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Effect of building roof insulation measures on indoor cooling and energy saving in rural areas in Chongqing

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Abstract

The big temperature differences between day and night in rural areas provided a good climate resource for the utilization of night ventilation. Night ventilation as a passive cooling measure has an important significance, which is of great potential for rural buildings' sustainable renovation. But the existing rural residential roof insulation is poor, it is the weak link of indoor cooling and energy saving. In this paper, the interest is focused on the energy consumption and indoor cooling of the thermal insulation roofs for intermittent air conditioning buildings. The indoor temperature and energy consumption of the typical rural residence in Chongqing were compared and analyzed by using DesignBuilder software to simulate different thermal insulation roofs. The results show that the energy saving rate value of light insulation roofing on the top floor can be increased to 40%-50% with the combination of night time ventilation and intermittent air conditioning to cooling. For heavy insulation roofing, the reasonable thickness of aerated concrete layer for the roof is 100-150mm, the heat transfer coefficient of roof is between 0.94 W / (m· K) and 1.25 W / (m· K). And the energy saving rate limit value of the aerated concrete roof is estimated below 40%.

Keywords: Rural building; Intermittent air conditioning; Insulation roof; Simulation research

1. Introduction

During the last few years, guided by the national policies, the housing problems of the farmer have been basically solved, but also higher demand of the indoor thermal environment has been put forward. It directly leads to the

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change of energy structure in rural areas, and the proportion of non-renewable energy increases gradually. From the economic point of view, combined with the rural residential has a good micro environment, passive technology is easier to implement. So it should make use of the local climate as much as possible, and find solutions for rural residential housing to decrease energy consumption and to improve the indoor thermal comfort to meet the demand of user。

Compared with other building envelope, the surface temperature of the roof is the highest, and its heat transfer is maximum in summer, so the rural residential roof is the key point of improving the indoor thermal environment [1].According to the existing research, the thermal insulation roof is a cheap passive strategy in hot climates. It can reduce the heat gain and improve the indoor thermal environment, and is often identified as a valuable strategy for making buildings more sustainable [2, 3].

According to the survey of rural areas near Chongqing, there was more than 60% of the rural residential installation of air conditioning [4]. Therefore, the roof has also become an important part of the study of rural building energy conservation [5]. In "Design standard for energy efficiency of rural residential buildings" [6], the thermal performance of building envelope is specified in detail. Limit value of Heat transfer coefficient of the roof is 0.8 ~ 1.0 W/ (m K), and it need to take thermal insulation measures on roof. According to the living habits of rural residents, they are more accustomed to use natural ventilation or other passive ways to lower temperature. When the outdoor weather is too hot, they will consider to open air conditioning and combine with night ventilation to reduce the indoor temperature. Then, the effect of intermittent air conditioning energy saving of the roof which using the insulation measures is worthy of further study.

This paper is based on the above analyses, a new cooling and energy saving scheme has been proposed to improve the indoor thermal environment by combining intermittent air conditioning with natural-night ventilation. And different forms of thermal insulation roof are simulated using DesignBuilder software to research its cooling effect and energy saving effect in summer.

Nomenclature

Tin	Temperature in indoor
Tout	Temperature in outdoor
D	Thickness of insulation layer and aerated concrete
U	Heat transfer coefficients of roof
E	Total cooling energy consumption
φ	The energy saving rate of the roof compared to existing roof
Effective time	the actual usage time of the room
Free time	the rest of the Effective time

2. Method

2.1. Building model

A simplified building model of 2-storey residential building in rural areas was built in DesignBuilder software, diagram of model as depicted in Fig. 1. And the interest is focused on temperature of the room under roof. The building is in a village in Chongqing, south-facing and on a flat ground, no major obstacles affecting the construction of ventilation and sunshine etc. Construction of various parts of the building model was reference to the actual situation of rural residential building in Chongqing. Exterior wall is a solid brick wall, the heat transfer coefficient is 2.17 W / (m, K); Windows is single-layer glass windows, the heat transfer coefficient is 4.7 w / (m, K);The roof is reinforced concrete flat roof, the heat transfer coefficient is 3.97 W/ (m K).

The common thermal insulation measures taken on the roof are used for thermal insulation, so the insulation layer（ Light roof） or aerated concrete layer （heavy roof） is added to the roof of the building model to obtain the thermal insulation roof. Heat transfer coefficients light roof and heavy roof is 0.26 ~ 1.389 W/ (m K) and 0.629 ~ 1.863 W/ (m K). Roof structures as depicted in Fig. 2.

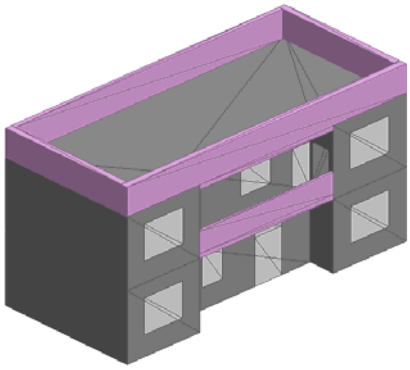

Fig. 1. Diagram of model.

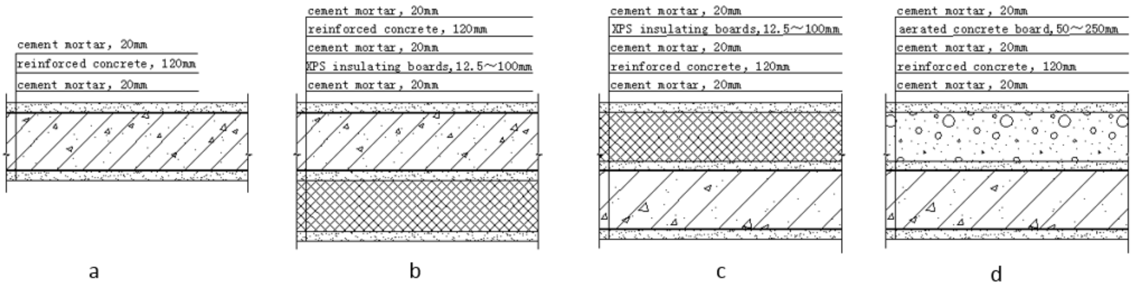

Fig. 2. (a) Contrast roof; (b) Light insulation roofing for inside; (c) Light insulation roofing for outside; (d) Heavy insulation roofing.

2.2. Simulation Settings

In rural areas, people prefer staying at the first floor of their houses in the daytime, because the room temperature on the first floor would be lower than that on the top floor room in summer. According to the living habits of rural residents, most of the room on top floor only has a bedroom for sleep with a lower rate of use, so the comfort of the bedroom on top floor at night is more important than the other time. In summer, the day is long and the night is short, farmers have been accustomed to go out very early, and come back until the evening. Therefore, the time to use the bedroom can be set to 22 PM to 7 AM.

According to the above analyses, the actual usage time of the room is defined as "Effective time", and the rest of the time is defined as "Free time". The average temperature and the maximum temperature on the effective time are mainly concerned for the thermal environment in the room. In the typical meteorological year of Chongqing, and weather data of typical days in summer was chosen as the simulation of climatic conditions. The daily mean air temperature is 31.6℃, and the maximum temperature is 37.7℃. Temperature for typical days as depicted in Fig. 3. According to “Design standard for energy efficiency of rural residential buildings” in China, indoor temperature below 30℃ is a comfortable for indoor thermal environment in summer. Therefore, in the typical days, the room can use natural ventilation to satisfy the demand of indoor thermal environment at night and in the morning, but in the afternoon, it needs to open the air conditioning to achieve the comfort temperature. So in typical days, the cooling and energy saving of the room should be combined with the use of natural ventilation and intermittent air conditioning.

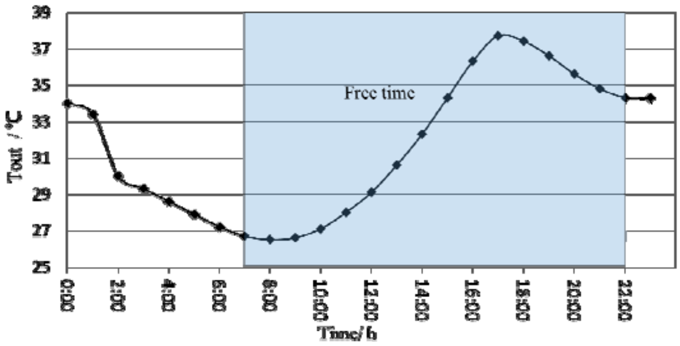

Fig. 3. Temperature for typical days.

In the intermittent air conditioning conditions, the opening time of the air conditioning in the effective time is 22 PM to 2 AM . After closing the air conditioning, opened the windows for ventilation when the indoor temperature was higher than the outdoor temperature. For only from the point of view of energy conservation, the time of turn off air conditioning and open window to ventilation is selected to meet the principle which is indoor temperature of not more than 30℃ in effective time and the minimum energy consumption. During the free time, opened the windows to ventilation in the morning, and closed the windows at noon to avoid outdoor high temperature air into the room and lead to high energy consumption of air conditioning.

In the effective time, indoor heat gain is 4.3 W/㎡, and the set-point temperature for the intermittent air-conditioned cooled room is 26℃. The model infiltration of the building is set to 1 ac /h, no internal heat loads in the room.

3. Result and analyses

3.1. Light insulation roofing

In the condition of intermittent air conditioning, the indoor temperature of the existing roof reaches to a comfortable temperature which needs to open air conditioning 3.5 hours, the total cooling energy consumption is 33.45 kWh. After adding the thermal insulation layer, the time to turn on air conditioning is reduced, and the energy consumption is reduced. Indoor temperature distribution of inside insulation and outside insulation with different thickness is shown in Fig.4(a) and Fig.4(b). In the effective time, the indoor temperature is affected by the change of natural wind speed, which cause the rise and fall of temperature between 2 AM and 8 AM, but the temperature is below 30℃, the indoor thermal environment is comfortable. After closing the window at 12 AM, the indoor temperature of the existing roof quickly became larger, but the thermal insulation roof changed little. Table 1 shows the cooling energy consumption of air conditioning in inside insulation and outside insulation of the different thickness for insulation layer, it can be seen that the air conditioning energy consumption decreases with the increase of the thickness of the insulation layer.

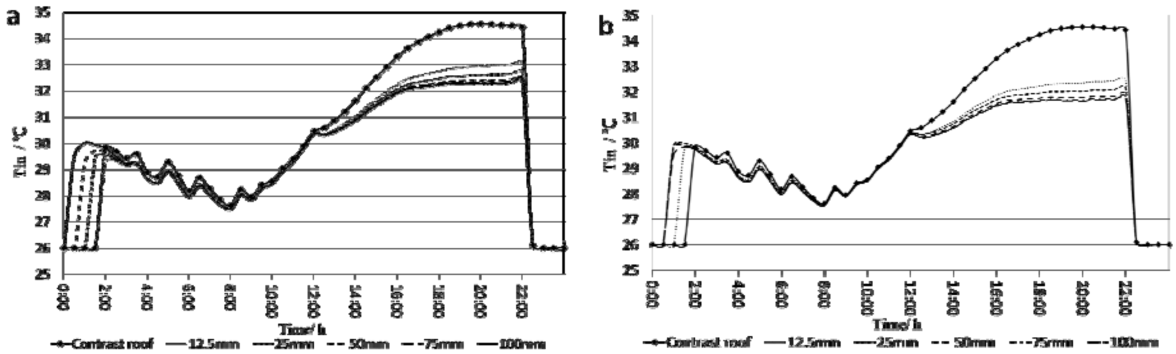

Fig. 4. Indoor hourly temperature for different insulation layer of insulation roof, (a) Inside insulation roof; (b) Outside insulation roof.

Table 1. The cooling energy consumption of air conditioning in inside insulation and outside insulation of the different thickness for insulation layer.

D (mm)	0	12.5	25	50	75	100
U（W/（㎡·K））	3.66	1.39	0.86	0.49	0.40	0.26
Ein （kWh）	33.45	28.16	24.39	20.86	17.35	17.25
Eout（kWh）	33.45	25.52	21.37	10.77	20.55	20.43

The energy saving rate of the roof with different insulation layer thickness compared to the existing roof as depicted in Fig.5, When the insulation layer thickness is less than 50mm, the heat transfer coefficient of roof is less than 0.49 W / (m, K), the relative energy saving rate of outside insulation roof is greater than the inside insulation roof. When the thickness increases to 50mm, the energy consumption of the two schemes is almost equal, which are 20.86 kWh and 20.77 kWh respectively, and the relative energy saving rate is 37.63% and 37.9%; When the thickness increases to 75mm, the relative energy saving rate of the inside insulation roof is greater than the outside insulation roof, which are 17.35 kWh and 20.55 kWh respectively, and the relative energy saving rates are 48.13% and 38.56%.

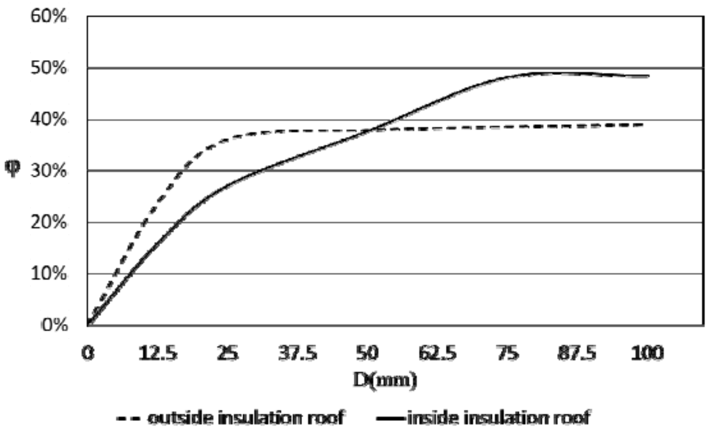

Fig. 5.The relative energy saving rate of the inside insulation roof.

For outside insulation roof, when the insulation layer thickness is less than 25mm, the heat transfer coefficient of roof is less than 0.86 W / (m· K),the change of energy saving rate is sensitive with the increase of insulation layer thickness. And then, The change of energy saving rate is very small with the increase of insulation layer thickness, from 25 mm to 100 mm, the relative energy saving rate is only increased by 2.81%. And the energy saving rate limit value estimated is 40%; But for inside insulation roof, when the insulation layer thickness is less than 75 mm, the heat transfer coefficient of roof is less than 0.40 W / (m· K), the change of energy saving rate is sensitive with the increase of insulation layer thickness. The energy saving rate is not as well as outside insulation when the thickness is less than 50 mm, but the energy efficiency is further improved when the insulation layer is greater than 50 mm. When thickness exceeds 75 mm, the change of energy saving rate is very small with the increase of insulation layer thickness, it gradually tends to be stable, and the energy saving rate limit value estimated is 50%.

From the above can be known, that if the scheme selection is outside insulation roof, the thickness of the 25mm is economical and reasonable; But for inside insulation roof, 75mm is better, and the energy saving rate limit value can be increased to about 50%. And from the aspect of energy conservation, inside insulation roof with 75mm XPS insulation board is more appropriate, if Consider the question of economics, outside insulation roof with 25mm XPS insulation board is better.

3.2. Heavy insulation roofing

Indoor temperature distribution of heavy insulation with different aerated concrete thickness is shown in Fig.6. In the effective time, the temperature is below 30℃, it can be considered that the indoor thermal environment is comfortable.

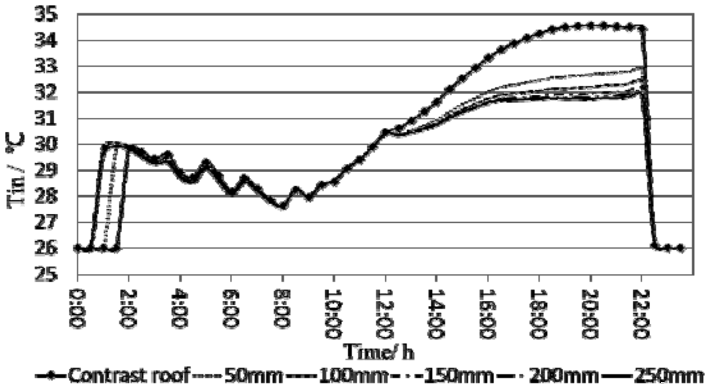

Fig. 6. Indoor hourly temperature for different aerated concrete layer of roof.

From Fig.7(a), with the increase of the thickness of the aerated concrete, the heat transfer coefficient of the roof is reduced, and the energy consumption is the air conditioner is reduced. When the thickness of less than 100mm, the air conditioning energy consumption is decline greater with the thickness increase, and the thickness is increased to 100mm, the energy consumption from 33.45 kWh dropped to 21.97kWh, and energy saving rate is 34.31%. And then, the change of energy saving rate is small with the increase of thickness.

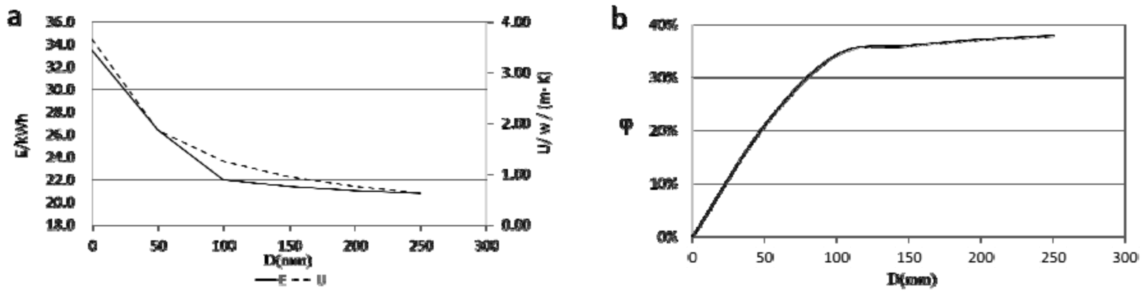

Fig. 7. (a) U and E for the roof with different thickness of aerated concrete; (b) φ for the roof with different thickness of aerated concrete.

From Fig.7, the reasonable thickness of aerated concrete layer for the roof is 100-150mm, the heat transfer coefficient of roof is between 0.94 w / (m· K) and 1.25 w / (m· K). The energy saving rate limit value of the aerated concrete roof is estimated below 40%.

4. Conclusion

In this paper, the interest is focused on the rural residential in Chongqing, Considering the living habits of rural residents, a new cooling and energy saving scheme which is used to improve the indoor thermal environment by combining intermittent air conditioning with natural-night ventilation has been proposed. And using DesignBuilder software simulate indoor thermal environment in different forms of thermal insulation roof, to research its cooling effect and energy saving effect in summer. The conclusions obtained are as follows.

1. For outside insulation roof of light insulation roofing, when the heat transfer coefficient of roof is less than 0.86 w / (m • K), the change of energy saving rate is sensitive with the increase of insulation layer's thickness. And then, the change of energy saving rate is very small with the increase of insulation layer's thickness. And the energy saving rate limit value estimated is 40%; But for inside insulation roof, when the heat transfer coefficient of roof is greater than 0.40 w / (m· K), the change of energy saving rate is sensitive with the increase of insulation layer's thickness. When the heat transfer coefficient of roof is less than 0.40 w / (m· K), the change of energy saving rate is very small with the decrease of the heat transfer coefficient of roof , it gradually tends to be stable, And the energy saving rate limit value estimated is 50%. When heat transfer coefficient is greater than 0.49, the energy saving rate of inside insulation roof is lower than the outside insulation roof, but when the heat transfer coefficient continues to decrease, the energy saving rate is higher than the outside insulation roof.

2. For heavy insulation roofing, the air conditioning energy consumption is decline greater with the thickness increase when the aerated concrete layer thickness is less than 100mm, and the thickness is increased to 100mm, the energy consumption from 33.45 kWh dropped to 21.97kWh. And then, the change of energy saving rate is small with the increase of thickness. The reasonable thickness of aerated concrete layer for the roof is 100-150mm, the heat transfer coefficient of roof is between 0.94 W / (m· K) and 1.25 W / (m· K). Energy saving rate limit value of the aerated concrete roof is estimated below 40%.

Acknowledgements

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