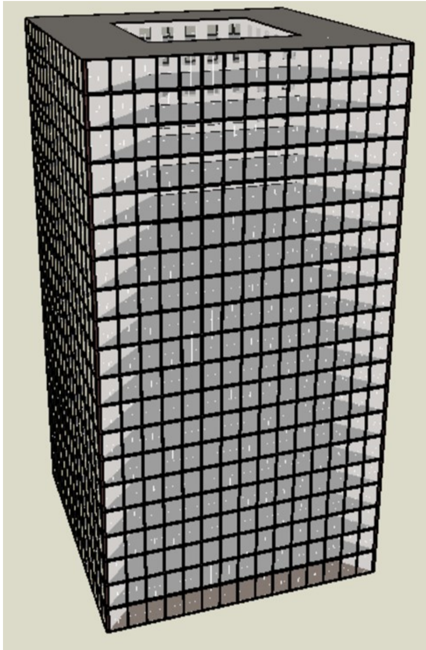


Figure S14. Simulation model of the normal building and the glass-curtain building.

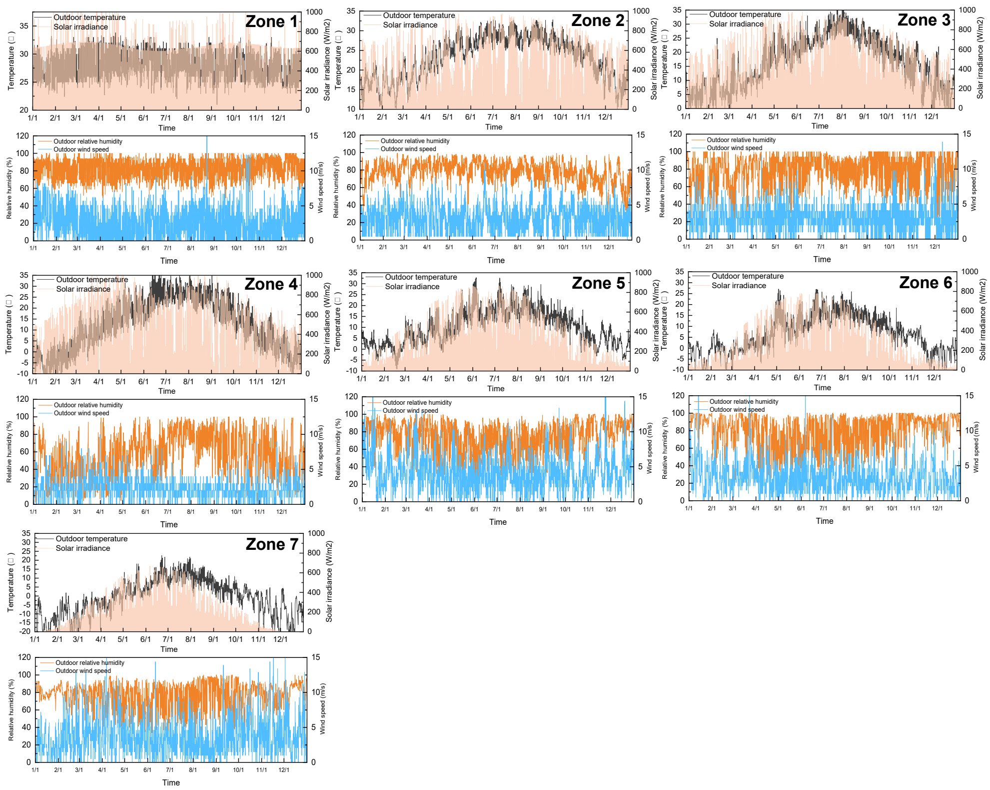


Figure S15. Annual meteorological parameters during energy consumption simulation in different regions.

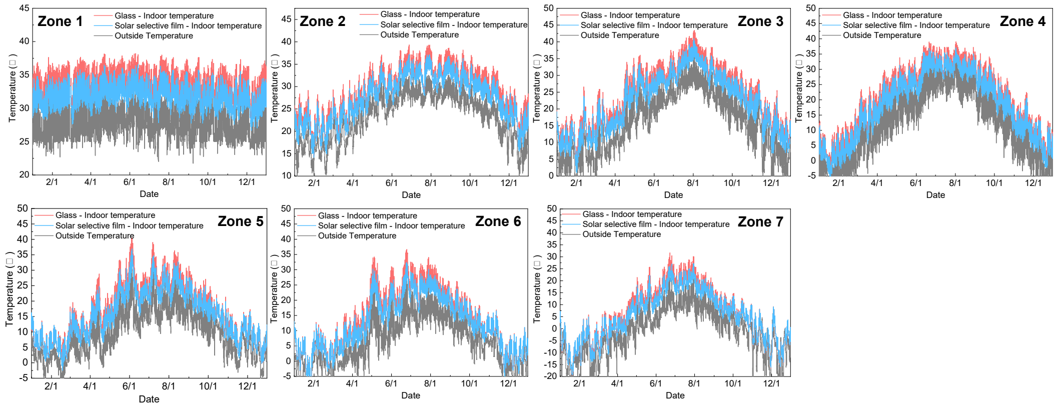


Figure S16. Indoor temperature before and after the application of solar selective film in normal buildings

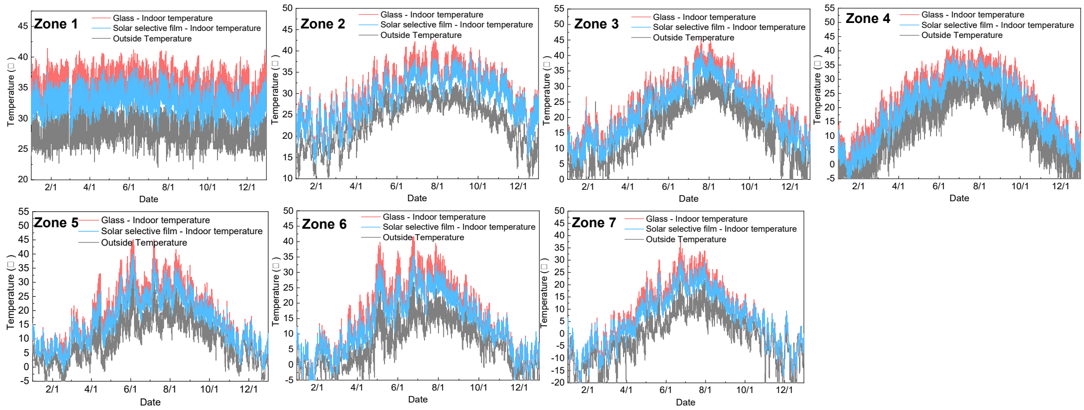


Figure S17. Indoor temperature before and after the application of solar selective film in glass-curtain buildings

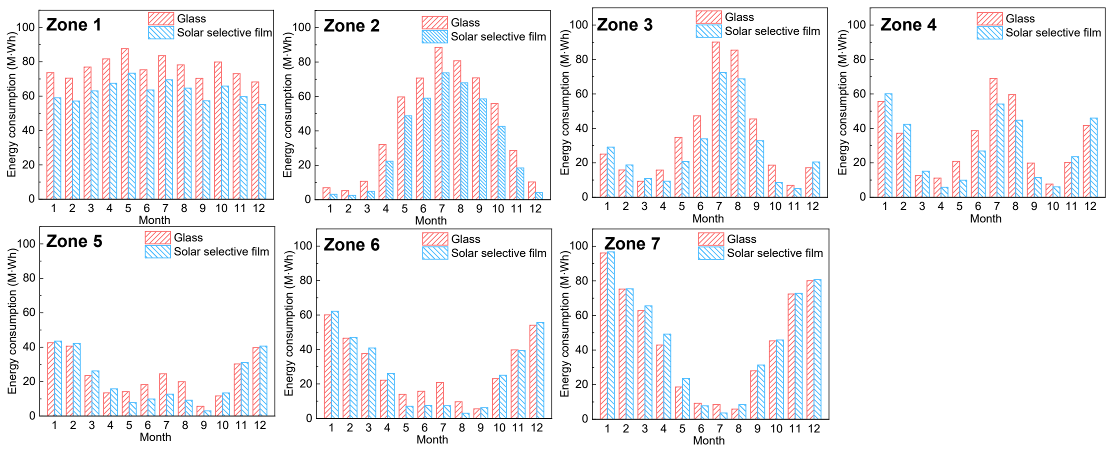


Figure S18. Monthly energy consumption of air conditioning in normal buildings different areas.

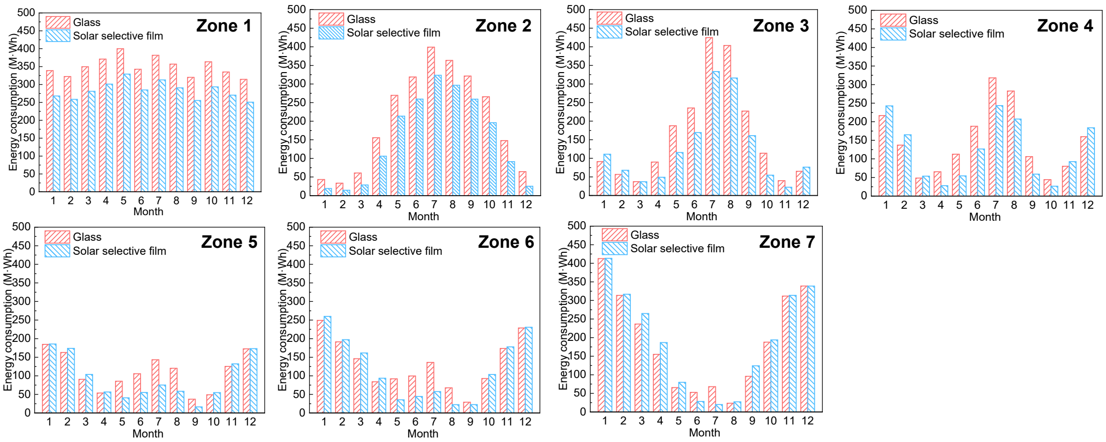


Figure S19. Monthly energy consumption of air conditioning in glass-curtain buildings different areas.

References

[1] W. Hu, X. Tan, X. Yang, G. Qi, S. Chen, S. Li, Y. Wang, F. Zhang, K. Yan, Z. Kang, *Opt. Mater.* **2024**, *149*, 114995.

[2] S. Dang, X. Wang, H. Ye, *Adv. Mater. Interfaces* **2022**, *9*, 1.

[3] Y. Xu, Y. Fang, S. Tao, Z. Fang, Y. Ni, C. Lu, C. Xu, W. Li, Z. Xu, *Compos. Commun.* **2023**, *43*, 101717.

[4] Q. Xuan, B. Zhao, C. Wang, L. Li, K. Lu, R. Zhai, X. Liu, B. Jiang, G. Pei, *Energy Convers. Manag.* **2022**, *273*, 116443.

[5] C. Ziming, W. Fuqiang, G. Dayang, L. Huaxu, S. Yong, *Sol. Energy Mater. Sol. Cells* **2020**, *213*, 110563.

[6] Q. Chen, T. Huang, J. Cheng, J. Zhang, X. Huang, H. Xu, Y. Lu, W. Song, *Sol. Energy* **2023**, *253*, 472.

[7] Q. Zhong, D. K. Macharia, W. Zhong, Z. Liu, Z. Chen, *Ceram. Int.* **2020**, *46*, 11898.

[8] Y. Qi, X. Yin, J. Zhang, *Sol. Energy Mater. Sol. Cells* **2016**, *151*, 30.

[9] Z. Zhou, X. Wang, Y. Ma, B. Hu, J. Zhou, *Cell Reports Phys. Sci.* **2020**, *1*, 100231.

[10] M. Kim, D. Lee, S. Son, Y. Yang, H. Lee, J. Rho, *Adv. Opt. Mater.* **2021**, *9*, 1.

[11] X. Zhang, X. Li, F. Wang, W. Yuan, Z. Cheng, H. Liang, Y. Yan, *Adv. Opt. Mater.* **2022**, *10*, 1.

[12] M. Q. Lei, Y. F. Hu, Y. N. Song, Y. Li, Y. Deng, K. Liu, L. Xie, J. H. Tang, D. L. Han, J. Lei, Z. M. Li, *Opt. Mater.* **2021**, *122*, 111651.

[13] F. Hu, L. An, C. Li, J. Liu, G. Ma, Y. Hu, Y. Huang, Y. Liu, T. Thundat, S. Ren, *Cell Reports Phys. Sci.* **2020**, *1*, DOI 10.1016/j.xcrp.2020.100140.

[14] C. Zhou, I. Julianri, S. Wang, S. H. Chan, M. Li, Y. Long, *ACS Mater. Lett.* **2021**, *3*, 883.

[15] S. Kim, S. Jung, A. Bobbitt, E. Lee and T. Luo, *Cell Reports Phys. Sci.*, 2024, **5**, 101847.