Supporting Information

Title: A new concept in thermal insulation via the photothermal effect of chlorophyll thin film coated “Green Window”

Yuan Zhao, Andrew Dunn, Donglu Shi\*

**Materials**

Petroleum ether (>95%, bp 40-60 oC) was purchased from Sigma-Aldrich. Methanol (>99.9%), Butanol (>99.4%), Acetone (>99.5%), Toluene (>99.5%), and Sodium Chloride (>99.0%) was purchased from Fisher Scientific. Isopropyl Alcohol (>99.8%) was purchased from Pharmco-Aaper. PMMA (MW = 25 kDa, 200 micron beads) was purchased from Polysciences.

**Chlorophyll (Chl) extraction**

Chl was extracted from spinach based on a method previously reported. [15] Specifically, fresh local spinach leaves were cut into small pieces (~5 × 5 mm2), then freeze-dried at –40°C for 48 h. The dry leaves (5 g) were washed twice using petroleum ether (boiling point 40–60 °C) to remove the carotenoids and waxes. The washed leaves were immersed and stirred in 300 mL of methanol/petroleum ether (3:1 v/v) at room temperature overnight. Remaining solids were removed by filtration and solutions transferred to a separatory funnel then washed with 200 mL saturated sodium chloride solution twice. The organic phase was filtrated and removed by rotary evaporation. The isolated film was then dissolved in 50 mL of acetone and stored at −20 °C for 24 h to precipitate impurities. Precipitates were pelleted by centrifugation and the supernatant collected. Acetone was removed by rotary evaporation. The isolated chlorophyll was dissolved in toluene and stored at -20 °C until use.

**Coating process**

Glass slides were cut to 25 x 25 mm2 as substrates and cleaned by sonication in methanol for 15 minutes followed by sonication in isopropyl alcohol for another 15 minutes. Finally, the glass substrates were dried in a vacuum oven at 50 °C, 0.2 atm for 30 min. A Chl-PMMA (1:1) solution in toluene was prepared for coating, in which there is 86 mg mL-1 Chl, and 86 mg mL-1 PMMA. Chl-PMMA thin films were spin-coated by a WS-400-6NPP\Lite spin coater. Specifically, each layer was created by dropping 0.05 mL Chl-PMMA solution on a glass substrate spinning at 6000 rpm. The coated samples were stored in a ventilated hood for 24 hours to ensure residue toluene was entirely evaporated. Using a sensitive scale, 0.025 mg cm-2 Chl was found to be deposited on per layer.

**U-factor calculation**

The rate of heat loss of a window is defined in terms of the standardized thermal transmittance, or U-factor. According to ASTM C1199-14 [18], the U-factor is expressed as (assuming steady-state condition, homogeneous temperature variables, and neglecting edge and radiation effects):

 (S1)

where *hh* and *hc* are the interior and exterior heat film coefficients respectively, and *UL* is the heat transfer coefficient of the windowpane assembly alone. *hh* can be calculated using the following equation:

 (S2)

where *L* is the total height of a window; *σ* is the Stefan–Boltzmann constant (5.67×10−8 W m-2 K-4); *e* is emissivity, and *Tg* and *Th* are the window inner surface temperature and indoor air temperature (K) respectively.

For buildings with 1 storey, and the windows on windward side, the outside heat film coefficient *hc* can be calculated through the wind speed, *v* by MoWiTT (Mobile Window Thermal Test) model[23]:

 (S3)

Assuming neglecting edge and radiation effects, *UL* can be derived by following equations [24]:

Heat lost through the window assembly =  (S4)

where *Tg,o* is the outside surface temperature of the window.

Heat lost from the room to the window indoor surface =  (S5)

These two heat loss rates **Equations (S4)** and **(S5)** must be equal:

 (S6)

Then, we have  (S7)

and  (S8)

According **Equation** **(S1)**, **(S2), (S3)** and **(S8)**, U-factor can be expressed as:

(S9)

The NFRC standardized environmental conditions for U-factor calculations: the indoor air temperature, *Th* = 294.27 K (21.11 oC); the outside surface temperature of the window, *Tg,o* = 255.38 K (-17.78 oC); wind speed, *v* = 3.42 m s-1; and window height, *L* = 1.524 m. Assuming the original interior temperature is 5 oC, *Tg* will be (278.16+*ΔTg*) K. 1.8 mm Tungsten Diselenide (WSe2) is selected as the possible dense solid insulating material, and *e* = 0.90 for a common single-pane window. These parameters are applied in **Equation (S9)** to calculate U-factors for each sample.