Environmental and energy performances of the nearly net-zero energy solar decathlon house with dynamic building facades: A comparison of four climate regions

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Section S1. Basic Information of the Zero-Carbon House "Nature Between"

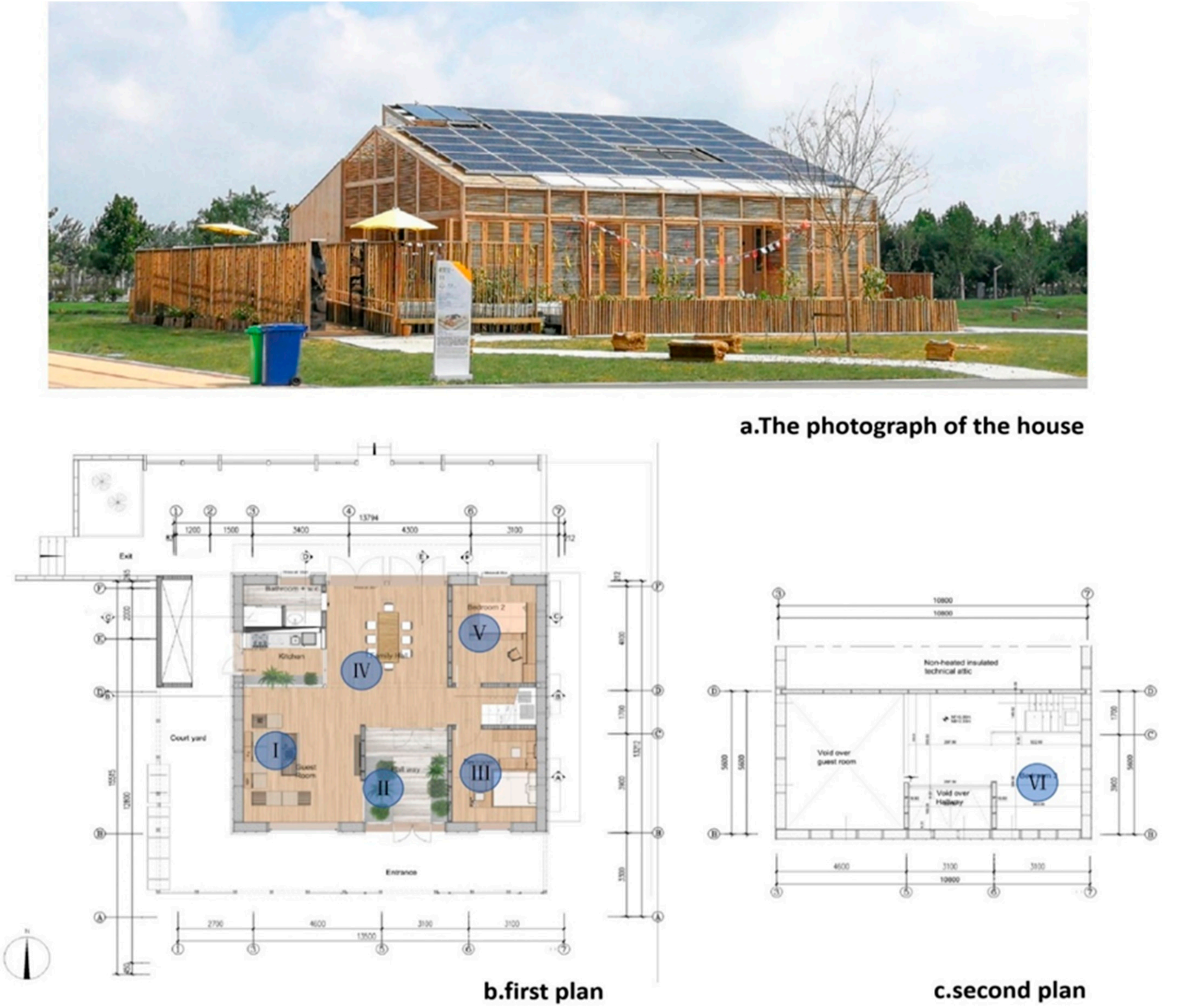

Figure S1 The nearly net-zero energy house "Nature Between": (a) the photograph of the house; (b) first plan; and (c) second plan: (Ⅰ) living room; (Ⅱ) courtyard; (Ⅲ) master bedroom; (Ⅳ) dining room; (Ⅴ) guest bedroom; and (Ⅵ) children's room.

Section S2. Design of dynamic facades in the nearly net-zero energy house "Nature Between"

S2.1 Strategies for coping with intense summer radiation: Dynamic exterior shading

Sun shading of windows is necessary for 11.4% of the entire year, primarily dur-ing the summer months according to the enthalpy diagram. Due to the temporal varia-tion in solar radiation, a dynamic shading system is crucial, capable of adjusting dy-namically to climatic changes to balance heat gain between winter and summer sea-sons. On the exterior of the south and west sides of the building, the three kinds of dynamic facades (electric folding blinds, ordinary electric blinds, and bamboo door) were used as dynamic exterior shading to form an outdoor enclosure, thus creating a transition space for climate adaptation and reducing the building energy consumption (Fig. S2a).

S2.2 Strategies for addressing cold climate conditions: Dynamic interior shading

Internal heat gain (27.1%) emerges as a significant strategy according to the en-thalpy diagram. However, in practice, the internal heat sources from electrical appli-ances and lighting fixtures used by residents are minimal, thus making reliance on in-ternal heat gain unlikely. Consequently, minimizing internal heat loss and ensuring effective insulation serve as compensatory measures. In this work, interior doors and windows were equipped with an electric honeycomb curtain to form the dynamic inte-rior shading, used for heat preservation and insulation, adjustment of indoor illumina-tion, and noise isolation (Fig. S2e). Dynamic interior shading served to delay and at-tenuate a part of the indoor heat gain for easy maintenance and cleaning and flexibly adjusted indoor light environment.

S2.3 Strategies for addressing day-night temperature variations: Buffer layer and PCM facades

Significant seasonal temperature variations and large fluctuations between day and night temperatures are observed in Xiamen (Fig. 1c). In response to this climatic feature, it is necessary to use materials with good thermal storage properties, which can maintain a stable indoor temperature in the case of severe fluctuations in outdoor temperature. The interior courtyard on the south side of the house acted as a buffer layer (Fig. S2c). An electric skylight and electric sunshade roller curtains were installed for heat insulation in summer and heat storage in winter (Fig. S2b). To enhance the heat storage capacity of the interior courtyard, PCM facades were placed under the courtyard floor (Fig. S2d), changing their phase at a biomass-specific temperature and absorbing or releasing a large amount of latent heat, with an effective performance of heat storage.

S2.4 Strategies for achieving zero-carbon goals: Intelligent ventilated facades and BIPV

Effective natural ventilation, combined with well-shaded and strategically ori-ented windows, can significantly reduce or even eliminate the need for air condition-ing during hot weather, thereby lowering building energy consumption and carbon emissions. In this work, two front and back patios and a north-facing electric-smart high window were used to organize the interior ventilation. The north electric high window was located in the second-floor attic, which could be opened at an angle of 30° (Fig. S2b). When the indoor temperature exceeded the set temperature, the electric high window automatically opened to promote ventilation.

The local solar radiation is abundant, with hourly horizontal radiation ranging from 316 to 474 Wh/㎡ for 10% of the year, and exceeding 474 Wh/㎡ for 18% of the year (Fig. 1b). Since solar panels were the only source of energy allowable in the com-petition, the building-integrated photovoltaics (BIPV) design was particularly im-portant for the house. Fifty-four photovoltaic panels and two water-heater solar panels were installed on the roof of the building (Fig. S2). The photovoltaic panels were installed on the south roof and tilted at a 20o angle to the water level so as to generate enough energy to meet the energy needs of the house in summer.

Figure S2 The dynamic facades of the nearly net-zero energy Solar Decathlon house: (a) dynamic exterior shading; (b) intelligent ventilated; (c) PCM facades; (d) buffer layer; and (e) dynamic interior shading facades.

Table S1 Construction and material definitions [47].

Building component	Construction	U Value (m^2*K/W)
Exterior wall	12mm facing panel +38*38mm keel + waterproof layer + 18mmoriented strand board(OSB)+breathable paper+350mm compressed straw panels+breathable paper+18mm OSB+38*38mm keel +12mm interior panel	0.21
Floor	Waterproof layer + 18mmOSB panel +350mm compressed straw panels + breathable paper +18mm OSB panel +38*38mm keel +12mm facing panel	0.21
Inside wall	12mm interior panel +l8mm OSB panel +l40mm straw board+12mm OSB +12mm interior panel	0.47
Roof	Photovoltaic panel +light steel keel + waterproof resin +waterproof insulation board + 18mm OSB panel +230mm glass wool + breathable paper + 18mm OSB panel +12mm interior panel	0.16
Door and Windows	Low-E triple-pane hollow glass +l3mm vacuum argon gas layer	0.8
Skylight	Low-E double-pane hollow glass +13mm vacuum argon gas layer	1.5

Section S3. Supporting Data for the Zero-Carbon House "Nature Between"

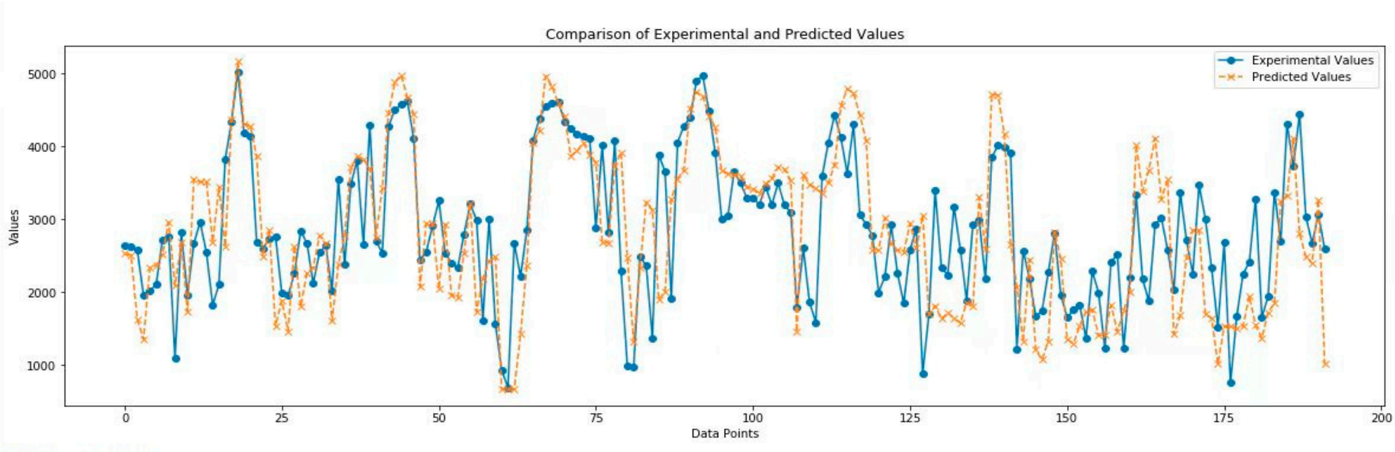

Figure S3 Hourly Comparison of Simulated and Measured Energy Consumption (Shi et al. 2019).

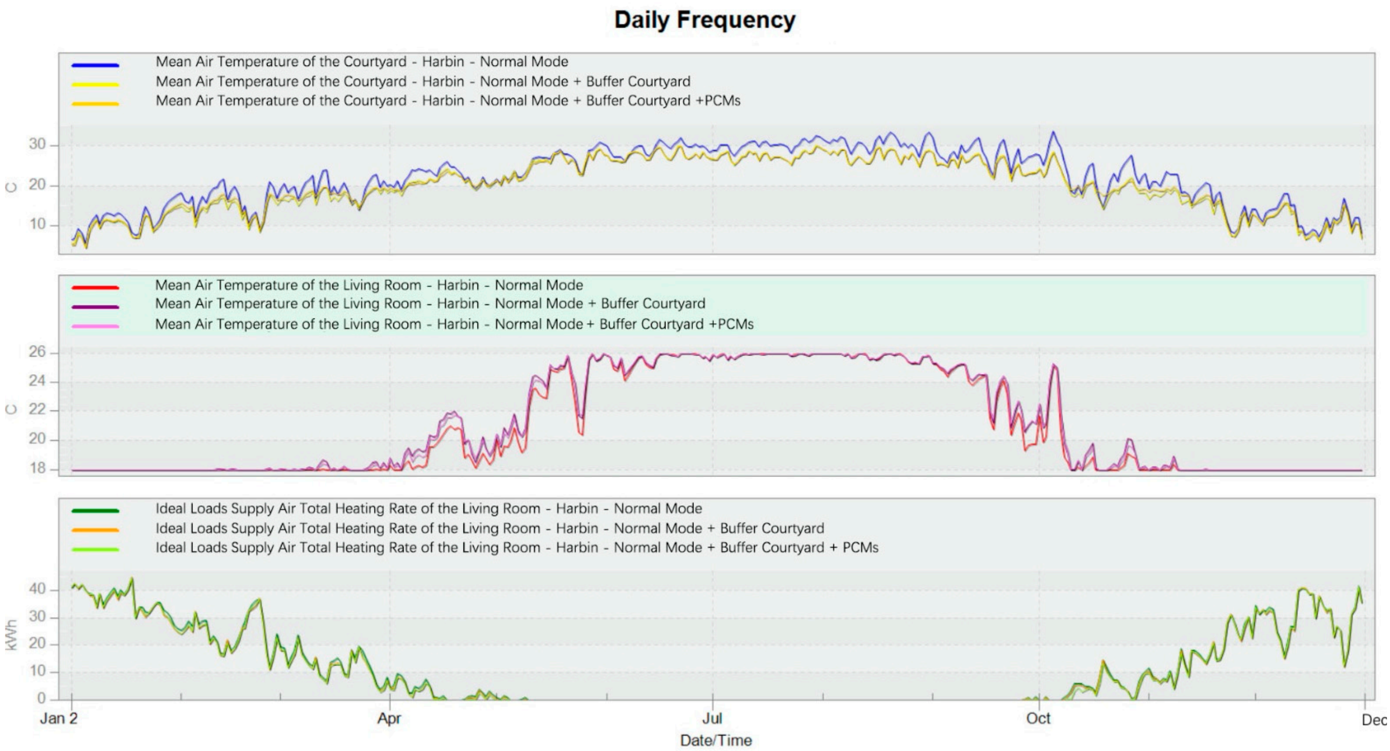

Figure S4 Temperature of the courtyard and living room and the daily heat load of the living room throughout the year in Harbin area

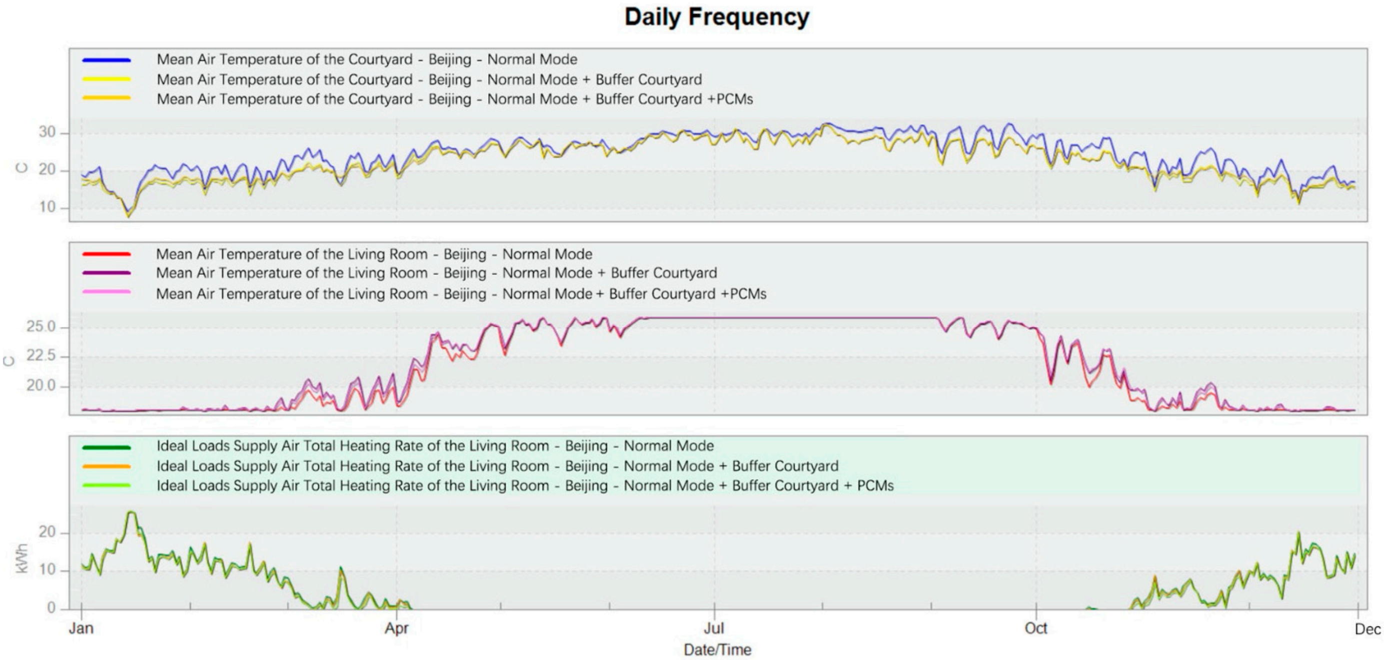

Figure S5 Temperature of the courtyard and living room and the daily heat load of the living room throughout the year in Beijing area

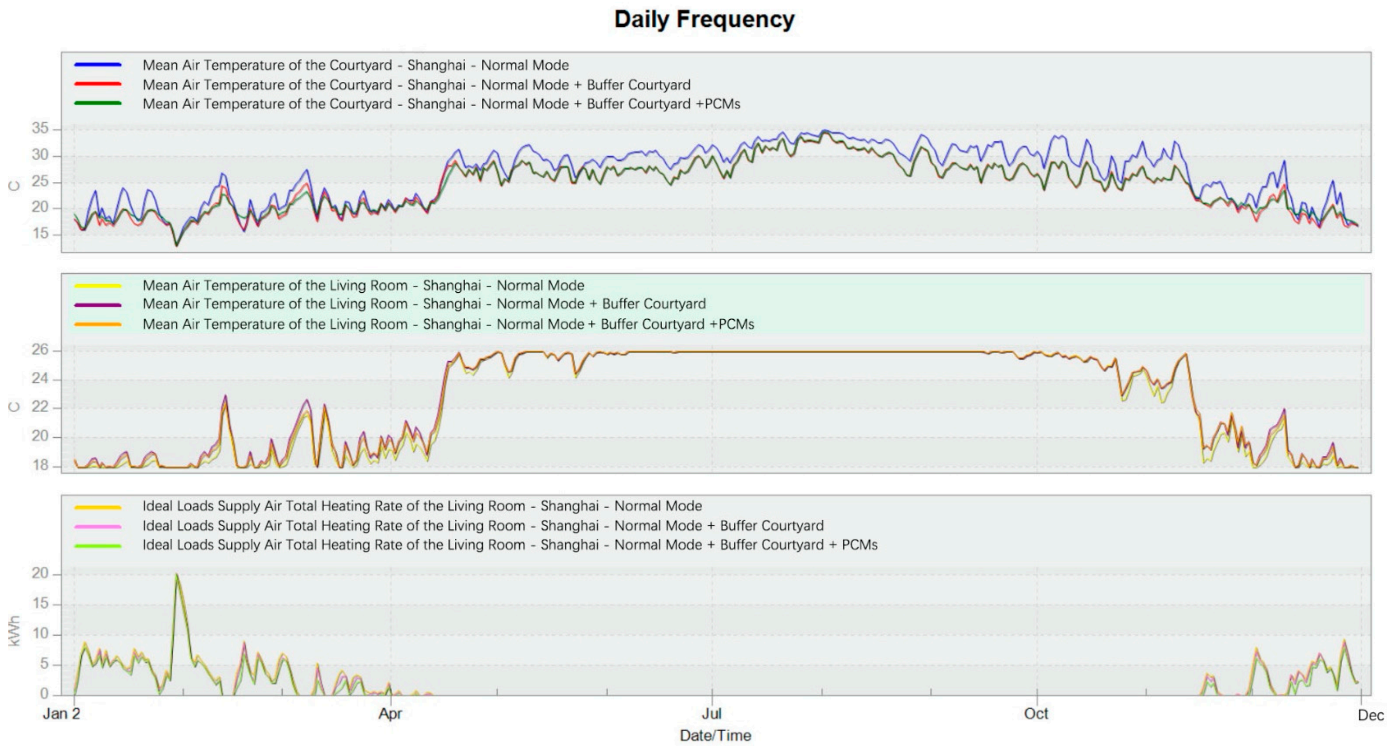

Figure S6 Temperature of the courtyard and living room and the daily heat load of the living room throughout the year in Shanghai area

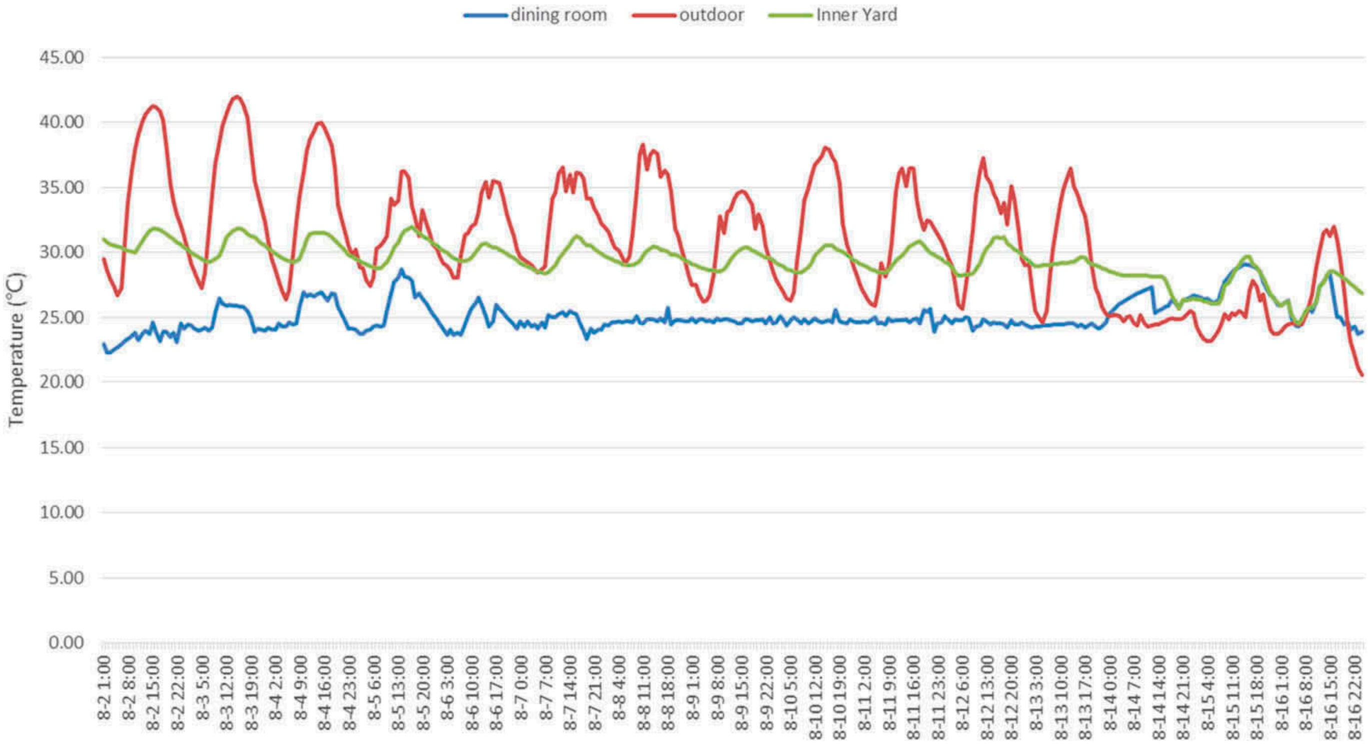

Figure S7 Air temperature during the competition outdoors, inner yard and dining room.