Support information

Calculation process of theoretical energy conversion efficiency of the hybrid system.

The total radiant flux from the sun can be expressed as

$$F = \int_0^\infty B(\lambda)\, \mathrm{d}\lambda. \tag{S1}$$

Introducing the reflection spectrum $R(\lambda)$ of the PV cell, the reflection energy can be expressed as

$$E_{\mathrm{ref}} = \int_0^\infty B(\lambda)\, R(\lambda) \mathrm{d}\lambda. \tag{S2}$$

When the total radiant flux F is set to 1000 W/m^2, the reflected power of the PV cell obtained is approximately 123.2 W/m^2 [15]. When the temperature of the PV cell T_{hA} is 55 °C, the room temperature is T_{am} = 22 °C, and the irradiation and convective heat loss can be calculated as

$$E_{\mathrm{rad}} = \varepsilon \cdot s \cdot (T_{\mathrm{hA}}^4 - T_{\mathrm{am}}^4) = 136.1\ \mathrm{W/m^2}, \tag{S3}$$

$$E_{\mathrm{con}} = h_{\mathrm{c}} \cdot (T_{\mathrm{hA}} - T_{\mathrm{am}}) = 165\ \mathrm{W/m^2}, \tag{S4}$$

where ε, s, and h_{c} are the average surface emissivity of silicon, the Stefan-Boltzmann constant, and air convection coefficient, which are 0.6, 5.67×10^{-8} W/(m^2·K^4), and 5 W/(m^2·K) [16,17], respectively.

The theoretical efficiency of the polycrystalline silicon solar cell used in the study is 19%. Under the above conditions, the PV cell power density is

$$E_{\mathrm{pv}} = \eta \cdot E_{\mathrm{in}} = 190\ \mathrm{W/m^2}. \tag{S5}$$

The heat flux density that can be transferred to the thermoelectric component is

$$E_{\mathrm{in}} - E_{\mathrm{ref}} - E_{\mathrm{pv}} - E_{\mathrm{con}} - E_{\mathrm{rad}} = 385.7\ \mathrm{W/m^2}. \tag{S6}$$

For thermoelectric modules, based on existing thermoelectric technologies, the efficiency of thermoelectric (TE) modules can be expressed as

$$\eta_{\mathrm{TE}} = \frac{(T_{\mathrm{h}} - T_{\mathrm{C}})}{T_{\mathrm{h}}} \times \frac{M-1}{M + T_{\mathrm{C}}/T_{\mathrm{h}}}, \tag{S7}$$

where T_{c} and T_{h} are the temperature of the cold junction and the hot junction of the thermoelectric module, respectively, M is

$$M = \left\{1 + Z \times \frac{(T_{\mathrm{C}} + T_{\mathrm{h}})}{2}\right\}^{1/2}. \tag{S8}$$

Z is the quality factor of the Bi_2Te_3 module. If Z is close to infinity, the TE efficiency will reach the Carnot limit

$$\eta_{\mathrm{TE}} = 1 - \frac{T_{\mathrm{C}}}{T_{\mathrm{h}}}. \tag{S9}$$

For the composite component, the contact heat loss between the interfaces is ignored, and the chiller outlet temperature is 25 °C for the cold junction temperature T_{C}, and T_{h} = 55 °C for the hot junction temperature. Under the conditions of Eq. (3), the conversion efficiency η is 9.1%. The power density generated by the TE module is

$$E_{\mathrm{TE}} = 385.7 \times 9.1\% = 35.1\ \mathrm{W/m^2}. \tag{S10}$$

The overall efficiency of the composite component is

$$\eta_{\mathrm{out}} = \frac{(190+35.1)}{1000} \times 100\% = 25.1\%. \tag{S11}$$

The heat flux density transferred to the liquid cooling layer is

$$E_{\mathrm{in}} - E_{\mathrm{pv}} - E_{\mathrm{ref}} - E_{\mathrm{con}} - E_{\mathrm{rad}} - E_{\mathrm{TE}} = 350.6\ \mathrm{W/m^2}. \tag{S12}$$

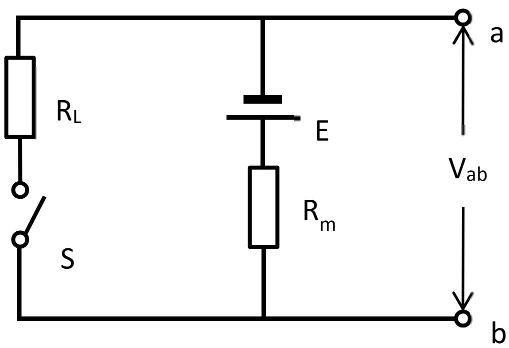

Fig. S1 Circuit for measuring the maximum power output and resistance of thermoelectric modules

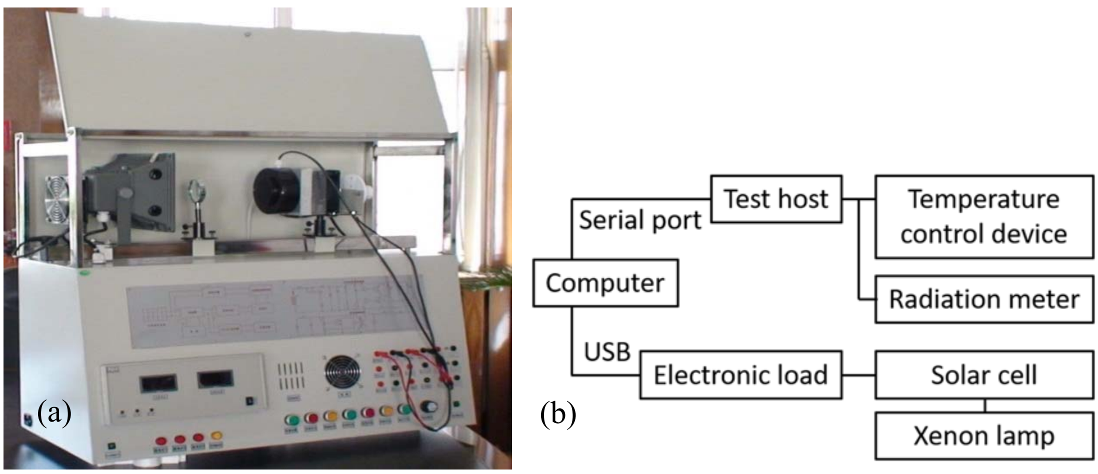

Fig. S2 TRM-JX1 solar PV cell experiment (exploration type) system test bench

(a) Real product photo; (b) frame diagram of the principle