Supplementary Material

Rapidly Solar-driven Atmospheric Water Harvesting with MAF-4 Derived Nitrogen-doped Nanoporous Carbon

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Section S1. Structure and water adsorption characterization of MAF-4

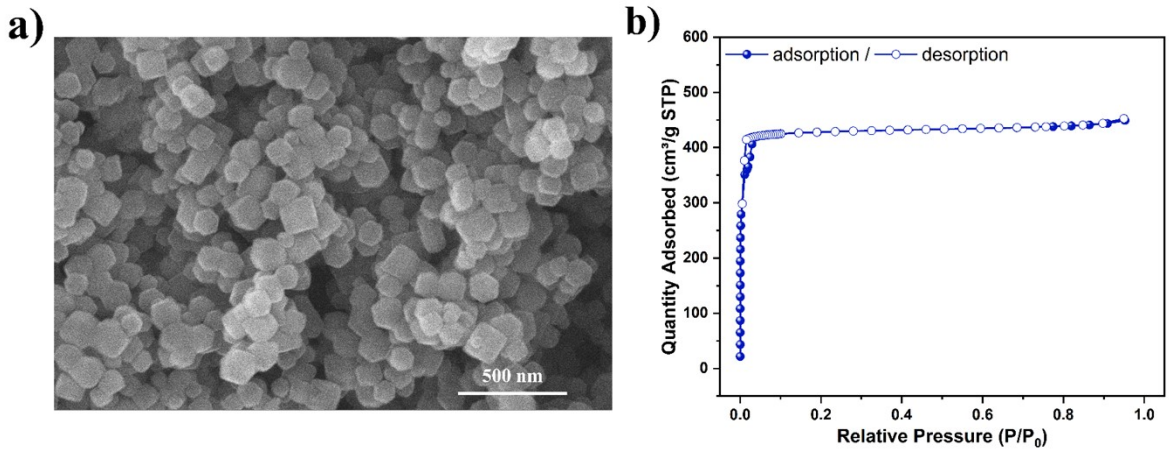

Fig. S1. a) SEM image and the N_2 adsorption-desorption isotherms of MAF-4 precursor at 77K.

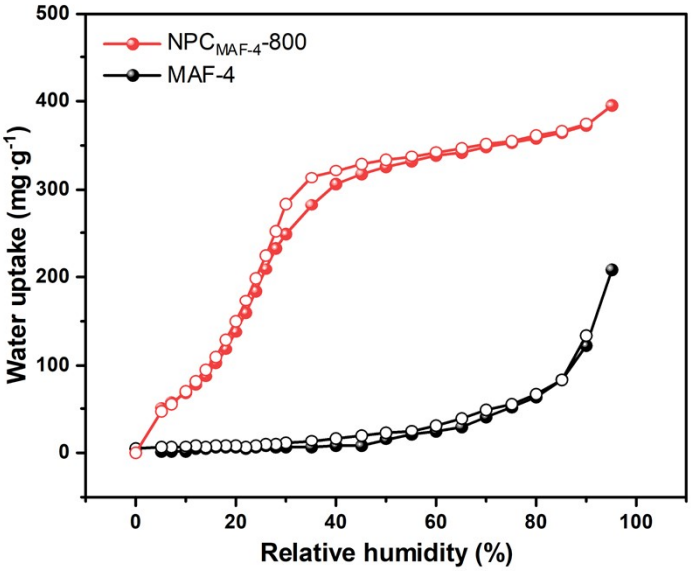

Fig. S2. The water sorption isotherm at 298 K of NPC_{MAF-4}-800 and MAF-4 precursor.

Section S2. Elemental analyses

Table S1. Bulk element compositions of All NPC_{MAF-4} by elemental analysis.

Samples	C%	H%	N%	C/N ratio	C/H ratio
NPC_{MAF-4}-700	44.27	3.36	19.58	2.26	13.19
NPC_{MAF-4}-800	48.99	2.78	16.62	2.95	17.66
NPC_{MAF-4}-900	84.19	0.89	3.67	23.01	97.39

Section S3. The calculation formula of the water adsorption and desorption kinetic

The water adsorption/desorption rate was calculated by water adsorption-desorption kinetics curve using BSD-DVS&VVS gravimetric vapor sorption analyzer (the water adsorption process: 40% RH, about 25 °C; The desorption process: heating step from 25 °C to 80 °C), and the specific formula as follows:

Water adsorption rate:

$$R_{abs} = (m_{abs} - m_0)/t_1$$

where m_0 ($mg \cdot g^{-1}$) is the water absorption weight of the absorbents after complete activation before the experiment; t_1 (minutes) is the adsorption time; m_{abs} ($mg \cdot g^{-1}$) is the water absorption mass of samples correspond to t_1 during the absorption process.

Water desorption rate:

$$R_{des} = (m_{des} - m_{sat}) / t_2$$

where m_{sat} ($mg \cdot g^{-1}$) is the water saturated weight of the absorbents; t_2 (minutes) is the desorption time; m_{des} ($mg \cdot g^{-1}$) is the desorbed water weight of samples from saturation state by heating or solar irradiation.

Section S4. Indoor solar-driven water desorption experiment

Firstly, 100 mg of $NPC_{MAF\text{-}4}$-800 was chosen for water adsorption in the climate chamber (BPS-50L) at 25 °C and 40% RH until reaching saturation states. Then, the saturated $NPC_{MAF\text{-}4}$-800 was transferred into the glove box (25±5 °C, 40±5% RH) and subjected to simulated sunlight originated from Xenon lamp for solar-driven water desorption experiment. Wherein, the weight change of samples and climate condition were recorded by electronic balance and hygrometer in real time, with measurements recorded every 5 seconds.

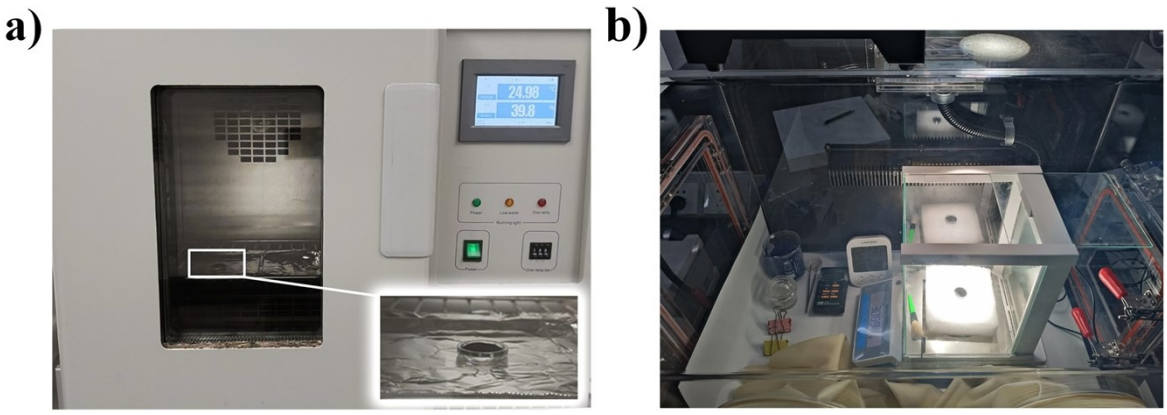

Fig. S3. The optical photo of the indoor solar-driven water desorption testing: a) The water adsorption of $NPC_{MAF\text{-}4}$-800 in the climate chamber; b) the solar-driven water desorption experiment in the lab. A solar simulator (PLS-SXE300, Perfect Light, China) as the light source. The mass change of the adsorbent during the water desorption process is monitored by a high-accuracy balance (TLE204/02, METTLER TOLEDO, U.S.A).

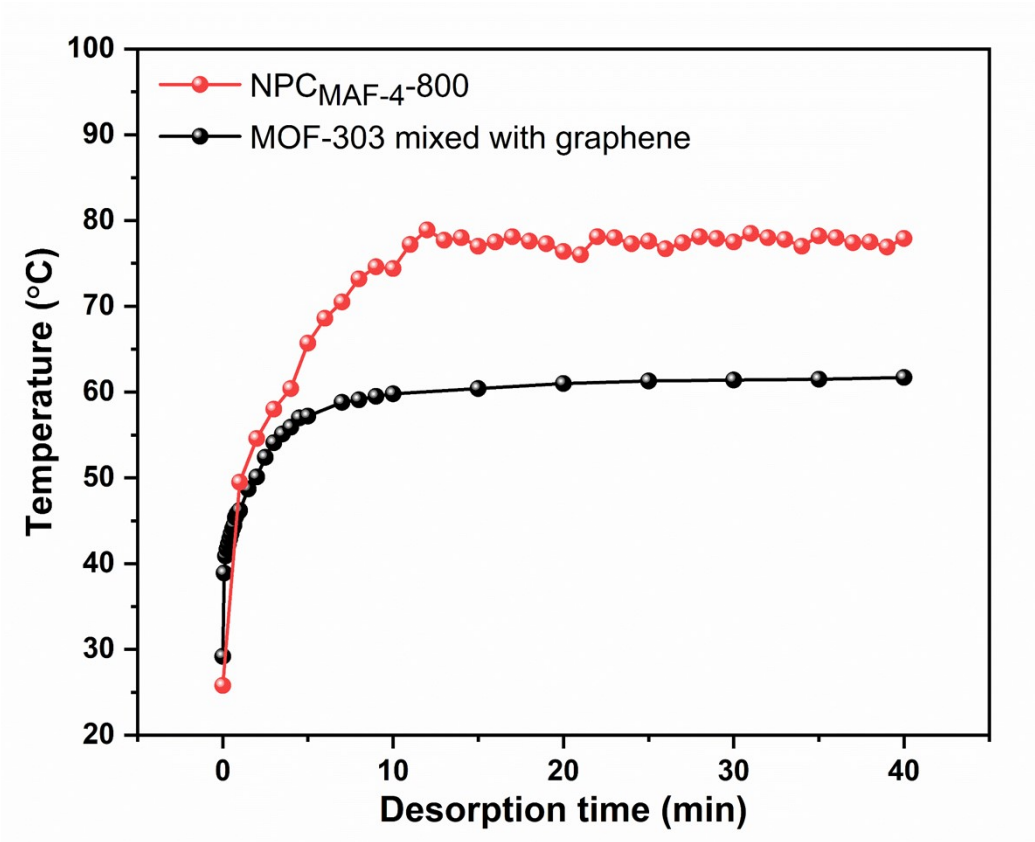

Fig. S4. The photothermal properties of MOF-303 mixed with graphene and NPC$_{MAF-4}$-800 under one solar irradiation.

Section S5. The actual operation of indoor AWH device

The NPC_{MAF-4}-800 sorbents were dried at 150 °C for 12 h for activation before the experiment. In the absorption process, about 100 mg of samples was spread out uniformly with the thickness of about 2 mm and supported by the circular vessel (diameter: 22mm; height: 5mm). In order to simulate the arid environment, the vessel loaded the samples were carried out in a constant temperature and humidity chamber with the atmosphere were fixed at 25 °C and 40% RH, respectively. The absorption time was set to 10 min, 20 min, and 30 min, respectively. Their adsorption masses were weighed and the water adsorption capacity at the three different adsorption times were calculated. In the desorption process, the adsorbed samples were then switched to the AWH device to release water, and the opening of the device is attached with sealing film to ensure complete closure. After that, the device with the adsorbents were heated by Xenon lamp as the solar simulator for three different light times (i.e., 10, 20, 30 min). The mass change of the adsorbent was real-time recorded by a high-accuracy balance. The water vapor released from the NPC_{MAF-4}-800 were condensed into droplets on the sidewall, and then accumulates at the bottom of the device due to gravity. The adsorption bed filled with adsorbents is removable, so we can invert the device to collect the liquid water. Finally, the released water was collected and the water production rate was calculated.

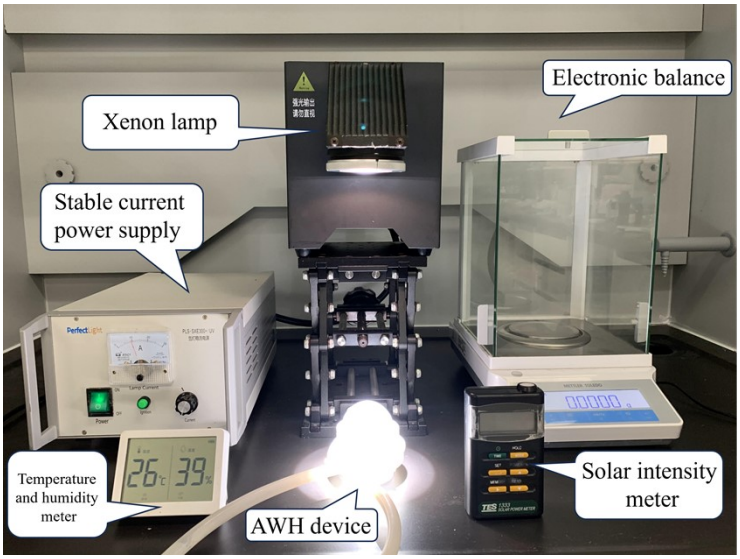

Fig. S5. The digital image of the indoor AWH experiment and its composition.

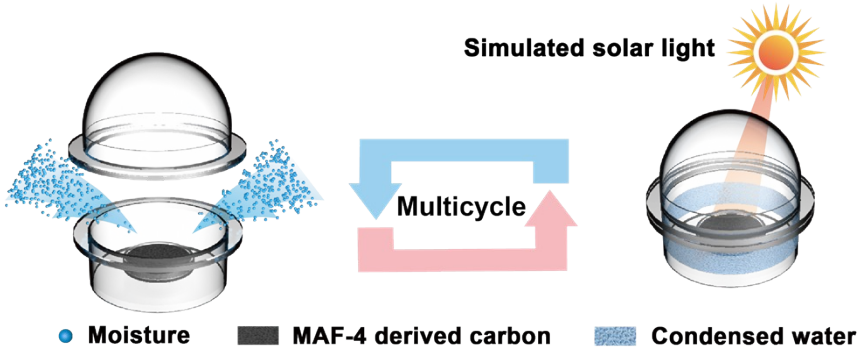

Fig. S6. The working principle of $NPC_{MAF\text{-}4}$-800 based atmosphere water harvesting (AWH) device in indoor experiment.

Table S2. Comparison of water production efficiency and applied humidity condition of reported state-of-art absorbents for indoor AWH.

Adsorbent	Applied humidity (%RH)	Water harvesting ($mg \cdot g^{-1}$)	Working times (min)	Water production rate ($mg \cdot g^{-1} \cdot h^{-1}$)	References
$NPC_{MAF\text{-}4}$-800	40	126.67	20	380	This work
Steam-80	60	2100	600	210	[53]
HCS-LiCl	60	840	480	105	[54]
PAM-CNT-$CaCl_2$	60	1106	2280	29.10	[55]
LiCl@MIL-101(Cr)	30	700	700	59.99	[30]
TaPa@LiCl	60	340	180	113.33	[56]
PDMAPS-LiCl-1	30	5870	1440	244.58	[57]
MOF-801	20	2800	1440	116.66	[58]
	24	3520	840	251.43	[59]
	40	280	660	25.45	[60]
Co_2Cl_2BTDD	35	870	270	193.33	[61]
CGF-mixed-MOFs $(Al)_5$	30	308	135	137	[62]
MOF-303	32	1300	1440	54	[63]
Al-fumarate	32	550	1440	23	

Section S6. The demonstration of outdoor atmospheric water harvesting

Prior to outdoor AWH experiment, 100 mg of $NPC_{MAF\text{-}4}$-800 were dried at 150 °C for 12 h to remove residual adsorbed water. Firstly, the AWH device is in the open state. At this time, the adsorbents were performed the sorption of moisture from atmosphere with 10 min in the light-shielded environment. Subsequently, the AWH device was sealed and water desorption was conducted for 10 min under sunlight irradiation. The liquid water is generated in the side wall with the assistance of cold resource, which is supplied by the thermostatic water bath (≈0 °C, v = 1 $m \cdot s^{-1}$). Finally, the liquid water was collected and subjected to water quality analysis.

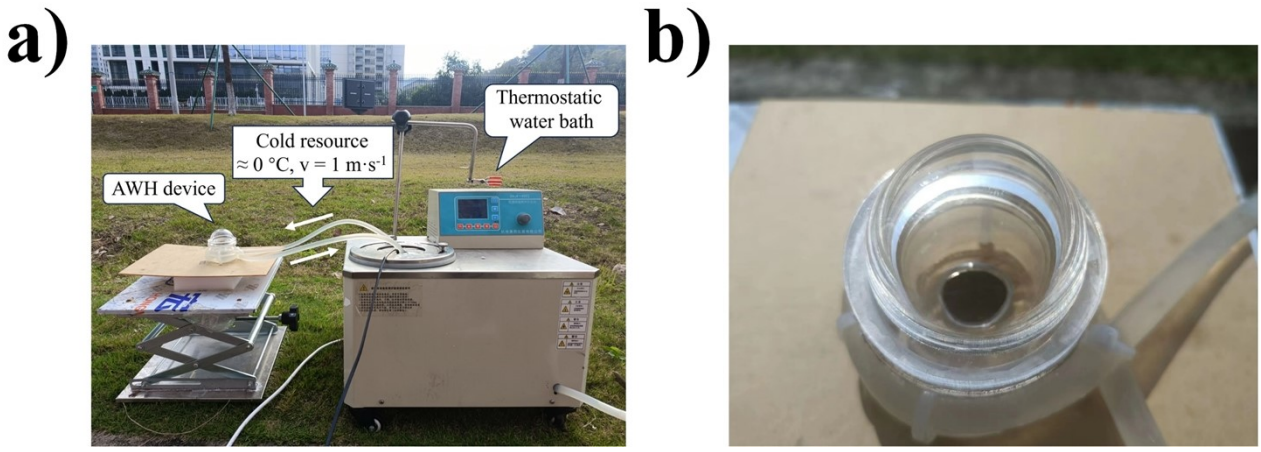

Fig. S7. The photographs of a) outdoor AWH device and b) $NPC_{MAF\text{-}4}$-800 in the device. (Time: February 18, 2023; Location: the Zhuhai campus of Sun Yat-sen University, 22.35° N, 113.59° E).

Section S7. Second-generation energy-saving outdoor AWH device

To further reduce the energy consumption of the AWH device and minimize the condenser' volume, we have equipped a solar energy generation system to power the device, and replaced the bulky thermostatic water bath with a smaller Dewar flask. Among them, cooled water (≈ 0 °C) as the cold resource. Based on this AWH device, we conducted an outdoor AWH experiment during a daytime with an average humidity of 60% RH and the temperature of about 30 °C. Ideally, the second-generation AWH device achieved an excellent cumulative water production of 2.57 $L \cdot kg^{-1}$ in a daytime within 7 h and with low energy cost.

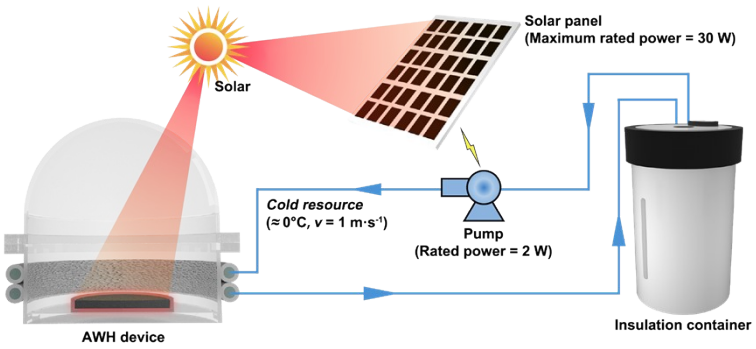

Fig. S8. The detailed schematic of the outdoor AWH system.

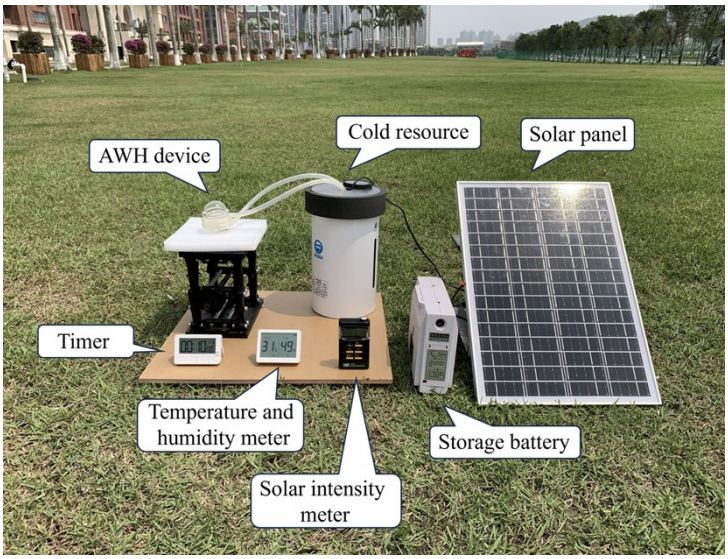

Fig. S9. The photograph of second-generation energy-saving outdoor AWH device and its composition.

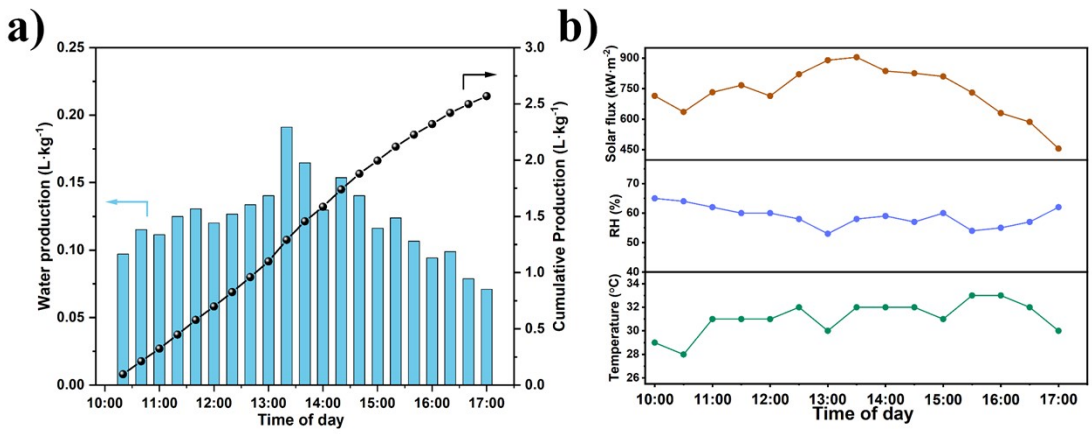

Fig. S10. a) The water collecting using second-generation AWH device in one daytime via 21 sorption-desorption cycles within 7 hours; b) The environmental data (Solar flux, relatively humidity and Temperature) (Time: April 12, 2024; Location: the Zhuhai campus of Sun Yat-sen University, 22.35° N, 113.59° E).

Section S8. Water quality analyses

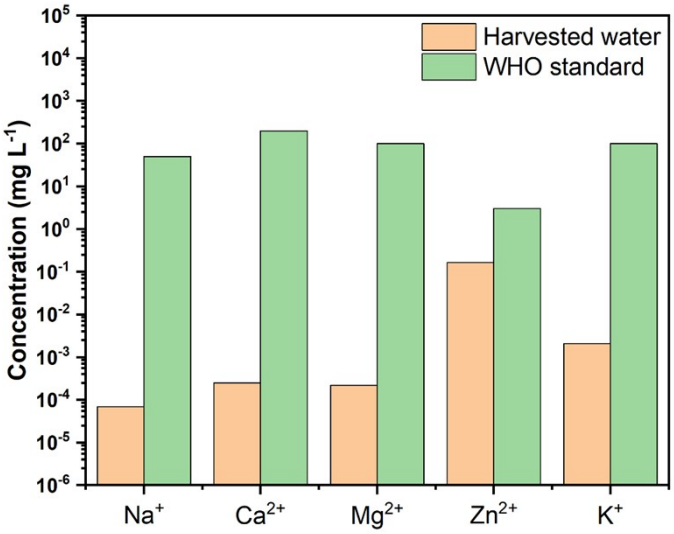

Fig. S11. The concentration assessment of primary metal elements in collected water measure by ICP-OES.