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Research on the Effect of a Planting Roof on the Thermal Load of a Business Building

Weijie Zhang, Professor; Jinshun Wu, postgraduate
Institute of Urban Construction, Hebei Engineering University
Handan P.R.CHINA, 056038
zhangweijie_5@sina.com

Yiran Wei, Associate Professor
Handan Polytechnic College
wyr682008@yahoo.com.cn

Xudong Gao, Lecturer
Institute of Urban Construction, Hebei Engineering University
Handan P.R.CHINA, 056038
zhangweijie_5@sina.com

Abstract: A pair of comparative testing rooms (one with an ordinary roof and the other with a planting roof) was established in our laboratory, and in- situ measurement (in summer) data have been collected and treated. The indoor thermal environment was analyzed and the thermal load within each room was calculated Comparative analysis of thermal loads of these two rooms was done. Reduction of thermal load by the planting roof is clearly shown from our research work. A theoretical analysis of the effect of the planting roof on the room's thermal load was done, and theoretical relations between outdoor air temperature and indoor thermal load within certain region were established. The feasibility analysis of the application of our research work to the business building was also completed. The summer cooling load reduction characteristics, the energy saving characteristics on air conditioning system, the yearly electricity consumption reduction, the yearly consumption amount reduction of "Primary Energy", the discharge amount reduction of sensible heat to outdoor atmosphere in summer, and the yearly discharge amount reduction of greenhouse gases to the outdoor atmosphere from air conditioning system due to the planting roof are also predicted. A corresponding economic analysis is also presented in this paper. The results show the advantages of the planting roof, and also promote the widespread application of the planting roof to business buildings.

Key words: planting roof; thermal load; business building; energy saving envelope; energy and environment

1. INTRODUCTION

The method of planting roof is one of the most promising and versatile means for reducing building energy consumption and ecological building construction. It has been well developed in many developed countries both for reducing building energy consumption and ecological reasons. The ratio of planting roof in some cities has been raised even over 40%. Now in China, the conception and inception of this kind of method has been also occurred for the same reasons of building energy saving and ecology, in addition, mostly promoted by the preparing the incoming Beijing Olympic game 2008. For further and better development of planting roof , researches on building energy consumption characteristics and building environmental effect characteristics affected by planting roof have to be done deeply and in detail . Within our work, a pair of comparative testing rooms (one has the ordinary roof and the other has the planting roof) have been established in our laboratory, in situ measurement (in summer) data have been collected and treated. These data including following items: outdoor air temperature, indoor air temperature, temperatures of outer surface of roof, temperatures of inner surface of roof, temperatures of top and bottom surface of the planting layer. Indoor thermal environment has been analyzed and thermal load within each room has been calculated, comparative analysis of thermal loads of these two rooms has been made. Reduction of thermal load by the planting roof is clearly shown from our research work. Some theoretical analysis on the effect of planting roof to the thermal load of a room has been made and some theoretical relations between outdoor air temperature and indoor thermal load within certain region have been established. The summer cooling load reduction characteristics, the energy saving characteristics on air conditioning system(both on capacity and operation mode selection) , the year electricity consumption reduction, the year consumption amount reduction of "Primary Energy", the discharge amount reduction of sensible heat to outdoor atmosphere in summer , and the year discharge amount reduction of some main "Green House Effect" gases(CO_2, SO_X, NO_X due to "Primary Energy " consumption) to outdoor atmosphere from air conditioning system due to the planting roof can also be predicted by our work . Corresponding economic analysis has also been done in our wok. All results we made are helpful to know the advantages of planting roof better, and therefore furthermore promote the widespread application of planting roof to business buildings.

2. TESTING WORK

A pair of comparative testing rooms (one has the ordinary roof and the other has the planting roof with natural wild grass) have been established in our laboratory (located in Handan City, Hebei Province, CHINA), the schematic figures are shown as figure 1, figure 2 and figure 3.

Both testing rooms are totally closed without air exchange with outside, 0.5m outer shades and thick inner blinds are set on the windows, the thickness of the ordinary planting layer is about 200 mm. During September 4 to 6, 2005, a continuous (hourly) testing work was done, the testing items are listed in table 1.

During September 4 to 6, 2005, a continuous (hourly) testing work was done, testing parameters of these three days (3×24 hours) were collected, an average day was made that consists of the average values of respective hour data within these three days, see figure 4 , figure 5 and figure 6

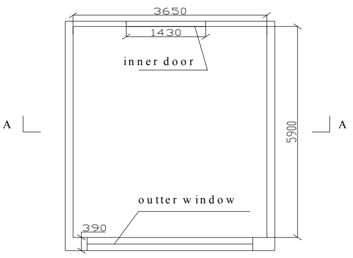

Fig.1 The horizontal layout of both testing room

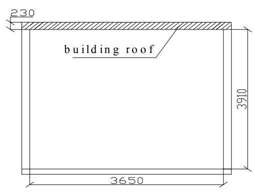

Fig.2 The A-A profile of ordinary testing room

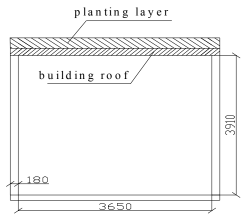

Fig.3 The A-A profile of the testing room with planting roof

Tab. 1 Testing parameters

Ordinary testing room		Testing room with planting roof	
Outdoor air temperature	$t_o(\tau)$	Outdoor air temperature	$t_o(\tau)$
Indoor air temperature	$t_{io}(\tau)$	Indoor air temperature	$t_{ip}(\tau)$
Outer surface temperature of the roof	$t_{oso}(\tau)$	Outer surface temperature of the roof	$t_{osp}(\tau)$
Inner surface temperature of the roof	$t_{iso}(\tau)$	Inner surface temperature of the roof	$t_{isp}(\tau)$

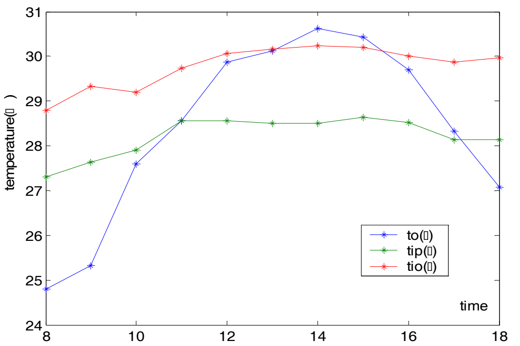

Fig.4 The variation of indoor air temperature within the average day

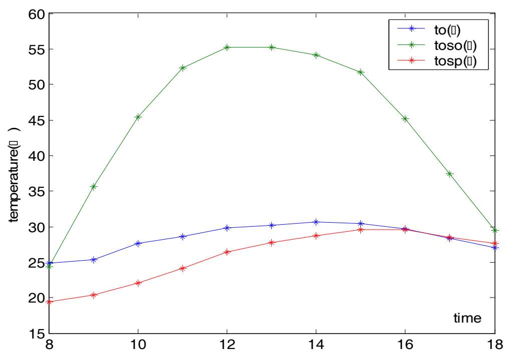

Fig.5 The variation of outer surface temperature of the roof within the average day

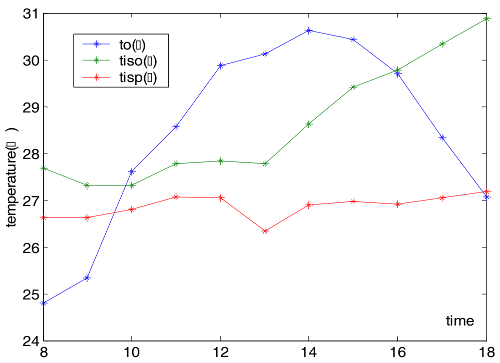

Fig.6 The variation of inner surface temperature of the roof within the average day

3. DATA TREATMENT

The inner dimensions of each room are: length =5.9m, width=3.65m, height=3.91m.The air volume inside each room Va = length × width× height = 5.9×3.65×3.91=84.2m^3 . The corresponding characteristic parameters of the air are: ρ=1.173kg/m^3, Cp=1.005kJ/(kg·k) .

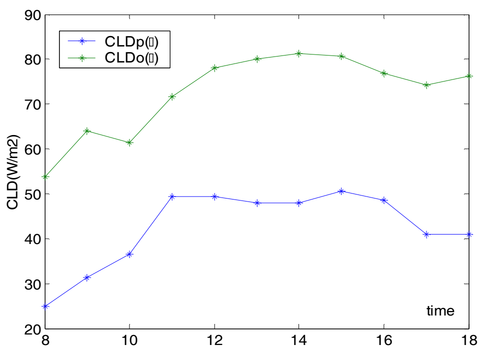

Fig.7 The distribution of hourly cooling load of the average day

For cooling load calculation, the set temperature of indoor air is 26℃, the thermal amount storaged in indoor air of the ordinary room is Qo(τ) =ρ·cp ·Va ·[tio(τ)- 26] , and its corresponding cooling load CLDo(τ)= Qo(τ) /T , the thermal amount storaged in indoor air of the room with planting roof is Qp(τ) =ρ·cp ·Va ·[tip(τ)—26] , and its corresponding cooling load CLDp(τ)= Qp(τ) /T (The amount of heat needed to be abstracted from indoor air per unit time), the average hourly load distribution of the average day is shown in figure 7 , here we take T = 4 min = 240 s .

4. CORRESPONDING ANALYSIS

In case of business premises, central air-conditioning system is used, the rating capacity of air-conditioning system is determine by the maximum cooling load of the whole building, the test room area A=5.9×3.65=21.535m², suppose the operation of the air-conditioning system can be adjusted by VFD(Variable Frequency Drive) , so the cooling output of the air-conditioning system can be adjusted according the hourly cooling load of the building. The working shift is from 8:00 a.m. to 18:00p.m. .The average COP(Coefficient of Performance) of the air-conditioning system is supposed as a constant 2.5 during its operation, The electricity consumption of the air-conditioning system is supplied by coal-burning power plant, every unit electricity consumption may consume 380g standard coal (380g/kWh) and at the same time may cause some environmental loads: 9.14g-SO_x /kWh, 3.32g-NO_x /kWh, 1.586kg-CO_2 /kWh(these data are collected from the corresponding university textbooks), so the operational data of the air-conditioner based on the parameter pattern of average day can be obtained as shown in table2 and table3 .

5. CONCLUSIONS

From our testing and analysis work have been done above, some useful conclusions can we get:

1) Planting roof plays an important role in building energy saving, only by a simple and ordinary planting roof just as we made, cooling load of the room, electricity consumption and corresponding “primary energy” consumption and its environmental load will be greatly reduced.

2) Within a business building, if 3000 m^2 of business roof will be planted, only at the average value of room cooling load, the positive effect of planting roof will be well shown in table 4.

3) Our research work is still a preliminary work in this field, it is far from enough and perfect, lots of work needs to be done. for example , the establishment of our average day parameter pattern is not evident enough because its local characteristics and its short testing period (only three days) , the characteristic relevance between our testing room and

Tab.2 The operational data of the air-conditioning system (per unit area) in the ordinary testing room (average day pattern)

time	Cooling load(W/m²)	Room area(m²)	Input power(W)	electricity (kWh)	Coal (g/h)	CO_2 (kg/h)	SO_x (g/h)	NO_x (g/h)	Sensible Heat discharge(kJ/h)
8:00	53.77	21.535	463.19	0.463	176.01	0.735	4.234	1.54	5836.18
9:00	64.01	21.535	551.42	0.551	209.54	0.875	5.040	1.83	6947.84
10:00	61.45	21.535	529.36	0.529	201.16	0.840	4.838	1.76	6669.92
11:00	71.70	21.535	617.59	0.618	234.68	0.979	5.645	2.05	7781.58
12:00	78.10	21.535	672.73	0.673	255.64	1.067	6.149	2.23	8476.36
13:00	80.02	21.535	689.27	0.689	261.92	1.093	6.300	2.29	8684.80
14:00	81.30	21.535	700.30	0.700	266.11	1.111	6.401	2.32	8823.75
15:00	80.66	21.535	694.78	0.695	264.02	1.102	6.350	2.31	8754.27
16:00	76.82	21.535	661.70	0.662	251.45	1.049	6.048	2.20	8337.40
17:00	74.26	21.535	639.64	0.640	243.06	1.014	5.846	2.12	8059.49
18:00	76.18	21.535	656.18	0.656	249.35	1.041	5.998	2.18	8267.93
SUM	798.25 W/(m²·d)	——	——	6.876 kWh/d	2612.93 g/d	10.91 kg/d	62.85 g/d	22.83 g/d	86639.52 kJ/d

Tab.3 The operational data of the air-conditioning system (per unit area) in the testing room with planting roof (average day pattern)

time	Cooling load(W/m²)	Room area(m²)	Input power(W)	electricity (kWh)	Coal (g/h)	CO_2 (kg/h)	SO_x (g/h)	NO_x (g/h)	Sensible Heat discharge(kJ/h)
8:00	24.965	21.535	215.05	0.215	81.72	0.341	1.966	0.714	2709.66
9:00	31.367	21.535	270.19	0.270	102.67	0.429	2.470	0.897	3404.44
10:00	36.488	21.535	314.31	0.314	119.44	0.498	2.873	1.043	3960.27
11:00	49.291	21.535	424.59	0.425	161.34	0.673	3.881	1.410	5349.83
12:00	49.291	21.535	424.59	0.425	161.34	0.673	3.881	1.410	5349.83
13:00	48.010	21.535	413.56	0.414	157.15	0.656	3.780	1.373	5210.88
14:00	48.010	21.535	413.56	0.414	157.15	0.656	3.780	1.373	5210.88
15:00	50.571	21.535	435.62	0.436	165.53	0.691	3.982	1.446	5488.79
16:00	48.651	21.535	419.08	0.419	159.25	0.665	3.830	1.391	5280.36
17:00	40.969	21.535	352.91	0.353	134.10	0.560	3.226	1.172	4446.62
18:00	40.969	21.535	352.91	0.353	134.10	0.560	3.226	1.172	4446.62
SUM	468.58 W/(m²·d)	——	——	4.038 kWh/d	1533.79 g/d	6.402 kg/d	36.895 g/d	13.401 g/d	50858.18 kJ/d

Tab.4 The comparative data between ordinary and planting business room (average day pattern)

	Cooling Load (W/m²)	Room area (m²)	Input power (10^4W)	electricity (kWh)	Coal (10^4 g/h)	CO_2 (kg/h)	SO_x (g/h)	NO_x (10^5 g/h)	Sensible Heat discharge (10^6kJ/h)
Ordinary room	72.568	3000	8.71	87.1	3.31	138.1	795.9	289.1	1.097
Planting room	42.598	3000	5.11	51.1	1.94	81	467.1	169.7	0.644
reduction	29.97	——	3.6	36	1.37	57.1	328.8	119.4	0.453

common business room also need further explored . Although many improvements must be taken in the future, the significance of planting roof and the its promising characteristics have been already well presented.

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