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Study on the Heating Methods of Rural Residential Building in Different Thermal Zones in Northern China

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Abstract

The indoor thermal environment of the traditional Kang building is poor. The different thermal zones differ quite a bit in the heat supply. Thus, the heating methods applied to the different thermal zones are also different. The heating methods and the biomass fuel mass, which were applicable to the different thermal zones, were studied. The dynamic heating load of the traditional Kang building in different thermal zones was calculated to provide the basis for the heating methods analysis. The results showed that the traditional Kang building cannot meet the heat demand in the severe cold and cold zones most. Thus, the transformation of heating method can reduce the auxiliary heat supply by 90% compared with the traditional Kang. The applicable heating method in different thermal zones was determined. The analysis can not only ensure the indoor thermal comfort, but also avoid the energy waste of the unadvisable heating method. The research results provide the basis for the rural households to select the appropriate heating method.

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Keywords: Chinese kang.; Dynamic heating load; Energy conservation; Heating methods

1. Introduction

Recently, the heating energy consumption of the rural house has already been to 100 million tce in northern China. The heating energy consumption accounted for 56% of the domestic energy [1]. Thus, reducing the heating energy consumption is the currently research field based on the indoor thermal comfort. The proportion of the Kang user has beyond 50%. However, some researchers showed that the indoor air temperature could only be maintained at 10 °C

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in the function of the single elevated Kang [2]. Hence, some auxiliary heating measure should be adopted to
guarantee the indoor thermal comfort. So, the heating load law of the traditional Kang building should be studied
deeply to extend the heating methods, which utilize the renewable energy as the heating source, to decrease the
heating energy consumption.

Currently, the thermal performance and the indoor thermal environment of several heating methods have received
much attention in recent years. There are many researchers focusing on the optimization and heating effect of these
heating methods in Chinese rural areas. Chen B showed that the Kang coupled with the passive solar-collected wall
can improve the indoor thermal environment [3]. Zhao Y showed that the hot-wall Kang possessed the great heat
supply [4]. Zhuang Z studied the contribution of the Kang to reduce the building heating load [5]. Ren W simulated
the heating load and the energy consumption of the rural house by Dest and TRANSYS [6]. However, it has been
hard to find the research about the applicable heating methods for different thermal zones in Chinese rural areas.

The rural areas have many heating methods, which possess the different extents heating quantity. Therefore, when
the heating method, which has a larger heating capacity, is applied to the zone which has the higher outdoor
temperature, the indoor air temperature may have the possibility of overheating. Nevertheless, most households
don’t comprehend the heating supply law of all kinds of heating methods. So, the unsuitable heating methods were
applied aimlessly and result in the high indoor temperature and the waste of energy. The appropriate heating
methods and the biomass material mass were proposed in different thermal zones to provide the basis for the rural
households to select the proper heating method.

2. Methods

2.1. Building parameters

The traditional Kang buildings were investigated through some literatures [7-8]. The research results showed that
the 49mm brick wall with double plaster is widely applied to the severe cold zone and the 37mm brick wall with
double plaster is widely applied to the cold zone. The roof type contains flat and sloping roof and the south window
always has large area. The size of room and Kang in the traditional Kang building are respectively 4.5m \( \times \) 3m \( \times \) 3m
(length \( \times \) width \( \times \) height) and 3m \( \times \) 2m. In addition, the size of south window and the door are 2m \( \times \) 1.8m and 1.2m
\( \times \) 2.0m, respectively. The parameters of the building envelope were shown in Table1.

<table>
<thead>
<tr>
<th>Building envelope</th>
<th>Zone</th>
<th>Material</th>
<th>Heat transfer coefficient W/(m(^2)·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall</td>
<td>Severe cold zone</td>
<td>The 49 brick wall with double plaster</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Cold zone</td>
<td>The 37 brick wall with double plaster</td>
<td>1.53</td>
</tr>
<tr>
<td>Internal wall</td>
<td>------</td>
<td>The 12 brick wall with double plaster</td>
<td>2.004</td>
</tr>
<tr>
<td>Roof</td>
<td>------</td>
<td>20mm cast in place concrete+80mm slab+20mm</td>
<td>2.461</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mortar</td>
<td></td>
</tr>
<tr>
<td>Window</td>
<td>Severe cold zone</td>
<td>Plastic steel single layer glass</td>
<td>4.7</td>
</tr>
<tr>
<td>Door</td>
<td>Cold zone</td>
<td>Alloy single layer glass</td>
<td>6.4</td>
</tr>
<tr>
<td>Floor</td>
<td></td>
<td>Wooden door</td>
<td>3.663</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25mm finish+20mm cement mortar +100mm</td>
<td>1.267</td>
</tr>
<tr>
<td></td>
<td></td>
<td>concrete+500mm rammed earth</td>
<td></td>
</tr>
</tbody>
</table>

Five representative cities including Hailar, Harbin, Shenyang, Dalian and Jinan were selected in the severe cold
A zone, severe cold B zone, severe cold C zone, cold A and B zone respectively based on the heating degree days
HDD18 and cooling degree days CDD26 of the main city shown in the severe cold and cold area residential building
energy efficiency design standards [9]. The rural residential building energy conservation design standards stipulate
that the indoor calculate temperature should be 14\(^\circ\)C [10].
2.2. Simulation tool

Dest was utilized to simulate the heating load and the indoor air temperature. This simulation tool was originally developed by Tsinghua University. In the simulation environment, corresponding heat balance equations are solved by using the state space solution method [11]. The researchers adopted the analytical tests, inter-model comparisons and empirical validation to compare with the simulation results of Dest [12]. The results illustrated that the simulation results of Dest possessed the accuracy and reliability. Thus, the simulation tool can apply to analyze the heating load and indoor air temperature of the rural house in different heating methods.

3. Results

3.1. Heating load of Kang building in different thermal zones

The dynamic heating load of the traditional Kang building in the five cities previously mentioned were simulated by Dest based on considering the existing heat gain of the Kang building sufficiently, which referred to the heat release of Kang in the condition of 6.5kg corncobs in the literature [13]. In addition, the dynamic heating load is considered to be the auxiliary heating needed in the single Kang effect. Thus, the dynamic heating load and the indoor air temperature from January 18th to 19th were shown in Figure 1.

![Fig. 1. Heating load and indoor temperature of Kang room in different thermal zones (a) heating load; (b) indoor air temperature](image)

The law of the heating load in different thermal zones presented differently. In the severe cold zone, the indoor air temperature was low to 5°C with the single Kang. Especially, the indoor temperature was below 0°C in the severe cold A zone and B zone. Thus, the heating method of single Kang is insatiable for the indoor thermal comfort in severe cold zone. For the cold zone, the indoor air temperature was improved, but remained below 14°C. Because of the different outdoor climate, the advisable heating method should be proposed to improve the indoor thermal environment and reduce the commercial energy consumption. Hence, the proper heating methods in different thermal zones were analyzed following the next section.

3.2. Appropriate heating methods in different thermal zones

The heating methods in severe cold and cold zone contain the traditional Kang, hot-wall Kang, burning cave, the hot water heating system driven by the stove combined with the heat collector, the passive solar house, the solar Kang, the solar energy floor radiant heating and so on. However, the biomass energy is applied extensively. The heating methods using the biomass energy were analyzed because the solar energy is susceptible to the weather and
has the high investment. The heat of these heating methods was referred to some literatures, which studied the heat variation already.

(1) Severe cold A zone

Hailar is the part of the severe cold A zone, which has the lowest outdoor temperature among the five cities. Thus, the hot-wall Kang and the traditional Kang coupled with burning cave were analyzed to determine whether the two heating methods were applied to the severe cold A zone. The hot-wall Kang possesses the great heat release when the stove and hot-wall operate at the same time. What’s more, the hot-wall Kang can adopt the single stove operation and single hot-wall operation. Two operation conditions were set as follows: 1) burning twice a day and the stove and hot-wall operate together at 7:00 and 19:00; 2) the stove and hot-wall operate together at 6:00, the single stove operates at 13:00 and the stove and hot-wall operate together at 20:00. The biomass material mass of the hot-wall Kang is 2kg corncobs and 5kg wood in every padding. The traditional Kang coupled with burning cave also owns great heat. The area of the burning cave is 7.5m² by matching the Kang room size.

The results shown in Figure 2b) illustrated that the indoor air temperature could not reach up to 14~18°C in the action of hot-wall Kang in condition 1. However, the indoor air temperature has been improved compared with the single Kang heating method. The indoor air temperature in condition 2 was higher than in condition 1 by the reason of the more feeding time. In addition, the proportions beyond 14°C and 18°C were 90.28% and 25% respectively. So, the hot-wall Kang can meet the indoor thermal comfort in condition 2. Figure 2a) showed that the heating load of the hot-wall Kang in the condition 2 decreased by 97.33% compared with the traditional Kang heating method. In conclusion, the heating method of the hot-wall Kang is appropriate for the severe cold A zone in condition 2, while the heating method of the traditional Kang coupled with burning cave and hot-wall Kang in condition 1 should not be considered because of the uncomfortable indoor temperature at night.

![Fig. 2. Heating load and indoor temperature of two heating methods (a) heating load; (b) indoor air temperature](image)

(2) Severe cold B zone

The representative city of the severe cold B zone is Harbin, which need great heat supply as well. Thus, the hot-wall Kang in condition 1 and 2 and the traditional Kang coupled with burning cave were analyzed in this zone by the same approach. The results shown in figure 3 presented that the indoor air temperature difference between the maximum and minimum of the traditional Kang coupled with burning cave was less than the hot-wall Kang and the indoor air temperature can be remained at 12~15°C, which illustrated that the heating method of the traditional Kang coupled with burning cave can guarantee the better thermal stability and comfort. The indoor air temperature of the hot-wall Kang in condition 2 was all higher than 14°C. However, the minimum of the indoor air temperature of the hot-wall Kang in condition 1 was lower to 8°C. Therefore, the hot-wall Kang in condition 2 and the traditional Kang coupled with burning cave were suggested to be applied in this thermal zone.
(3) Severe cold C zone

The outdoor temperature of Shenyang, which belongs to the severe cold C zone, is higher than the severe cold A and B zone. The heating methods of the relatively less heat supply can be considered to analyze. Therefore, the hot-wall Kang in condition 1 and the traditional Kang coupled with burning cave were proposed to determine whether these heating methods were suitable. The indoor air temperature in different heating methods was shown in figure 4.

The results shown in figure 4 illustrated that the indoor air temperature of these heating methods satisfied the thermal comfort. However, when the hot-wall Kang in condition 1 and the traditional Kang coupled with 7.5m$^2$ burning cave were applied to the thermal zone, the indoor air temperature could reach up to 24°C, which is overheating for the rural households. The traditional Kang coupled with 5m$^2$ burning cave could conform to the thermal comfort range, which is 14~18°C. Thus, the traditional Kang coupled with 5m$^2$ burning cave was suggested to be applied in severe cold C zone.
(3) Cold A and B zone

The cold A and B zone have higher outdoor temperature than the severe cold zone. Thus, the hot-wall Kang in the condition of the biomass material mass mentioned previously is unsuitable for the cold A and B zone. The heating method of the relatively less heat supply should be selected. The heating methods of the traditional Kang coupled with radiator driven by the stove combined with heat collector and the traditional Kang coupled with 3m² burning cave were analyzed to gain the indoor air temperature and heating load.

In the cold A zone, the indoor air temperature reaching up to 14°C in the traditional Kang coupled with radiator driven by the stove combined with heat collector accounted for less shown in Figure 5a). The frequency of the range, which is less than 10°C, was 5.56% when the traditional Kang coupled with radiator driven by the stove combined with heat collector was applied, while the heating method of the traditional Kang coupled with burning cave was higher than 10°C. The reason was that the heat release of the radiator decreased when the stove stopped working at night. Consequently, the traditional Kang coupled with burning cave could guarantee the lower indoor air temperature fluctuation and the indoor air temperature was higher than 12°C, which ensured the indoor thermal comfort.

In the cold B zone, Jinan was selected to be the representative city. In Figure 5b), the results showed that the traditional Kang coupled with burning cave and radiator both can satisfy the thermal comfort. The two heating methods mentioned above allowed the less auxiliary heat compared with traditional Kang.

![Fig. 5. a) Frequency of the indoor temperature in different heating methods in Dalian; b) Indoor air temperature in different heating methods in Jinan](image)

4. Discussion

Through analyzing the heating methods in different thermal zones, the appropriate heating methods were determined. According to the indoor thermal comfort in rural areas, the heating method shouldn’t be utilized aimlessly. The greater heat supply allows the indoor overheating when the heating method is applied to the cold zone, which results in the waste of energy. However, the hot-wall Kang possessed the flexibility. For the severe cold C zone and cold zone, the indoor thermal comfort can achieve the requirement by reducing the fuel mass of the hot-wall Kang. Thus, the fuel mass in different methods in different thermal zones was calculated shown in Table 2.

Table 2 showed that the hot-wall Kang can be applied into all the zones. The fuel mass in severe cold zone were higher than the cold zone because the long heating period and great heat supply in severe cold zone. In the two heating methods of the severe cold B zone, C zone and cold zone, the biomass material mass of the hot-wall Kang and the traditional Kang coupled with radiator driven by the stove combined with heat collector were less than the traditional Kang coupled with burning cave. The reason is that the thermal efficiency of the traditional Kang coupled with the burning cave is lower than the other two heating methods mentioned above. Most notably, this is the first
study to our knowledge to investigate suitable heating methods in different thermal zones. The study can provide the basis for rural households to select the proper heating methods, which can ensure the indoor thermal comfort and reduce the energy consumption. Future work should extend other heating methods to provide more choice for rural households.

Table 2. Suitable heating methods and biomass material mass

<table>
<thead>
<tr>
<th>Thermal zone</th>
<th>Heating method</th>
<th>The fuel mass (kg/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Corn cobs</td>
</tr>
<tr>
<td>Severe cold A</td>
<td>Hot-wall Kang</td>
<td>8107</td>
</tr>
<tr>
<td>Severe cold B</td>
<td>Hot-wall Kang</td>
<td>5559</td>
</tr>
<tr>
<td></td>
<td>Traditional Kang coupled with 7.5m² burning cave</td>
<td>7089</td>
</tr>
<tr>
<td></td>
<td>Traditional Kang coupled with 5m² burning cave</td>
<td>4690</td>
</tr>
<tr>
<td>Severe cold C</td>
<td>Hot-wall Kang</td>
<td>2927</td>
</tr>
<tr>
<td></td>
<td>Traditional Kang coupled with 3m² burning cave</td>
<td>3714</td>
</tr>
<tr>
<td></td>
<td>Hot-wall Kang</td>
<td>2336</td>
</tr>
<tr>
<td></td>
<td>Traditional Kang coupled with the hot water system driven by the stove combined with heat collector</td>
<td>1440</td>
</tr>
<tr>
<td>Cold A</td>
<td>Traditional Kang coupled with 3m² burning cave</td>
<td>2972</td>
</tr>
<tr>
<td></td>
<td>Hot-wall Kang</td>
<td>1708</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusions

The suitable heating methods in different thermal zones were studied based on the heating load and indoor air temperature in the traditional Kang building. The concluded remarks of this study may be explained as follows:

(1) The existing heat gain of the traditional Kang building cannot meet the indoor thermal comfort both in severe cold and cold zone. The heating methods transformation should be adopted to guarantee the indoor thermal comfort and reduce the energy consumption.

(2) The suitable heating method in different thermal zones is discriminative. The auxiliary heat of the transformational heating methods can be reduced by 90% compared with the traditional Kang.

(3) The mass of the biomass materials in the heating methods of hot-wall Kang and the traditional Kang coupled with radiator driven by the stove combined with heat collector were less than the traditional Kang coupled with the burning cave. The hot-wall Kang can be applied to all the zones. The vast number of rural households can use the analysis to select the proper heating methods, which can meet the biomass materials mass and the indoor thermal comfort.

Acknowledgements

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