Video Article

Study on the Moisture Absorption and Desorption Rate of Bamboo Scrimber in a Hot-Humid Climatic Wind Tunnel

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Abstract

The absorption and desorption rate U_{ab} is an important indicator to evaluate the hygric performance of hygroscopic building materials. However, standard methods to obtain this value are normally carried out in a static indoor environment, which cannot represent a dynamic outdoor environment. This protocol presents a Hot-Humid Climate Wind Tunnel (HHCWT) method to examine the hygric behavior of bamboo scrimber (BFB) in outdoor conditions, with the hourly solar radiation, air temperature, relative humidity, and constant wind speed of a typical summer day in the south of China. The complete meteorological parameters were repeated for 72 h, of which the last 48 h were selected for analysis. By comparison with the hardwood specimen (HW) in this test, BFB showed a more stable hygric performance. The BFB to HW ratio of the U_{ab} mean value and maximum value were, respectively, 64.35% and 66.02%. The maximum absorption rate $U_{a.max}$ and desorption rate $U_{d.max}$ from the dynamic test were correspondingly $2.91E^{-05}$ kg/(m^2/s) and $4.45E^{-05}$ kg/(m^2/s), far larger than the results of $7.74E^{-07}$ - $12.58E^{-07}$ kg/(m^2/s) from the static test. The significant difference in magnitude shows the necessity of a dynamic evaluation approach that can take more practical climate conditions into consideration. The HHCWT enables the reproducibility and standardization of climate-related experiments for building materials by creating climate conditions with complete meteorological parameters.

Introduction

Bamboo scrimber is considered to be an ideal product to achieve a high value-added utilization of the widely distributed bamboo forest resources, by decomposing raw bamboo and recombining it into bamboo panels that could be applied as outdoor flooring or a building facade. There already are studies on the hygrothermal properties of bamboo scrimber with static standard methods carried out in indoor environments[1,2]. However, the performance in more practical outdoor conditions needs further investigation. The hygric properties of bamboo scrimber obtained in our prior study are shown in **Table 1.**

The moisture absorption and desorption rate U_{ad} are an important indicator characterizing the hygric transport performance, and also closely affect the thermal performance of certain building materials, especially for those hygroscopic materials such as bamboo and timber. Normally, the U_{ad} value is measured by static standard methods in a laboratory environment, with constant ambient air temperature T and relative humidity RH (*e.g.*, T = 23 °C, RH = 50%)[3]. However, the constant indoor testing conditions are very different from the practical application in an outdoor environment, where the meteorological conditions are more complex. The effect of solar radiation on the heat and moisture transfer cannot be ignored[4,5]. Other studies have investigated the dynamic performance by establishing dynamic models and transfer functions[6,7] andshow different characteristics compared to the static standard tests[8].

To test the material objects in real outdoor climate conditions is a more persuasive method to evaluate the targeted performance. However, outdoor climate conditions do not reappear, making the experiments difficult to standardize, let alone when done by different operators at different periods. For solving the above challenges, we studied reproducible meteorological conditions and developed them with a climate wind tunnel. A wind tunnel is a comprehensive concept to create different simulated conditions (*e.g.*, wind resistance testing, evaporative cooling, or a microclimate on building envelope) to examine certain performances of the research objects[9,10,11,12].

For this study, the HHCWT was created with a motivation to reproduce the outdoor climate conditions for examining the hygrothermal performance of building materials and building components closer to the practical application conditions[13,14]. The HHCWT consists of 18 elements: a protection room (**Figure 1.1**) with an air conditioner, a heater, a humidifier, a dehumidifier (**Figure 1.12** - **1.15**), a wind tunnel (**Figure 1.2**) with an entrance region, a stilling region, a test region, an auxiliary region, a diffusion region and a fan region in the order (**Figure 1.5** - **1.10**), a solar radiation chamber (**Figure 1.11**) overhead and an air conditioning chamber (**Figure 1.16**) below, the specimen slot (**Figure 1.4**) with a balance (**Figure 1.17**) on the boundary of the wind tunnel and the air conditioning chamber (**Figure 1.3**), and the operating condition control and data collection system (**Figure 1.18**) outside the protection room. An operating condition control and data collection system were set outside the protection room for the input and output control of the whole system. The climatic wind tunnel enabled the complete control of climate conditions, therefore realizing the repeatability and standardization of the climate-related experiment (**Figure 1**).

In this study, a dynamic absorption and desorption pair-test was carried out for bamboo scrimber and hardwood specimens. The HHCWT was used to create complete climate conditions, including the solar radiation, air temperature, relative humidity, and wind speed of a TMD (Typical Meteorological Day) of Guangzhou, a typical subtropical city located in the south of China. The obtained values were compared with the results from the static standard method to show the progress of this experimental method.

Since factors such as bulk density, open porosity, and surface treatment had an impact on the hygric properties of the products[15,16], typical samples were selected from the company that owned the core patent (**Table 2**).

Protocol

1. Specimens Treatment

1. **Specimens preparation**
    1. Select the material: for the bamboo (BFB), a bamboo scrimber panel made of Moso (*Phyllostachys Pubescens*); for the timber (HW), a hardwood panel made of *Intsia* spp. (Caesalpiniaceae).
    2. Ask the bamboo and wood factories to cut the specimens to a size of 30 x 30 cm (side length), while keeping the original thickness of 28 mm.
    Note: The normal size of the bamboo panels used is 122 x 244 cm (width x length), and the thickness is 28 mm or 18 mm. The samples can best be cut at the factories because they have the suitable cutting machines. Chose the thickness of 28 mm instead of 18 mm, because the thicker sample generally ensures more stable results.
    3. Prepare the specimens in duplicate.

2. **Vacuum saturation**
    1. Arrange the equipment as follows: 1 vacuum chamber and pump (a sliding vane rotary vacuum pump, extreme pressure 600 Pa, speed 8 L/s); 1 independent and movable water sink of 35 x 35 x 20 cm (length x width x height); and 20 stainless-steel nut supports of equal size.
    2. Plain lay the stainless-steel nut supports on the bottom of the water sink, and side stand the specimens on the supports.
    3. Suppress it with a stainless-steel grid on the top.
    Note: The weight of the grid should be enough to ensure that the specimens can be kept immersed in the water when the water is later injected into the water sink.
    4. Move the specimens with the water sink into the vacuum chamber, then close the chamber and make sure that the water inlet valve has already been closed.
    Note: The chamber is part of the vacuum pump, and the size of the chamber is 40 x 40 x 40 cm (length x width x height). If another type of machine is used, it can be a different size, as long as it is large enough to hold the water sink.
    5. Connect the power plug of the vacuum pump to the 380 V electric source.
    Note: The voltage of the power supply is decided by the requirement of the vacuum pump. We needed 380 V for the device we used, but it may also be 220 V or other values depending on the devices used.
    6. Press the start switch to start the vacuum pump. Lower down the air pressure in the chamber to 20 mbar. Keep the vacuum pump running to hold the air pressure inside the chamber ≤ 20 mbar for 6 h.
    Note: The purpose of this step is to make sure that the air inside the internal pores of the specimens is exhausted, so that water can fill in the pores in the following steps. Different materials might require different time lengths due to a difference in the transport resistance of the materials.
    7. Keep the air pressure in the vacuum chamber ≤ 20 mbar, as mentioned above. Turn on the water inlet valve to slowly inject distilled water into the sink.
    8. Keep the water level rise rate to be about 5 cm/h. Stop injecting water when the water level reaches about 5 cm over the top surface of the specimens, then turn off the vacuum pump.
    9. Keep the specimens immersed in water for 3 days, until an initial moisture content of capillary saturation is reached.
    10. One by one, take specimens out of the water and wipe off the attached water from the surface with a soft damp cloth.
    Note: Due to the water surface tension, some water attached to the surface of the specimens will follow up when the specimens are taken out of the water.

3. **Bottom and side sealing**
    1. Air-dry the specimens in an indoor environment (*ca.* T = 23 °C, RH = 50%) for 1 h, until the surface is dry.
    Note: Make sure that the specimens are not covered by anything that might stop the surface from drying.
    2. Seal the bottom and side surfaces with 1 - 2 mm petroleum jelly.

2. Wind Tunnel Operation

1. **Equipment arrangement**
    1. Check the system components, as shown in **Figure 1** and **Table 3.**
    2. Reset the computer time of the operating condition control and data collection system according to the climate data.
    Note: In this step, each computer has different requirements. Click on the time in the lower right corner and input the condition time. It might be different at another computer system. In the following introduction, all the mentioned time is condition time that is synchronized with the climate data. The preheating of the wind tunnel is set to be at 4:00, the specimens' installation at 5:00, and the data recording starts at 6:00. The 24 h single-days are required to be repeated continuously at least 3x.

2. **Wind tunnel preheating (at 4:00)**

1. Start the wind tunnel system for preheating. Run it with the climate parameters as shown in **Table 2**.
   Note: The TMD in this study is from Guangzhou and can be changed to other cities according to the experimental purposes **(Table 4)**.
2. Observe the received data from the wind tunnel and ensure the hourly deviations of the real climate conditions in the test region are within the scope of the error requirements: the air temperature ≤ 0.3 °C, the relative humidity ≤ 5%, the solar radiation ≤ 5%, and the wind speed ≤ 5%. Extend the preheating time, if necessary.
   Note: The scope of the error requirements is confined to the accuracy of the sub-systems of the HHCWT. A smaller or larger range might be also acceptable if the equipment is different.
3. Keep the air temperature in the air conditioning chamber at 26 °C ± 1 °C, and the wind speed ≤ 0.5m/s.

3. **Specimens installation (at 5:00)**
   1. Place the specimens into the test tanks and seal the gap between the edges of the specimens and the tanks with petroleum jelly.
   2. Place the specimens in the test region in the test tanks of the wind tunnel and connect the bottom of the tanks to the balance below with prefabricated steel frames.
      Note: The function of the steel frames here is to transfer the gravity of the specimens to the balances below. All specimens are tested together but the mass change rate for each specimen is recorded individually by each balance below.
   3. Adjust the height of the balance to keep the top surface of the specimens' flush with the inner surface of the wind tunnel.
      Note: In this operation, make sure that the test tanks do not come into contact with each other to avoid mass measurement errors.

4. **Data recording (at 6:00)**
   1. Reset the balances to start the mass record at 0.
      Note: Press the **Clear** of the balances to reset them to 0.
   2. Use the computer (the operating condition control and data collection system) to record the data.
      Note: During the data recording, pay attention to the data receiving ports for instantaneous mass values and climate conditions, and also to the alarm (which only happens when the real hourly deviations of the climate conditions run beyond the error tolerance).
   3. Repeat the 24-h climate control for 3x, and continuously record for 72 h.

3. Post-operation

1. **Dry the specimens**
   1. Arrange the following equipment: a drying oven (a digital stainless steel electric blast oven with an accuracy of ± 1 °C) and a balance (with an accuracy of 0.01 g). Keep the drying temperature of the oven at 70 °C.
   2. Place the wet specimens in the drying oven and weigh 1 week later.
   3. Continue to weigh the specimens each 24 h and measure the convergence until the difference between the two consecutive weighing results does not exceed 1%. Record the final weighing result.

4. Data Processing

1. **The values of the mass**
   1. Average all the instantaneous mass values within each h as the mass of time i (m_i).

$$m_i = \frac{1}{n} \sum_{j=1}^{n} m_{i-1,j}$$

Where:
m_i is the specimens' mass of time i in kg;
$i-1,j$ is the jth measured value within 1 h after time $i-1$ in kg;
n is the number of measured value within 1 h (e.g., $n = 60$ when the recording interval is 1 min).
   2. Consider the final value in step 3.1.3 as the dry mass of the specimens m_d.

2. Calculate the absorption and desorption rate U_{ad} value.

$$U_{ad,i} = \frac{m_i - m_{i-1}}{A}$$

Where:
$U_{ad,i}$ is the absorption and desorption rate of time i (when the $U_{ad,i} > 0$, it means absorption rate; when the $U_{ad,i} < 0$, it means desorption rate) in kg/(m^2/s);
m_i, m_{i-1} is the mass value of time i and the value at the previous time $i-1$ in kg;
A is the measurement area of the specimens in m^2.

Representative Results

The recorded data of the last 48 h from the whole 72 h were selected and analyzed (**Figure 2**, **Table 5**).

The dynamic test in the wind tunnel was performed and the results showed that the bamboo scrimber (BFB) had a lower U_{ad} value than the reference hardwood (HW). Compared to HW, BFB showed a more stable hygric performance. The U_{ab} mean value $U_{ab.mean}$ of BFB and HW were $4.45E^{-05}$ kg/(m^2/s) and $6.74E^{-05}$ kg/(m^2/s), respectively and the max value $U_{ab.max}$ were $1.49E^{-05}$ kg/(m^2/s) and $2.32E^{-05}$ kg/(m^2/s) respectively, of which the BFB to HW ratios were, respectively, 64.35% and 66.02%. The hourly U_{ad} values of BFB were up to $33.69E^{-06}$ kg/(m^2/s) lower than that of the HW specimen, except in certain areas where the moisture process was in the absorption-desorption transition stage.

The maximum absorption rate U_a and desorption rate U_d of the dynamic test results of BFB were, correspondingly, $2.91E^{-05}$ kg/(m^2/s) and $4.45E^{-05}$ kg/(m^2/s), far larger than the results of $7.74E^{-07}$ - $12.58E^{-07}$ kg/(m^2/s) from the static test. The significant magnitude difference indicated that the indoor test results were far from being sufficient to describe the hygric performance in outdoor conditions. Therefore, the evaluation approach with more practical climate conditions was necessary. Due to the changing climate conditions of solar radiation, temperature, relative humidity, and wind, the wind tunnel test showed much more mutative results that could describe the dynamic hygric behavior in practical conditions.
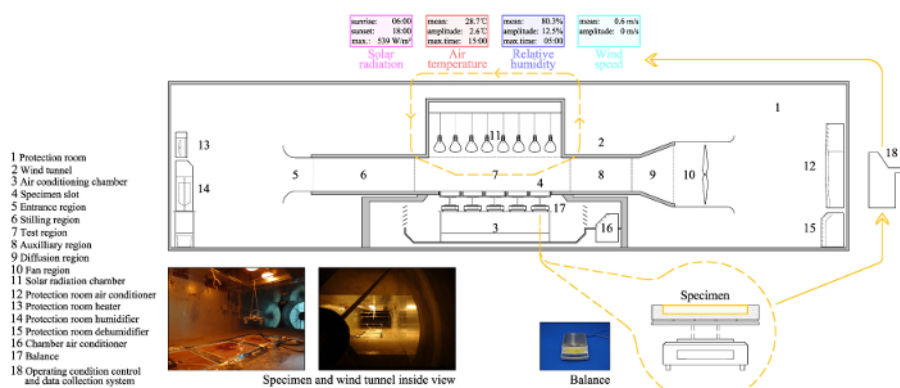
Figure 1. Equipment and control system of the Hot-Humid Climatic Wind Tunnel (HHCWT). The figure marks out the setup of the HHCWT. The HHCWT consists of 18 elements that are used to create climate conditions of solar radiation, air temperature, relative humidity, and wind. The balance and the operating condition control and data collection system work together to receive the mass change rate of the specimens within the wind tunnel. Please click here to view a larger version of this figure.
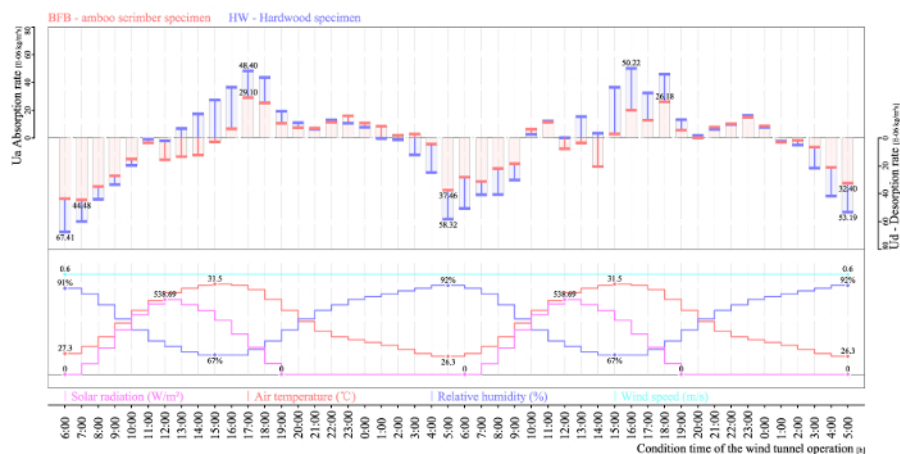
Figure 2. Absorption rate U_a and desorption rate U_d of bamboo scrimber and hardwood specimens. The figure shows the actual climate conditions within the wind tunnel, including the solar radiation, air temperature, relative humidity, and wind speed, and the absorption rate U_a and desorption rate U_d test results of the bamboo scrimber and hardwood specimens. The U_{ab} mean value $U_{ab.mean}$ of BFB and HW are $4.45E^{-05}$ kg/(m^2/s) and $6.74E^{-05}$ kg/(m^2/s) respectively, and the max value $U_{ab.max}$ are $1.49E^{-05}$ kg/(m^2/s) and $2.32E^{-05}$ kg/(m^2/s) respectively, of which the BFB to HW ratios were, respectively, 64.35% and 66.02%. The hourly U_{ad} values of the BFB were up to $33.69E^{-06}$ kg/(m^2/s), lower than that of the HW specimen, except in certain areas where the moisture process w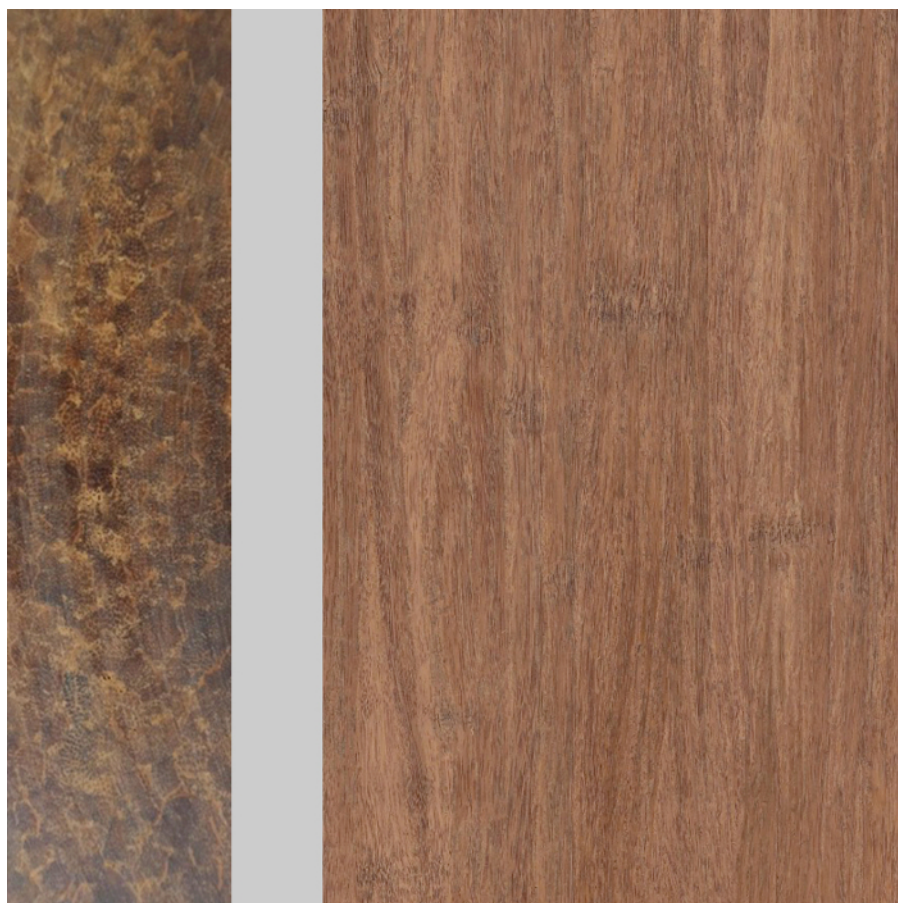as in the absorption-desorption transition stage. The maximum absorption rate U_a and desorption rate U_d dynamic test results of BFB were, correspondingly, $2.91E^{-05}$ kg/(m^2/s) and $4.45E^{-05}$ kg/(m^2/s). Please click here to view a larger version of this figure.

Figure 3. Photo of the bamboo scrimber sample. The figure shows the cross-section and frontal photographs of the bamboo scrimber sample. Please click here to view a larger version of this figure.

Rolling processing: Bamboo tube-strip-fiber bundle   Bamboo fiber bundle unit   Bamboo scrimber board
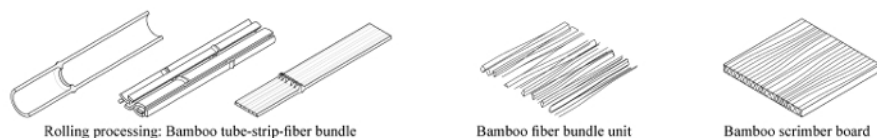
Figure 4. The manufacturing process of the bamboo scrimber sample. The figure shows a schematic diagram of the manufacturing process of the bamboo scrimber, including rolling, decomposing to a bamboo fiber bundle unit, and recombining to a bamboo scrimber board. Please click here to view a larger version of this figure.

Items		Unit	BFB -Bamboo scrimber	
Basic properties	Dry bulk density ρ	$[kg/m^3]$		1108.77
	Open porosity Φ	$[-]$		17.36%
Hygric properties	Drying rate (T =23ºC, RH=50%)	$[E\text{-}07 kg/(m^2 \cdot s)]$	$U_{u12\%\text{-}u11\%}$	12.58
			$U_{u11\%\text{-}u10\%}$	11.46
			$U_{u10\%\text{-}u9\%}$	10.38
			$U_{u9\%\text{-}u8\%}$	9.71
			$U_{u8\%\text{-}7\%}$	8.98
			$U_{u7\%\text{-}u6\%}$	7.74
	Capillary saturation moisture content w_{cap}	$[kg/m^3]$		165.93

Table 1. Bamboo scrimber hygric properties static test results. The table shows the information of the bamboo scrimber hygric properties static test results, including the drying rate done in a static environment (T = 23 °C, RH = 50%), showing that the drying rate of bamboo scrimber was between 7.74E^{-07} - 12.58E^{-07} kg/(m^2/s).

BFB (Bamboo scrimber)	Constituent unit	Assembly	Thickness	Main application
Photo of the bamboo scrimber sample (fig.3)	Bamboo bundle	Parallel	28.0 mm	Outdoor flooring
	Manufacturing process of the bamboo scrimber sample (fig.4)			

Table 2. Information on the bamboo scrimber sample. The table shows the information on the bamboo scrimber sample, including the constituent unit, assembly method, thickness, main application, and the sample sources.

HHCWT: Hot-Humid Climatic Wind Tunnel, including control systems for:
Air temperature: 2 air conditioner (KFRd-60LW/VA-ZXF, 6kW, and KFR-72LW/08FZBPC-a, 7.2kW) and 2 electric heating fans (1.5kW and 5kW), range 20-40°C, accuracy 0.3°C;
Relative humidity: 2 electrode humidifiers (BFD-01-04, 0.4kg/h) and 1 dehumidifier (DH-890C, 90L/d), range 40-90%, accuracy 3%;
Solar radiation: 8 infrared lights (305-3000nm), range 0-1030W/m^2, accuracy 10W/m^2;
Wind: axial fan, range 0-5m/s, accuracy 0.2m/s.
The HHCWT (Hot-Humid Climatic Wind Tunnel) was developed by the Building Energy Conservation Research Center of South China University of Technology. The HHCWT consists of 18 elements: protection room with air conditioner, heater, humidifier, dehumidifier, wind tunnel with entrance region, stilling region, test region, auxiliary region, diffusion region and fan region in order, a solar radiation chamber overhead and an air conditioning chamber below, the specimen slot with balance on the boundary of the wind tunnel and the air conditioning chamber, and the operating condition control and data collection system outside the protection room.
The mass record was done by electronic balance (range 0-4kg, accuracy 0.01g; time step: 10s), together with the operating condition control and data collection system. The mass information from the electronic balance was transmitted to the computer through the USB data acquisition & control card. And the signal was received and converted by a software attached to the HHCWT system.

Table 3. Equipment and control system of the Hot-Humid Climatic Wind Tunnel (HHCWT). The table shows the equipment and control system of the HHCWT, including the sub-systems for the control of the solar radiation, air temperature, relative humidity, and wind within the wind tunnel.

Hour	Air temperature	Relative humidity	Solar radiation	Wind speed
	[°C]	[%]	[W/m^2]	[m/s]
0:00:00	27.3	88	0	0.6
1:00:00	27.1	89	0	0.6
2:00:00	26.8	90	0	0.6
3:00:00	26.5	91	0	0.6
4:00:00	26.3	92	0	0.6
5:00:00	26.3	92	0	0.6
6:00:00	26.5	91	0	0.6
7:00:00	27	89	77	0.6
8:00:00	27.7	85	190	0.6
9:00:00	28.7	80	322	0.6
10:00:00	29.6	76	428	0.6
11:00:00	30.3	72	508	0.6
12:00:00	30.9	70	539	0.6
13:00:00	31.2	68	501	0.6
14:00:00	31.4	67	458	0.6
15:00:00	31.5	67	389	0.6
16:00:00	31.4	67	291	0.6
17:00:00	31.1	69	194	0.6
18:00:00	30.4	72	78	0.6
19:00:00	29.6	76	0	0.6
20:00:00	28.8	80	0	0.6
21:00:00	28.1	83	0	0.6
22:00:00	27.7	85	0	0.6
23:00:00	27.5	87	0	0.6
TMD (24hr repeated)	mean value: 28.7°C	mean value: 80.3%	sunrise: 06:00	constant as 0.6m/s
	amplitude: 2.6°C	amplitude: 12.5%	sunset: 18:00	
	max. time: 15:00	max. time: 05:00	max. value: 539.0W/m^2	
Note: the TMD (Typical Meteorological Day) in this study was from Guangzhou, and could be changed to other cities according to the experimental purposes				

Table 4. Standard condition: Climate data of Guangzhou summer typical meteorological day. The table shows the information of the climate conditions, including the solar radiation, air temperature, relative humidity, and wind speed of a TMD (Typical Meteorological Day) of Guangzhou, a typical subtropical city located in the south of China.

Assumed date	Time	Cumulative time [h]	Hourly mass change $[g/h]$		Hourly mass change rate $[g/(m^2 \cdot h)]$		Hourly mass change rate $[kg/(m^2 \cdot s)]$		Hourly mass change rate $[kg/(m^2 \cdot s)]$	
			BFB	HW	BFB	HW	BFB	HW	BFB	HW
9/5/2016	6:00:00	0	0	0						
9/5/2016	7:00:00	1	-12.92	-19.66	-157.14	-242.67	-4.37E-05	-6.74E-05	4.37E-05	6.74E-05
9/5/2016	8:00:00	2	-13.16	-17.49	-160.12	-215.96	-4.45E-05	-6.00E-05	4.45E-05	6.00E-05
9/5/2016	9:00:00	3	-10.32	-12.83	-125.51	-158.38	-3.49E-05	-4.40E-05	3.49E-05	4.40E-05
9/5/2016	10:00:00	4	-8.05	-9.77	-97.94	-120.58	-2.72E-05	-3.35E-05	2.72E-05	3.35E-05
9/5/2016	11:00:00	5	-4.45	-5.74	-54.17	-70.89	-1.50E-05	-1.97E-05	1.50E-05	1.97E-05
9/5/2016	12:00:00	6	-1	-0.22	-12.12	-2.76	-3.37E-06	-7.66E-07	3.37E-06	7.66E-07
9/5/2016	13:00:00	7	-4.63	-0.57	-56.27	-7.04	-1.56E-05	-1.96E-06	1.56E-05	1.96E-06
9/5/2016	14:00:00	8	-3.97	2.02	-48.3	24.88	-1.34E-05	6.91E-06	1.34E-05	6.91E-06
9/5/2016	15:00:00	9	-3.61	5.07	-43.95	62.59	-1.22E-05	1.74E-05	1.22E-05	1.74E-05
9/5/2016	16:00:00	10	-0.79	8.01	-9.61	98.85	-2.67E-06	2.75E-05	2.67E-06	2.75E-05
9/5/2016	17:00:00	11	1.96	10.66	23.83	131.58	6.62E-06	3.66E-05	6.62E-06	3.66E-05
9/5/2016	18:00:00	12	8.61	14.11	104.75	174.24	2.91E-05	4.84E-05	2.91E-05	4.84E-05
9/5/2016	19:00:00	13	7.52	12.73	91.42	157.11	2.54E-05	4.36E-05	2.54E-05	4.36E-05
9/5/2016	20:00:00	14	3.17	5.64	38.55	69.64	1.07E-05	1.93E-05	1.07E-05	1.93E-05
9/5/2016	21:00:00	15	2.23	3.25	27.14	40.08	7.54E-06	1.11E-05	7.54E-06	1.11E-05
9/5/2016	22:00:00	16	2.15	1.9	26.16	23.44	7.27E-06	6.51E-06	7.27E-06	6.51E-06
9/6/2016	23:00:00	17	3.37	3.81	41.02	47.07	1.14E-05	1.31E-05	1.14E-05	1.31E-05
9/6/2016	0:00:00	18	4.73	3.14	57.5	38.7	1.60E-05	1.08E-05	1.60E-05	1.08E-05
9/6/2016	1:00:00	19	3.24	2.28	39.36	28.14	1.09E-05	7.82E-06	1.09E-05	7.82E-06
9/6/2016	2:00:00	20	2.54	-0.08	30.84	-0.95	8.57E-06	-2.65E-07	8.57E-06	2.65E-07
9/6/2016	3:00:00	21	0.59	-0.38	7.23	-4.64	2.01E-06	-1.29E-06	2.01E-06	1.29E-06
9/6/2016	4:00:00	22	0.85	-3.52	10.36	-43.46	2.88E-06	-1.21E-05	2.88E-06	1.21E-05
9/6/2016	5:00:00	23	-1.29	-7.22	-15.65	-89.11	-4.35E-06	-2.48E-05	4.35E-06	2.48E-05
9/6/2016	6:00:00	24	-11.08	-17.01	-134.84	-209.95	-3.75E-05	-5.83E-05	3.75E-05	5.83E-05
9/6/2016	7:00:00	25	-8.32	-14.74	-101.25	-181.96	-2.81E-05	-5.05E-05	2.81E-05	5.05E-05
9/6/2016	8:00:00	26	-9.24	-11.89	-112.44	-146.77	-3.12E-05	-4.08E-05	3.12E-05	4.08E-05
9/6/2016	9:00:00	27	-6.48	-11.87	-78.86	-146.57	-2.19E-05	-4.07E-05	2.19E-05	4.07E-05
9/6/2016	10:00:00	28	-5.44	-8.81	-66.17	-108.74	-1.84E-05	-3.02E-05	1.84E-05	3.02E-05
9/6/2016	11:00:00	29	1.89	0.77	23.01	9.5	6.39E-06	2.64E-06	6.39E-06	2.64E-06
9/6/2016	12:00:00	30	3.39	3.6	41.25	44.5	1.15E-05	1.24E-05	1.15E-05	1.24E-05
9/6/2016	13:00:00	31	-2.26	0.07	-27.52	0.89	-7.64E-06	2.48E-07	7.64E-06	2.48E-07
9/6/2016	14:00:00	32	-1.01	4.51	-12.33	55.69	-3.43E-06	1.55E-05	3.43E-06	1.55E-05
9/6/2016	15:00:00	33	-6.09	1.02	-74.06	12.53	-2.06E-05	3.48E-06	2.06E-05	3.48E-06
9/6/2016	16:00:00	34	0.87	10.68	10.64	131.91	2.96E-06	3.66E-05	2.96E-06	3.66E-05
9/6/2016	17:00:00	35	5.93	14.65	72.11	180.81	2.00E-05	5.02E-05	2.00E-05	5.02E-05
9/6/2016	18:00:00	36	3.83	9.48	46.63	117.07	1.30E-05	3.25E-05	1.30E-05	3.25E-05
9/6/2016	19:00:00	37	7.75	13.41	94.26	165.61	2.62E-05	4.60E-05	2.62E-05	4.60E-05
9/6/2016	20:00:00	38	1.71	3.86	20.83	47.62	5.79E-06	1.32E-05	5.79E-06	1.32E-05
9/6/2016	21:00:00	39	0.07	0.58	0.86	7.12	2.39E-07	1.98E-06	2.39E-07	1.98E-06
9/6/2016	22:00:00	40	2.37	1.83	28.8	22.58	8.00E-06	6.27E-06	8.00E-06	6.27E-06
9/7/2016	23:00:00	41	3.04	2.84	37.01	35	1.03E-05	9.72E-06	1.03E-05	9.72E-06

9/7/2016	0:00:00	42	4.44	4.78	54.01	59.03	1.50E-05	1.64E-05	1.50E-05	1.64E-05
9/7/2016	1:00:00	43	2.6	2.27	31.59	28.02	8.77E-06	7.78E-06	8.77E-06	7.78E-06
9/7/2016	2:00:00	44	-0.89	-0.61	-10.8	-7.56	-3.00E-06	-2.10E-06	3.00E-06	2.10E-06
9/7/2016	3:00:00	45	-0.49	-1.46	-6.01	-18.08	-1.67E-06	-5.02E-06	1.67E-06	5.02E-06
9/7/2016	4:00:00	46	-1.92	-6.29	-23.37	-77.7	-6.49E-06	-2.16E-05	6.49E-06	2.16E-05
9/7/2016	5:00:00	47	-6.23	-12.16	-75.74	-150.09	-2.10E-05	-4.17E-05	2.10E-05	4.17E-05
9/7/2016	6:00:00	48	-9.59	-15.51	-116.65	-191.48	-3.24E-05	-5.32E-05	3.24E-05	5.32E-05
Max value			8.61	14.65	104.75	180.81	2.91E-05	5.02E-05	4.45E-05	6.74E-05
Min value			-13.16	-19.66	-160.12	-242.67	-4.45E-05	-6.74E-05	2.39E-07	2.48E-07
Mean value			-1.13	-0.64	-13.78	-7.94	-3.83E-06	-2.21E-06	1.49E-05	2.32E-05
Note: BFB- bamboo scrimber; HW- hardwood										

Table 5. Mass records and the calculated absorption and desorption rate U_{ad} value. The table shows the information on the absorption rate U_a and desorption rate U_d test results of the bamboo scrimber and hardwood specimens. The U_{ab} mean value $U_{ab.mean}$ of BFB and HW were $4.45E^{-05}$ kg/(m^2/s) and $6.74E^{-05}$ kg/(m^2/s) respectively, and the max value $U_{ab.max}$ were $1.49E^{-05}$ kg/(m^2/s) and $2.32E^{-05}$ kg/(m^2/s) respectively.

Discussion

The protocol presented a Hot-Humid Climatic Wind Tunnel (HHCWT) test method to measure the moisture absorption and desorption rate of bamboo scrimber. The critical steps included the specimen's treatment, which in turn included the specimen's preparation, vacuum saturation, and bottom and side sealing; the wind tunnel operation, which in turn included the equipment arrangement, wind tunnel preheating, specimens installation, and data recording; the post-operation including drying the specimen; the data processing, which in turn included calculating the values of the hourly mass and the absorption and desorption rate U_{ad} value.

The problem of a climate-related experiment, especially in an outdoor environment, was that the climate conditions could not be reproduced, let alone that experiments done by different operators at different periods could be standardized. However, the HHCWT test method enables the complete control of climate conditions. With a TMD (Typical Meteorological Day) as the climate conditions, the HHCWT test method could help to realize the repeatability and standardization of outdoor experiments[13,14].

Unlike disciplines such as chemistry, where the material samples, testing equipment, and operation processes are strictly standardized, the HHCWT is a combined system that consists of several different sub-systems, which is much more complicated. On the other hand, building materials are generally much more inhomogeneous and their properties are normally evaluated on more macroscopic perspectives. Therefore, the test method by wind tunnel shown in this protocol is, in a certain sense, a demonstration rather than a strict regulation.

The detailed information for each step in this experiment is presented in the protocol, but that does not mean that everything must be followed strictly. There is flexible space to adjust. For example, the sub-systems like the heating fans, air conditioners, humidifiers, and dehumidifiers, *etc.*, could be changed to other types. Secondly, the goal of the vacuum saturation treatment in step 1 is to reach an original state of moisture content for the specimens. When this is achieved, it is acceptable to change the vacuum pump and the chamber. Thirdly, different materials have a varying time length requirement to exhaust the inner air and reach the state of vacuum saturation. The bamboo scrimber in this study required a long time due to the high moisture transport resistance, but other materials will require a different time length.

The method has potential to be applied to climate-related experiments and as the verification of simulation results by a computer program.

Disclosures

The authors have nothing to disclose.

Acknowledgements

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