Measurement of the Equivalent Thermal Resistance of Rooftop Lawns in a Hot-Climate Wind Tunnel[1]

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Abstract: In a very hot summer equivalent to a Guangzhou summer, the reduction of heat coming into rooms is very important with respect to thermal comfort and energy efficiency. The objective of this study is to investigate the evaporation cooling effect on a rooftop lawn. A hot-climate wind tunnel experiment was carried out in order to obtain and analyze the heat and moisture transport in the rooftop lawn. Furthermore, a calculation with the energy conservation equation was carried out using the results of the hot-climate wind tunnel experiment. The calculated equivalent thermal resistance and synthesis exterior surface heat transfer coefficient were in fairly good agreement with that in the design standard for energy efficiency of residential buildings in the hot summer and warm winter zone, while the average velocity in hot-climate wind tunnel equals the summer average outdoor velocity in Guangzhou.

Key words: Rooftop lawn; Hot-climate wind tunnel; Equivalent thermal resistance; Exterior surface heat transfer coefficient

1.INTRODUCTION

In recent years, environmental problems have become more serious in china. Especially in urban areas, the need for vegetation is increasing, because rooftop lawn are effective not only in reduction in air conditioning load of building、improvement of indoor and outdoor thermal environment but in energy conversation of buildings, thus the need for vegetation is increasing in china.

The study on thermal characteristics of the rooftop lawn have been mostly concerned to the effects of photosynthesis and transpiration from soil and the earlier researches on rooftop lawn were mostly based on numerical analyses and experimental study[1~3].

In this study, the author conducted a measurement in the hot-climate wind tunnel in order to test the equivalent thermal resistance of rooftop lawn, clarified the thermal process of the rooftop lawn, and exploded a new method of testing the thermal parameter of this kind of roof material.

2.EXPERIMENTAL SETUP

2.1 Test-Bed

Test-bed locates in hot-climate wind tunnel lab in South China University of Technology in China. It can simulate the representative outdoor climate by controlling and accommodating environmental air temperature 、relative humidity 、solar radiation and wind speed. Fig.1 shows five 400mm×400mm test grooves for samples lay along the testing sect in wind tunnel.

Wind speed is controlled by computer program according to connecting blower and transducer in hot-climate wind tunnel, and the changed range is from 0m/s to 5m/s.

Solar radiation is simulated by eight infrared lamps, the spectral distribution of the lamp included shot and medium wave of the sun, the location is sketched in Fig.2. Heat flux at the sample surfaces are almost equal, and the maximum is equal to 751.2

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W/m^2。

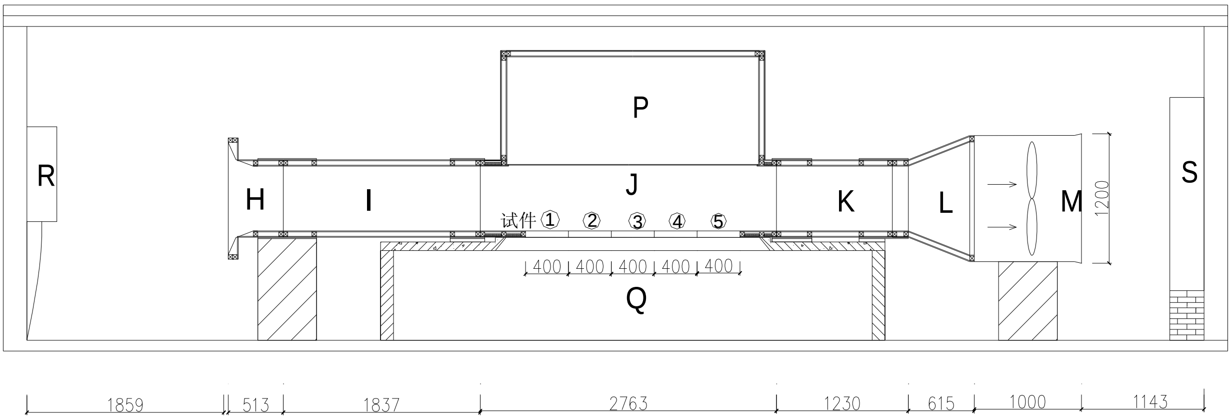


Fig.1 Hot-climate wind tunnel section plane (unit:mm)

H-entrance I-stabilization section J-testing section K-assistant exceeding section L-diffusing section P-lamp-house Q-air conditioning chamber R-humidifier S-air conditioner

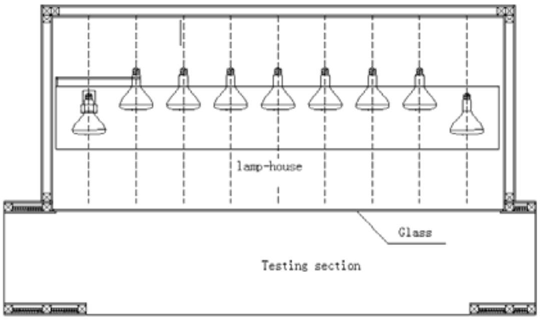


Fig.2 Lamp-house section plane

2.2 Samples

Sedum linear were used in this hot-climate wind tunnel experiment. Sedum linear can endured dry and hot climate、and have better adaptability. The average height of the used sedum linear was 100mm, and those were planted in several pieces of four-perforated clay bricks, those are sketched and shown in Fig.3.

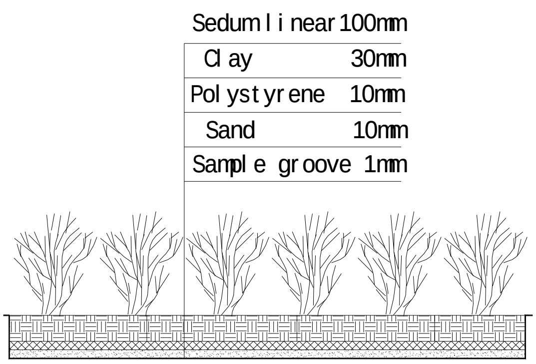


Fig.3 Sedum linear sample

3. ENERGY CONVERSATION EQUATION

Energy conservation equation for rooftop plant sample presented in Fig.4 and following equation (1)~(6).

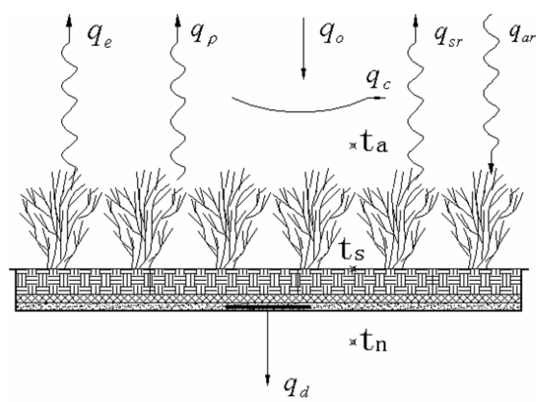


Fig.4 Energy conservation for rooftop plant sample

$$q_o + q_{ar} = q_{sr} + q_\rho + q_e + q_c + q_d \quad (1)$$

Where

q_o is solar radiation (W/m^2); q_{ar} is atmosphere long wave radiation (W/m^2); q_ρ is surface reflect radiation (W/m^2); q_{sr} is surface long wave radiation (W/m^2); q_e is sample evaporation heat flux (W/m^2); q_c is convection heat flux between sample surface and air flow (W/m^2); q_d is heat transfer flux (W/m^2).

And

$$q_{ar} = \sigma\left(\frac{t_a + 273}{100}\right)^4 \times \left(0.802 + 0.004 t_d\right) \quad (2)$$

$$q_e = \frac{El}{3600 \times S} \quad (3)$$

$$q_c + q_e + q_{sr} = \alpha_w (t_s - t_a) \quad (4)$$

$$q_d = k(t_a - t_n) \quad (5)$$

$$k = \frac{1}{\frac{1}{\alpha_n} + \frac{1}{\alpha_w} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \mathrm{R_z}} \quad (6)$$

Where

σ ——Strfan-Boltxmann constant;

t_d ——outdoor air dew point temperature, ( );

E——surface evaporation, (g/h);

l——latent heat, (kJ/kg);

S ——sample area, (m^2);

α_w ——synthesis exterior surface heat transfer coefficient, $(W/m^2 \cdot K)$;

t_s ——surface temperature, ( );

t_a ——outdoor air temperature, ( );

t_n ——indoor air temperature, ( );

k ——heat transfer coefficient, $(W/m^2 \cdot K)$;

λ_1、λ_2、λ_3 ——material thermal conductivity, $(W/m \cdot K)$;

d_1、d_2、d_3 ——material thickness,(mm);

R_z ——synthesis equivalent heat resisitance, $(m^2 \cdot K/W)$。

4. EXPERIMENTAL PROCEDURES

Environment parameters in hot-climate wind tunnel were set corresponding to outdoor climate parameters in GuangZhou in summer.

Tab.1Experiment parameters and corresponding outdoor climate parameters

Environment parameters in hot-climate wind tunnel	Corresponding outdoor climate parameters
Wind speed	Outdoor wind speed
Air temperature and humidity	Outdoor air temperature and humidity
Air temperature in air-conditioning house	Indoor air temperature
Infrared radiation lamp	Solar radiation

Therefore, the following three cases of measurements according to the changed wind speed were carried out:

Tab. 2 Measurement cases

Case	Time	Wind speed in wind tunnel (m/s)
1	2005-09-28 14：00~18：00	2.0
2	2005-09-29 10：00~16：00	1.5
3	2005-09-30 16：30~21：00	1.0

In hot-climate wind tunnel the air temperature 、sample surface temperature 、air temperature in air-conditioning room were measured by thermocouples; solar radiation was measured by a hemisphere pyranometer that gave the sum of direct and diffused sky solar radiation. Evaporated vapor was measured by BW-4200H electron balance; heat transfer flux through the sample was measured by heat flow meter. The measuring apparatus in hot-climate wind tunnel were shown in Fig.5. Sampling interval was set to three minutes, and measuring duration were from 4 to 6 hours, all the measuring datum were available.

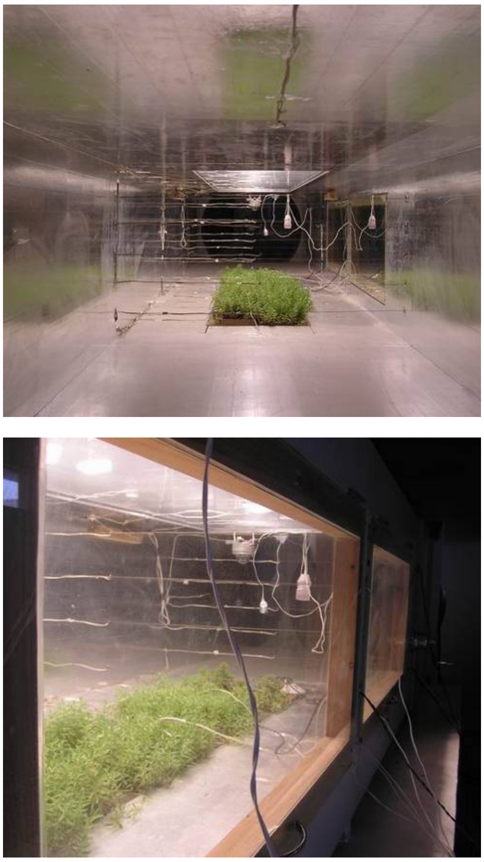


Fig.5 Measuring environment

5. RESULTS OF THE HOT-CLIMATE WIND TUNNEL EXPERIMENTAL

Fig.6~8 showed the calculated rooftop lawn exterior surface synthesis heat transfer coefficient in three cases:

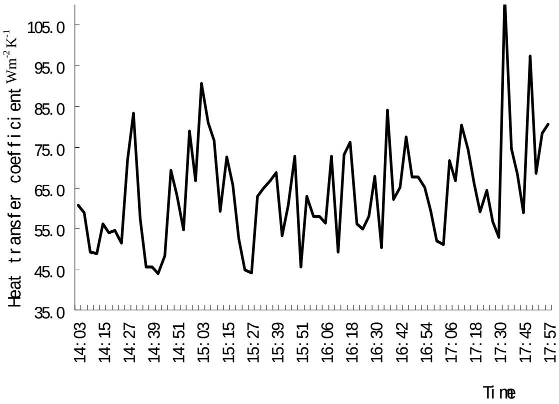


Fig.6 Rooftop lawn exterior surface synthesis heat transfer coefficient in case1

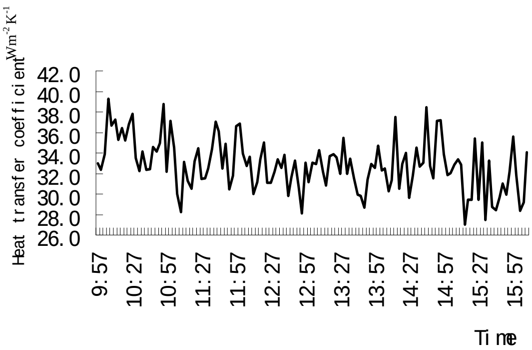


Fig.7 Rooftop lawn exterior surface synthesis heat transfer coefficient in case2

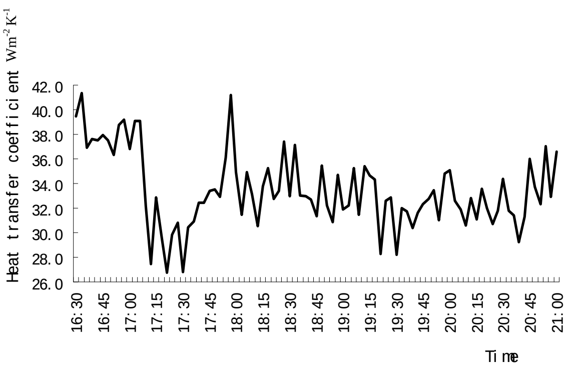
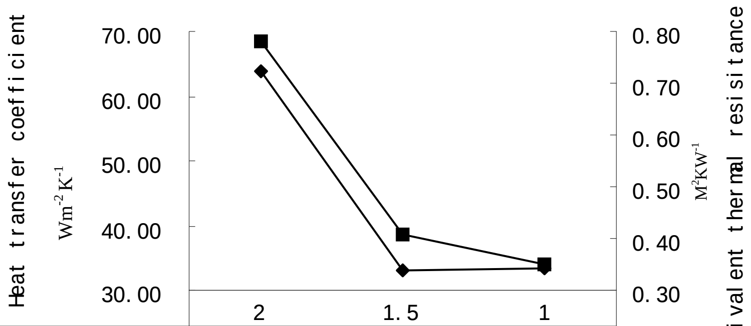


Fig 8 Rooftop lawn exterior surface synthesis heat transfer coefficient in case 3

In the case with 2.0 m/s wind speed, rooftop lawn exterior surface synthesis heat transfer coefficient changed from 45 to 105 $W/m^2 \cdot K$. In the cases with 1.5 m/s wind speed, rooftop lawn exterior surface synthesis heat transfer coefficient changed from 27 to 39 $W/m^2 \cdot K$. In the cases with 1.0 m/s wind speed, rooftop lawn exterior surface synthesis heat transfer coefficient changed from 26 to 41 $W/m^2 \cdot K$.

Judging from these results, rooftop lawn exterior surface synthesis heat transfer coefficient was influenced by wind speed. It increased rapidly with high wind speed and fluctuated greatly between sampling intervals, while it reduced in the cases with 1.5 m/s and 1.0 m/s wind speed, and fluctuated lower between sampling intervals.

Fig.9 showed the calculated mean rooftop lawn exterior surface synthesis heat transfer coefficient and equivalent resistance in three cases .



	2	1.5	1
Heat transfer coefficient	63.93	33.12	33.45
Equivalent thermal resistance	0.78	0.41	0.35

Wind speed (m/s)

Fig.9 The mean rooftop lawn exterior surface synthesis heat transfer coefficient and equivalent resistance

In the case with 2.0 m/s wind speed, exterior surface synthesis heat transfer coefficient was 63.93 $W/m^2 \cdot K$, and equivalent resistance was 0.78 $W/m^2 \cdot K$. In the case with 1.5 m/s wind speed, exterior surface synthesis heat transfer coefficient was 32.12 $W/m^2 \cdot K$, and equivalent resistance was 0.41 $W/m^2 \cdot K$. In the case with 1.0 m/s wind speed, exterior surface synthesis heat transfer coefficient was 33.45 $W/m^2 \cdot K$, and equivalent resistance was 0.35 $W/m^2 \cdot K$.

Without considering the evaporation effect of rooftop lawn, the mean rooftop lawn exterior surface synthesis heat transfer coefficient were 44.73 $W/m^2 \cdot K$, 23.21 $W/m^2 \cdot K$, 24.64 $W/m^2 \cdot K$ respectively in three cases , while the equivalent resistance nearly were not changed.

6. CONCLUSIONS

1. Rooftop lawn exterior surface synthesis heat transfer coefficient increased with high wind speed and fluctuated more greatly between sampling intervals.
2. Exterior surface synthesis heat transfer coefficient changed slowly when wind speed was below 2.0 m/s , and fluctuated lower between sampling intervals.
3. The measured rooftop lawn equivalent resistance was from 0.41 to 0.63 $m^2 \cdot K/W$ with wind speed in hot-climate wind tunnel equal to 1.5~1.8 m/s, which is the mean outdoor wind speed in Guangzhou in summer, and that result was in good agreement with that in the Design standard for energy efficiency of residential buildings in hot summer and warm winter zone[4].

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