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Study on Energy Efficiency of Several Different Roof Plants in Wuhan

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Abstract. The green roof is developing rapidly in China now, while different roof plants have prominent influence on the effect of energy saving and cooling. This passage uses Design Builder, which is a green building simulation software based on Energy Plus computing engine, to establish a typical low-rise residential building model in Wuhan. According to the integrated software parameters and the relevant standard and specifications, the paper set the design of the residential layout, indoor staff status, air conditioning settings and other settings related to the model. The summer energy saving and cooling effect of seven different roof plants were studied in this paper. The simulation results show that the leaf area index of the plant, the thermal reflectivity of the solar radiation and the heat gain of the roof in the summer were inversely proportional to each other. Plum has the best effect on summer energy saving and cooling in seven plants, and Fatsia japonica has the best effect on summer energy saving and cooling among three kinds of shrubs.

Introduction

The green roof is mainly reflected in its structural innovation of conventional roof, so that different kinds of green plants can be grown on it. Related theses show that the green roof has the properties of energy saving, land saving, water saving, protection of building structure, improving the urban ecological environment, enabling people to relax, etc. Combined with today's domestic outstanding ecological and environmental problems, the construction and research of green roof are of great significance. In the green roof construction process, the choice of roof plants is a crucial phase, good plant selection will play a multiplier effect. However, there are few studies which concentrated on the selection of plantation roof plants. Based on the successful commercial building energy consumption simulation software-Design Builder, this thesis studied summer air-conditioning cold load and summer heat gain when the roof is planted seven different kinds of roof plants. These seven different roof plant species are all derived from recommended central China roof plants of national architectural standard design 14J206"planting roof structure". This thesis hopes to find a higher energy efficiency roof plant and open up a practical approach for the comparison of roof plants.

Characteristics and Parameters of Seven Plants

After selection, this paper identified seven kinds of plants as the species of the experiment, including three kinds of trees, namely: Magnolia grandiflora, Red Maple, Plum. Three kinds of shrubs, namely: Hibiscus mutabilis, Fatsia japonica, China rose. A kind of ground cover: Sedum lineare. Combining different species of trees, shrubs and ground cover plants, there are a total of nine different combinations. Because the software's setting of plant height cannot exceed 1m, the height of the trees and shrubs are set to 1m, the height of the ground cover is set to 0.1m. All plant leaf area index is obtained according to Zheng Peng[1]. The blade emissivity of Sedum lineare, the reflectivity of the solar radiation heat of Sedum lineare, the blade emissivity of other plants, the blade reflectivity of the long-wave of other plants are obtained according to the study of Feng Chi[2]. The reflection coefficient of the solar radiation heat of the remaining plant leaves is calculated according to the famous leaf reflection model-Prospect model. The prospect model was developed on the basis of Allen's plate model, which simulates the radiation flux from 400nm to 2500nm based on the biochemical parameters (chlorophyll content, dry matter content, moisture content)

Table 1. The properties and parameters of plants.

Category	Plant species	Plant family	Biological habit	Blade emissivity	Solar radiation heat absorption coefficient	Plant height（m）	Leaf area index	Blade reflectivity of the long-wave	Minimum stomatal resistance（s/m）
	Magnolia grandiflora	magnoliaceae	Like light，bear shade，anti-smoke		0.532		3.15		
tree	Red Maple	aceraceae	positive，like humid and cool environment, fertile soil		0.759	1	2.42		
	Plum	rosaceae	Like light，humid and warm environment, can bear cold	0.92	0.711		3.52	0.08	
	Hibiscus mutabilis	malvaceae	Like light，can adapt to acid and fertile soil		0.727		1.85		150
shrub	Fatsia japonica	araliaceae	Like shade, warm and humid environment		0.712	1	3.07		
	China rose	rosaceae	Like light，can adapt to acid soil		0.539		2.41		
Ground cover	Sedum lineare	crassulaceae	Can bear extremely awful environment	0.83	0.68	0.1	2.9	0.17	

And leaf mesophyll structure parameters of plant leaves. This band concentrates more than 90% of the solar radiation energy, so the model can be used to approximately calculate the reflectivity of the solar radiation heat of the blade. The minimum stomatal resistance of the plant is generally 100s/m-200s/m, and the minimum stomatal resistance between different plants is very small. Therefore, the minimum stomatal resistance of the plant is set to the average value of 150s/m. The specific parameters of each plant are shown in Table 1.

Building Model

Roof Model

As the plant species studied here include trees, shrubs and ground cover plants, trees and shrubs are generally planted on "garden-style" roofs, so the model is set to "garden-style" roof. According to the "Building Structure Load Standard"GB50009-2012, the standard value of the live load of the roof garden is 3KN/m2. Therefore, the model adopts 200mm thick C40 cast-in-place reinforced concrete structure roof, and its total Load carrying capacity can reach to 15KN/m2, this load carrying capacity can meet the structural load bearing requirements. Planting roof structure refer to ZW5 construction structure of Chinese national architectural standard design Atlas "planting roof structure"14J206 [3], this roof structure applies to the Wuhan area "garden-style" roof. The specific structure of the roof model and the parameters of each layer are shown in Table 2.

Building Size and Basic Parameters

In order to accurately simulate the heat gain of the roof and the cold load of air-conditioning in summer when using different roof plants in typical low-rise residential buildings in Wuhan, a representative building model should be established and the model parameters should be set reasonably. According to the revised "Residential Design Standard"(GB50096-2011) in 2011, the low-rise residential is one to three floor. According to the "Measures for the Implementation of Land Management in Hubei Province" article 33: urban residents must apply for the use of state-owned land, each household area shall not exceed 100 square meters. According to the "civil building energy efficiency design standards"JGJ26-95: building shape factor should be controlled within 0.3(include 0.3); if the shape factor is greater than 0.3, the roof and the external walls should be strengthened thermal insulation. According to the "2009 national civil engineering design technical measures (HVAC power)"the relevant recommendations, when the room contains the window or door, the building penetration rate should be set to 0.5 times/hour. According to the above information and the general design standards of low-rise residential buildings in Wuhan, the following building model is set up. The building is a two-story building with a length of 13.8m and a width of 7.2m. The floor height of building is 3m, and the total floor area in each floor is 99.36m^2. Architectural design is suitable for 4 people to live in. The building model includes rooms such as bedroom, living room, dining room, toilet, study room and storage room. Details of the building model parameters in Table 3.

The Thermal Characteristics of Exterior Protected Construction

"Civil building thermal design specifications"GB50176-93 provides: When building is set the central heating equipment construction, the envelope of the insulation performance should meet the minimum requirements of thermal resistance of the envelope-$R_{0,min}$. After calculation, the minimum heat transfer resistance of the external wall is 0.328m^2·K/W, flat roof is 0.492m^2·K/W. “Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone”JGJ134-2001 stipulates that the heat transfer coefficient of the roof, the external wall, the partition wall and the household door should respectively no exceed 1.0W/(m^2·K), 1.5W/(m^2·K), 2.0W/(m^2·K), 3.0 W/(m2·K). And the thermal inertness index D of the roof and exterior walls should exceed 3.0.

Table 2. The structure of roof model and parameters of each layer.

<table>
<tr><th>Structural layer</th><th>Name</th><th>Thickness（mm）</th><th>Density（Kg/m^3）</th><th>Specific heat KJ/(Kg·K)</th><th>Thermal conductivity W/(m·K)</th><th>Heat transfer coefficient W/（m^2·K）</th><th>Resistance of heat transfer（m^2·K/W）</th></tr>
<tr><td>Planting soil</td><td>Inorganic planting soil</td><td>800</td><td>550</td><td>1.01</td><td>0.76</td><td rowspan="6">0.664</td><td rowspan="6">1.507</td></tr>
<tr><td>filtration layer</td><td>non-woven fabrics</td><td>2</td><td colspan="3">-</td></tr>
<tr><td>Drainage (water-storing) layer</td><td>Deep concavo-convex drainage（water storing slab</td><td>1</td><td colspan="3">-</td></tr>
<tr><td>Protective layer</td><td>fine aggregate concrete</td><td>40</td><td>2100</td><td>0.92</td><td>1.28</td></tr>
<tr><td>Insulated layer</td><td>PE film</td><td>0.4</td><td colspan="3">-</td></tr>
<tr><td>Root resistance isolated</td><td>Plastic modified asphalt waterproof roll</td><td>4</td><td>900</td><td>1.60</td><td>0.23</td></tr>
</table>

layer							
leveling blanket	1：3cement mortar	20	1800	1.05	0.93		
Find the slope layer	LC5.0light aggregate concrete	30	1300	1.05	0.53		
Reinforced concrete roof slab	Steel reinforced concrete	200	2500	0.92	1.74		
	Cement mortar	20	1800	1.05	0.93		
	Lime gypsum mortar	20	1500	1.05	0.76		

Table 3. The parameters of building model.

Parameters	Value
Gross area（m^2）	198.72
Monolayer area （m^2）	99.36
Floor height（m）	3
shape factor（m^{-1}）	0.42
Window area（m^2）	26.46
Area ratio of window to wall	0.1
Door area（m^2）	37.36
permeability（ac/h）	0.5

In accordance with the above specifications, set up the following building envelope model, see Table 4. envelope structure parameters table.

Indoor Heat Source Settings

Indoor heat sources include indoor human activities, heat dissipation by lighting, heat dissipation by residential equipment. In summer, the heat generated by the indoor heat sources increase the heat of the room and increase the air conditioning cooling load. When setting up the building model, the indoor heat source is based on the model size, the number of people designed, the standard and the book: "Architectural Lighting Design Standard"GB50034-2013, "Civil Building Electrical Design Standard", and “Building Physics” [4]. The density of the personnel in the model, the lighting power, the equipment power and the corresponding schedule are described below.

The Density of the Personnel, the Lighting Power and the Equipment Power. According to the designed number of occupants and the construction area, the value of residential building staff density is 0.02 people/m^2. The value of personnel heat according to the function of different rooms and the human metabolic calorie generation scale in the standard value. The standard thermal resistance of the general hot day clothing (short skirt, shorts pants, open collar shirt, sock and sandals) is 0.3. The power density of the equipment is calculated according to the equipment and power of the general room. Refer to architectural lighting design standards GB50034-2013, the current value of lighting power density is 7W/m^2.

The Time Schedule of the Activities of Occupants and Equipment. This thesis based on the general family schedule in Wuhan to set the housing model which includes the parameters of the staff at room rate, lighting switch time and equipment utilization. As this thesis simulates the summer(July 1-July 31)air conditioning load, it is assumed that two adults go out to work every day, working hours from Monday to Friday, every day 8:00-18:00. The rest of the occupants all day at home, and they get up 8:00 am in the morning and go to bed at 10:30 pm. Ignore the possession of the toilet, storage room, staircase.

The Operative Model of Air-conditioning

Residential building set the split air-cooled unit for summer cooling and winter heating. This thesis according to the "indoor air quality standards" to set air conditioning system operating mode, specifically in Table 5, the regional operating time according to the regional personnel. Kitchen, storage room, staircase, walkway, bathroom do not set air conditioning.

Analysis of Simulative Result

The above model data are set into the simulation software-Design Builder, and the meteorological data are set as the meteorological data of Wuhan area of China Standard Meteorological Database (CSWD). Operating the simulation program of Wuhan from July 1 to July 31 for air conditioning and refrigeration design. This paper analyzes the summer air-conditioning cold load, the summer heat gain of the roof and the relationship between leaf area index, leaf solar radiation reflectivity, and summer roof heat, summer air conditioning load.

Table 4. The parameters of exterior protected construction.

Position	The name of materials（from outside to inside, from top to bottom）	Thickness（mm）	Density（Kg/m^3）	Specific heat KJ/(Kg·K)	Thermal conductivity W/(m·K)	Heat transfer coefficientW/（m^2·K）	Resistance of heat transfer（m^2·K/W）
Exterior wall	ceramic tile	8	2300	0.84	1.3	0.896	1.117
	Cement mortar	20	1800	1.05	0.93		
	EPS	25	30	1.386	0.042		
	the tile sintered from shale	240	1800	1.05	0.87		
	Cement mortar	20	1800	1.05	0.93		
	Lime gypsum mortar	20	1500	1.05	0.76		
Interior wall	Lime gypsum mortar	20	1500	1.05	0.76	1.584	0.632
	Cement mortar	20	1800	1.05	0.93		
	the tile sintered from shale	240	1800	1.05	0.87		
	Cement mortar	20	1800	1.05	0.93		
	Lime gypsum mortar	20	1500	1.05	0.76		
ground	ceramic tile	10	2300	0.84	1.3	-	-
	Cement mortar	35	1800	1.05	0.93		
	C15 concrete cushion	100	2100	0.92	1.28		
	packed soil	-					
floor	ceramic tile	10	2300	0.84	1.3	2.314	0.432
	Cement mortar	35	1800	1.05	0.93		
	steel reinforced concrete	120	2500	0.92	1.74		
	Cement mortar	20	1800	1.05	0.93		
	Lime gypsum mortar	20	1500	1.05	0.76		
lintel	reinforced brick	The same as exterior and interior wall					
ring beam	steel reinforced concrete	The same as the wall	2500	0.92	1.74	2.767	0.361
window	Aluminum alloy single glazing	5	2500	0.84	0.76	5.7	-

Table 5. The operating model of air-condition system.

Type of equipment	Gree KFR-26GW/K(2658)B2-HN5 split air conditioner
setting temperature	26℃
energy efficiency ratio	2.79
relative humidity	50%
air change flow （m^3/h·人）	30

Roof Thermal Gain in Summer and Cooling Load in Summer

The average daily heat gains of the roof of the seven different plants were simulated in th e simulated time period: Magnolia grandiflora 0.41178KW; Red maple 0.4326KW; Plum 0.3 864KW; Hibiscus mutabilis 0.4656KW; Fatsia japonica 0.4097KW; China rose 0.4303KW; Sedum lineare 0.4341KW.

The average daily building cooling load during the simulation period is: Magnolia grandiflora 14.9239KW; Red maple 14.9197KW; Plum 14.8368KW; Hibiscus mutabilis 15.0358KW; Fatsia japonica 14.9129KW; China rose 14.9258KW; Sedum lineare 14.9413KW.

Analysis of Variable Correlation

Based on the above experimental results, the leaf area index of different plants, the thermal reflectivity of solar radiation and the corresponding summer heat gain of roof, summer air conditioning load are shown in Table 6.

Compared with the data in the table, we can see that the solar radiation heat reflectivity of Plum(0.279) is the same as that of the Fatsia japonica, but the leaf area index of Plu m is higher (3.52), while the heat gain of roof and air conditioning cooling load of Plum are lower than that of Fatsia japonica. Red maple and China rose are almost equal to the leaf area index, but the red maple solar radiation heat reflectivity lower than the China ros e, heat gain of roof of Red maple is higher than the China rose. From the above comparis on, it can be concluded that there is a negative correlation between the leaf area index an d the heat gain of roof, and the thermal reflectivity of the solar radiation of the plant leav es is negatively correlated with the heat gain of roof.

Table 6. The parameters of plants and the result of experiment.

	Magnolia grandiflora	Red Maple	Plum	Hibiscus mutabilis	Fatsia japonica	China rose	Sedum lineare
LAI	3.15	2.42	3.52	1.85	3.07	2.41	2.9
The thermal reflectivity of solar radiation	0.245	0.233	0.279	0.262	0.279	0.289	0.32
Heat gain of roof（KW）	0.41178	0.4326	0.3864	0.4656	0.4097	0.4303	0.4341
Air conditioning load （KW）	14.9239	14.9197	14.8368	15.0358	14.9129	14.9258	14.9413

Conclusion

From the results of the software simulation, it can be seen that the best energy saving and cooling plants in the seven plants is Plum, which is due to its larger plant leaf area index(3.52) and the larger solar radiation heat reflection coefficient(0.279). In the analysis of the three shrubs, Fatsia japonica has the best summer energy-saving effect, so in the study of nine combinations in Wuhan area for the "garden-style" roof plants, the combination of plum-Fatsia japonica-Sedum lineare has the best summer energy saving effect.

Although the characteristics of seven different plants in Wuhan area and plant parameters were studied in this thesis, the energy saving and cooling characteristics of these plants as green roofs were simulated. However, the selection of plants is far more than seven kinds of plants in this paper, the research of this thesis is only the tip of the iceberg, and future research in this area can be more in-depth comprehensive study. And the technology roadmap of studying the energy efficiency of different roof plants can be used: the study of plant growth characteristics and the initial selection-the study of plant leaf area index-the study of the plant leaf biochemical parameters-using prospect model to calculate the optical properties of the blade-using Design Builder simulation analysis.

Based on many merits of green roof and the national "ecological civilization construction "strategic decision, the national development of green roof, green building is imperative. Roof greening in China started late, roof greening technology and experience gap with the developed countries is still great. We should learn from the advanced experience of foreign countries, combined with the actual situation in China, strengthen the process of greening the roof, optimize the selection and setting of vegetation, improve the planting technology and the green roof construction technology, seriously solve the problems of roof greening, let China's green roof has a better development and play a greater role in Chinese ecological civilization construction.

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