INVESTIGATION OF INDOOR THERMAL ENVIRONMENT IN A RURAL HOUSE IN DAQING

by

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Original scientific paper
https://doi.org/10.2298/TSCI170821061L

At present, the rural population of China is large. The rural population accounts for about 50% of the total population in Heilongjiang Province, which is located in cold region. The winter is cold in severe cold region, for example, the average outdoor temperature in winter is about –25 °C in Daqing which is located in Heilongjiang Province, the indoor residential thermal environment is poor, people living there are uncomfortable. The existing rural residential building was researched in Daqing of Heilongjiang and the study of the indoor thermal environment was carried out. In this paper, the numerical simulation method is used to study the changes of indoor temperature field before and after adopting the wall insulation of existing house. The results show that the thermal environment of the existing rural house without wall insulation can not satisfy the requirements of human comfort, and the bedroom temperature is about 15 °C, and the temperature of the entrance hall is about 11 °C. However, the insulation of the building envelope has an obvious effect on the indoor thermal environment, and the temperature of the bedroom and the entrance hall increase about 5 °C and 3 °C with wall insulation, respectively.

Key words*: cold area, rural residential, indoor thermal environment*

Introduction

Nowadays, the total population of China is beyond 1382.71 million, of which the rural population is about 589.73 million, accounting for about 2/5 of the total population. In the severe cold zone, the rural population in Heilongjiang Province is 16.68 million, accounting for about 1/2 of the total population of Heilongjiang. Based on the environment of severe cold zone which average temperature is about –25 °C in winter, the indoor thermal environment of the rural house is important. With the development of people's living and economic level, the indoor thermal environment of the rural house in Daqing has been difficult to achieve the requirement of the occupants. This trend improving the indoor thermal environment of rural area becomes an urgent problem. Therefore, the methods for improving the indoor thermal environment become necessary.

Jin *et al*. [1] analyzed the influencing factors of the indoor thermal environment of building in the rural area in winter, which is in the cold area, and proposed the range of the

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indoor comfort temperature about the rural area in winter, which is 15-18 °C. Zhen *et al*. [2] found that a good control of the factors which affected the indoor thermal environment could improve the indoor thermal environment effectively. Chen [3] studied the best orientation, and the relationship between the floor number and the heat consumption index in Urumqi area based on DeST software. Xue [4] investigated the indoor thermal environment by using FLUENT, and established the most appropriate form of the wall and the roof. Ma [5] measured thermal environment of the rural residential building in Shenyang, and got the relationship between the indoor thermal environment and the energy consumption of the building envelope. Fu [6] put forward the most effective opening ratio of the ventilation roof and the best thermal insulation of the roof structure. Georges *et al*. [7] measured and simulated a super-insulated building envelope, and found the temperature between each room was not very different, but the response of changing the temperature of each room was relatively slow. Orosa and Oliveira [8] studied the hot inertia building in Spain, and got the conclusion that it could reduce the consumption and improve comfort, and even replaced the HVAC system. Kim *et al*. [9] compared the indoor thermal environment of the mobile energy housing (MeSH) in winter and summer seasons and the energy consumption of existing temporary housing shelter houses and MeSH, which found that the MeSH was cool in summer and hot in winter and a 60% difference in energy demand between MeSH and existing temporary housing shelter houses. Couret *et al*. [10] studied daylight simulations in three different urban areas, and found the urban form generated from detached buildings separated by corridors was more appropriate for the warm and humid climate of Havana than the compact colonial urban model. Amr *et al*. [11] developed an integration of direct evaporative cooling tower with a solar chimney multi-zone thermal ventilation model. Simulation was done using commercial couple multi-zone air-flow under COMIS-TRNSYS software to assess natural ventilation and indoor thermal comfort. The findings show that the new integrated system interacts with the building envelope and weather conditions to achieve a decrease in indoor temperatures that reach 10 °C to 11.5 °C compared to outdoor temperatures. Taro *et al*. [12] developed a method for predicting temperatures at any point in a room with a small number of temperature sensors based on color rendering index (CRI), and examined the accuracy of the method by comparing the prediction with a coupled simulation of CFD and radiation. Yoshino *et al*. [13] investigated the indoor thermal environment in Harbin, Beijing, Xi'an, Shanghai, and Hong Kong of China. The results showed that the indoor thermal condition in heating usage zone is good, such as Harbin, Beijing, and Xi'an. The indoor thermal comfort is strongly affected by the outdoor climate in non-heating usage zone, such as Shanghai and Hong Kong. Georges and Skreiberg [14] developed a modelling procedure in order to investigate the indoor thermal environment generated by wood stoves in buildings. The experiments proved that the model gave a fair insight into the global thermal comfort. Yang *et al*. [15] analyzed the changes of thermal environment of a one-room system under various conditions. The thermal environment was measured in seven different households and the change of temperature and humidity was measured at different two locations. The results of this study were that the change of environment of the one-room system according to the indoor condition was not proper from the point of thermal comfort.

Although there are many studies on indoor thermal environment, most of them are mainly focused on urban construction, rural room with color steel, new room, *etc*. There is no simulation of the existing house whose material is clay. This paper put forward a rural house whose material is clay as a typical house and the indoor thermal environment of it is simulated with the CFD technique, which lays the foundation to improve the indoor thermal environment.

Physical model

Physical model of the existing rural house

The basic information of the existing rural house

The typical house is located in Xingshugang which is in Daqing, Heilongjiang of China. The physical diagram of the house and the schematic diagram of the building plan are shown in figs. 1 and 2, respectively. The form of windows and doors about this structure is provided in tab.1. The exterior size of the typical house is 8800 mm × 7800 mm × 3000 mm with the window of double frame and single skin, the doors and the flat roof which are made by wood. The thickness of the external wall is 400 mm and that is 150 mm about inner wall.

Figure 1. The physical diagram of the house

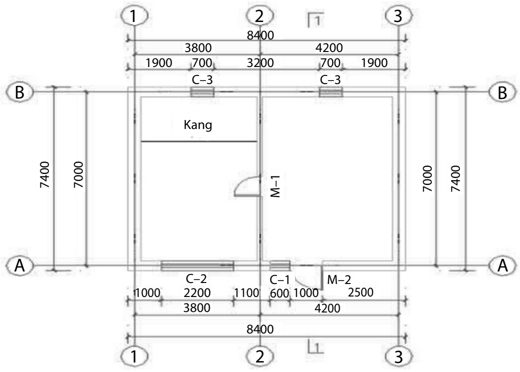

Figure 2. The schematic diagram of the house

Physical model

Physical model is shown in fig. 3, which established in accordance with the actual rural house. In the process of establishing the physical model, it is a certain degree of difficulty if considering each detail in the actual house. Therefore, the model is appropriately simplified and assumed as follows on the premise that the result has little impact.

– The interior is unattended.
– The door of the cold air intrusion, the window of the cold air infiltration, personnel activities, and other factors about the impact of air-flow are ignored. There is no other heat source device except Kang, which is especial thermal storage unit in the rural house in China.
– Heat conduction is converted into heat convective because the thickness of the envelope is ignored, the doors and windows are simulated as a wall.

The direction is defined: The X-axis is the width direction of the rural house. The Y-axis is

Table 1. The form of building windows and doors

Type	Model	Hole size	Quantity
Window	C-1	600 × 1600	1
	C-2	2200 × 1600	1
	C-3	700 × 1600	2
Door	M-1	800 × 2100	1
	M-2	1000 × 2500	1

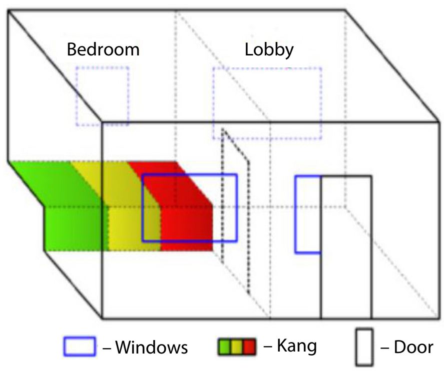

Figure 3. The physical model of the existing rural house

the length of the rural house. The Z-axis is the height of the rural house. The origin is located in the center of the room.

Physical model of the improving envelope rural house

The improvement of the envelope structure is mainly to add insulation material inside the envelope which is aimed at reducing the convective heat transfer coefficient. So the physical model is unchanged, except changing the physical model assumptions *the doors and windows are simulated as the wall* into *the doors and windows are simulated in accordance with the actual parameters.*

Mathematical model

Control equation

The simulation is simplified:
- the flow is at low velocity, 3-D, incompressible, consistent with the Boussinesq hypothesis,
- the thermal properties of the external walls and windows were unchanged, and
- the ground does not participate in heat transfer and set to adiabatic.

The governing equations for the indoor flow field are:

– Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

where u, v, and w are the velocity component of the fluid in direction of x, y, z, and ρ is the fluid density.

– Momentum equation:

$$\begin{gathered}\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho uu)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}=\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial u}{\partial z}\right)-\frac{\partial p}{\partial x}\\ \frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho vv)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}=\frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial v}{\partial z}\right)-\frac{\partial p}{\partial y}\\ \frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho wu)}{\partial x}+\frac{\partial(\rho wv)}{\partial y}+\frac{\partial(\rho ww)}{\partial z}=\frac{\partial}{\partial x}\left(\mu\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial z}\right)-\frac{\partial p}{\partial z}+\rho\beta(T_0-T)\mathrm{g}\end{gathered} \tag{2}$$

where p is the pressure, β – the thermal expansion coefficient, T_0 – the temperature of the reference point, g – the gravity acceleration in direction of z, $\beta(T_0 - T)$g – the floating force.

– Energy equation:

$$\frac{\partial(\rho T)}{\partial t}+\frac{\partial(\rho uT)}{\partial x}+\frac{\partial(\rho vT)}{\partial y}+\frac{\partial(\rho wT)}{\partial z}=\frac{\partial}{\partial x}\left(\frac{\kappa}{c_p}\frac{\partial T}{\partial x}\right)-\frac{\partial}{\partial y}\left(\frac{\kappa}{c_p}\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{\kappa}{c_p}\frac{\partial T}{\partial z}\right) \tag{3}$$

where κ is the thermal conductivity, c_p – the specific heat capacity.

– k-ε equation:

k equation:
$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\frac{\eta}{\sigma_k}-\frac{\partial k}{\partial x_j}\right]+P_k+G_k-\rho\varepsilon \tag{4}$$

ε equation:
$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho u_j\varepsilon)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\frac{\eta_t}{\sigma_\varepsilon}-\frac{\partial\varepsilon}{\partial x_j}\right]+\frac{\varepsilon}{k}+(c_1p_k+c_3G_k-c_2\rho\varepsilon) \tag{5}$$

where k is the turbulence kinetic energy, ε – the turbulent dissipation rate, P_k – the turbulent kinetic energy generated by the laminar velocity gradient, the expression is:

$$P_k = \eta_t \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{\partial u_i}{\partial x_j} \tag{6}$$

where G_k is the turbulence generated by buoyancy, the expression is:

$$G_k = \beta g_i \frac{\eta_t}{\sigma_T} \frac{\partial T}{\partial x_i} \qquad \eta_t = \frac{c_\mu \rho k^2}{\varepsilon} \tag{7}$$

where c_1, c_2, c_3, c_μ, σ_k, and σ_ε are the model constants which have already optimized for some kind of normative flow, their values are:

$$c_1 = 1.44 \quad c_2 = 1.9 \quad \sigma_k = 1.0 \quad \sigma_\varepsilon = 1.2 \quad c_3 = 1.0 \quad c_\mu = 0.09$$

Boundary conditions

Windows, the external walls, roof and doors: setting to the boundary conditions of the convective heat transfer. The thickness of the wall is not considered in this simulation, so the convection heat transfer coefficient of the outer surface and the thermal conductivity of the wall are regarded as the convective heat transfer coefficient of the inner surface. It is found that the equivalent method does not affect the distribution of the indoor flow field by the thermal resistance analysis method:

$$h = k = \frac{1}{\dfrac{1}{h_1} + \dfrac{\delta}{\lambda}} \qquad t = t_f \tag{8}$$

where h is the equivalent convection heat transfer coefficient of the inner surface, h_1 – the convective heat transfer coefficient of the exterior surface of the building envelope, λ – the thermal conductivity of exterior building envelope, δ – the thickness of building envelope, and t_f – the temperature of the exterior fluid.

Kang: the kang's surface is divided into three temperature regions which are set to the first category of boundary conditions, they are expressed:

$$\begin{aligned} t\big|_{x_1,y_1,z_1} = t_{w_1} \quad & (-200 \le x_1 \le -1400, \quad -3300 \le y_1 \le -1500, \quad z_1 = 700) \\ & (-1400 \le x_1 \le -200, \quad y_1 = -1500, \quad 700 \le z_1 \le 1500) \end{aligned} \tag{9}$$

$$\begin{aligned} t\big|_{x_2,y_2,z_2} = t_{w_2} \quad & (-2600 \le x_2 \le -1400, \quad -3300 \le y_2 \le -1500, \quad z_2 = 700) \\ & (-2600 \le x_2 \le -1400, \quad y_2 = -1500, \quad 700 \le z_2 \le 1500) \end{aligned} \tag{10}$$

$$\begin{aligned} t\big|_{x_3,y_3,z_3} = t_{w_3} \quad & (-3800 \le x_3 \le -2600, \quad -3300 \le y_3 \le -1500, \quad z_3 = 700) \\ & (-3800 \le x_3 \le -2600, \quad y_3 = -1500, \quad 700 \le z_3 \le 1500) \end{aligned} \tag{11}$$

Ground: this boundary condition set to adiabatic, meet:

$$\frac{\partial t}{\partial n}\Big|_s = 0 \tag{12}$$

where n is the meaning of direction.

Inner door, inner wall: the building envelope which in the house is set to couple:

$$T_{\mathrm{w}} = T_f \tag{13}$$

where T_w is the temperature of the wall and T_f – the temperature of the air near the wall.

Model validation

The Boussinesq assumption is used in natural convection of indoor air. Turbulence is described by using k-ε model. The numerical simulation of indoor thermal environment by adopting heated kang is done by using FLUENT software, and the temperature field distribution at the Z = 2 m monitoring surface is attained. The results and the data of reference [16] are shown in the fig. 4.

It can be seen from fig. 4, the relative error is lower than 2%, which shows the feasibility and accuracy of the model.

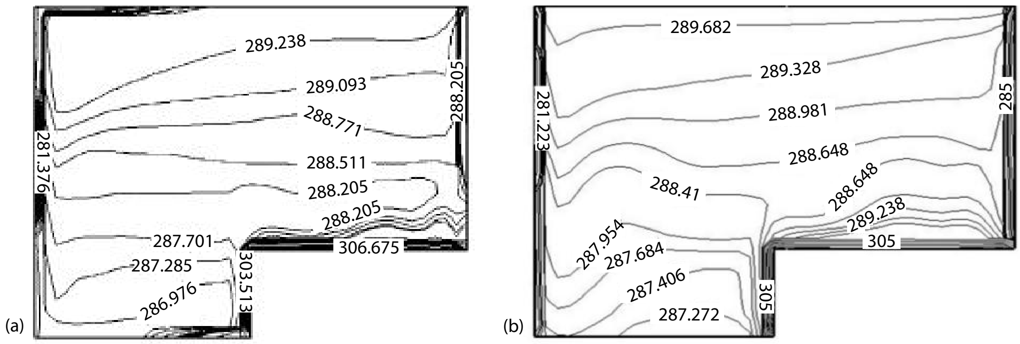

Figure 4. Comparison of temperature field of Z = 2 m cross-section in kang heating room; (a) literature, (b) verification

Results and discussion

Simulation of indoor thermal environment of typical house without insulation

This simulation simulates the temperature field changes about the whole house using the kang heating at night. In the room, the position of Y = 2.0 m, Y = 0 m, Y = –2.0 m, X = 2.0 m, X = –1.8 m, Z = 0 m, Z = 0.4 m, Z = 1.0 m were set the monitoring surfaces to monitor the indoor temperature field changes.

The average temperature of the X-axis monitoring surface

Figure 5 shows the X-axis direction of the monitoring surfaces of the average temperature changes. In order to better and intuitively to observe the average temperature changes inside the rural house, only take the X-axis direction of the monitoring surfaces for analysis.

From fig. 5, the following conclusions can be drawn: the temperature of bedroom rises slightly in the first 800 s and then maintains at a certain value, and the temperature of entrance hall has a greater drop. The main reason for this phenomenon is that the insulation performance of the envelope is bad. The average temperature of the bedroom is more stable because of a higher temperature of the *Kang*. There are two reasons why the temperature of the entrance hall is low: first, there is no heat source in the room. Second, the areas of the doors and the windows in the entrance hall are bigger than that in the bedroom and the heat transfer coefficient of them are large which result in more heat loss. The phenomenon can be analyzed by the heat balance: the heat that is provided by the *Kang* to the bedroom and the heat transfers from the bedroom to the entrance hall is equal to the heat loss to the outside, the heat dissipated out of the entrance hall is higher than the heat transfer from the bedroom to the entrance hall.

As can be seen from fig. 5, the temperature of bedroom is about 15 °C and the temperature of the foyer is about 11 °C which are obviously cannot meet the requirements of the thermal comfort of people. In result, the indoor thermal environment needs to be improved.

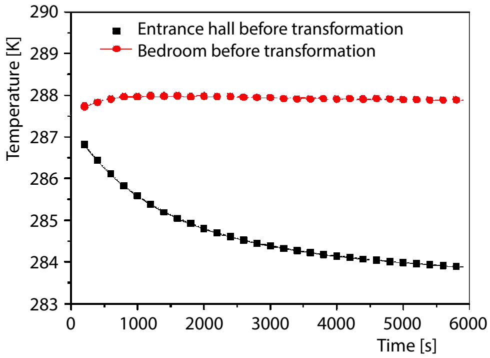

Figure 5. Average temperature profile of the X-axis monitoring plane

Indoor temperature field distribution

The cloud diagrams about Y-axis direction show the changes of the indoor temperature field, which as shown in fig. 6.

It can be seen from fig. 6, when the indoor thermal environment is steady-state and the enclosure is not insulated, the temperature of the entrance hall is unchanged. Due to the role of the *Kang*, there is a great improvement of the temperature in the bedroom and the effect of hot air rises so that the air in the bedroom appears stratification phenomenon, and the air temperature indoor is much higher than that near the envelope. Comparison of three cloud diagrams, the distance from the *Kang* is closer, the temperature is higher. From $Y = -2.0$ m cross-section cloud can be seen: there is a more obvious temperature fault at the top of the *Kang*, one of the reason is the temperature partition of *Kang* surface, the other is the role of the rising air which pushes the cold air to the direction of the *Kang* surface.

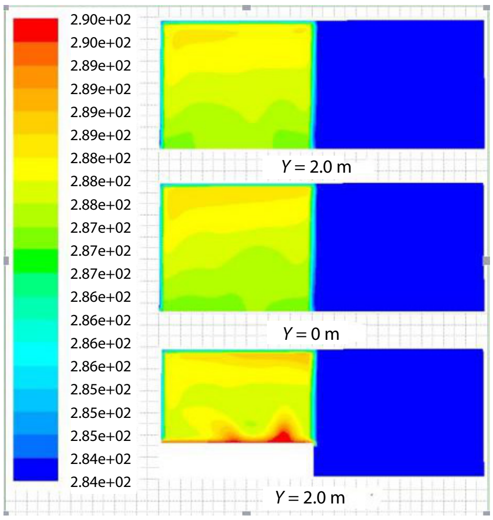

Figure 6. The Y-axis cross-section temperature contour

Simulation of indoor thermal environment of typical house with insulation

The range of the heat transfer coefficient is provided in the *Design standard for energy efficiency of a building in severe cold and cold zones* (JGJ26-2010). So the heat transfer coefficient of the external wall is changed to 0.3 W/m^{2}K, the heat transfer coefficient of the roof is changed to 0.25 W/m^{2}K. Considering the economic problems of the rural residents, the windows in the rural house are replaced by the double-skin windows with a heat transfer coefficient of about 2.5 W/m^{2}K, the door made of wood is changed into a steel security door, the heat transfer coefficient is 1.7 W/m^{2}K.

The X-axis monitoring surface average temperature comparison

Figure 7 shows that the envelope insulation can improve the indoor thermal environment effectively. The average temperature of the bedroom rises from 15-19 °C, and there is a rising trend, the average temperature of the bedroom can reach 20.5 °C when it is in steady-state. The average temperature of the entrance hall rises from 11-14 °C. Whether the entrance

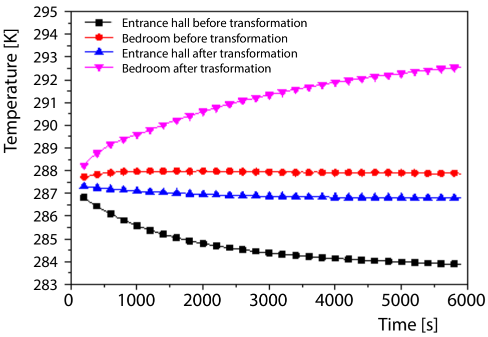

Figure 7. Average temperature profile of the X-axis monitoring plane

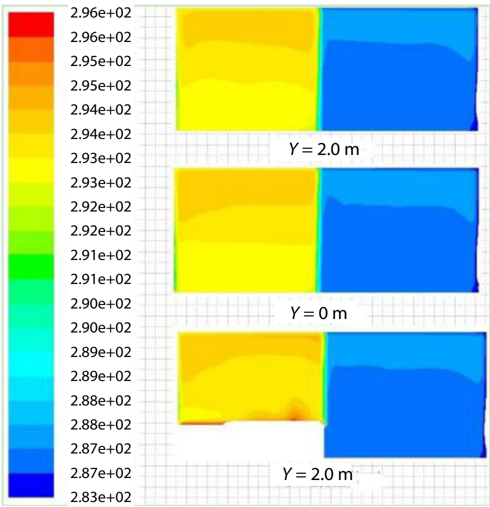

Figure 8. The Y-axis monitoring surface temperature field distribution

hall or the bedroom, the average temperature is higher than that before the transformation. The bedroom thermal environment is comfortable which achieve the purpose of transformation.

Indoor temperature field distribution

The cloud diagrams about Y-axis direction show the changes in the indoor temperature field, as shown in fig. 8.

As can be seen from fig. 8, the temperature rising in the bedroom is obviously, and the temperature around the envelope is significantly increased. Due to the good insulation of the envelope, the air temperature in the bedroom has a great influence on that in the foyer. Analyzing of the temperature distribution in the bedroom which can be found the temperature above the third area of *Kang* is lower than that in the bedroom, the reason is the temperature of the first and second areas of the *Kang* are higher and the temperature of the third area is lower, and the good insulation performance of the envelope, the hot air is mixed at the top so that the air temperature is higher than that of the third area air temperature.

Conclusions

In this paper, the CFD software was used to simulate the indoor thermal environment of the rural house under the insulation or no insulation in Daqing. The conclusions are as follows.

- When the envelope structure does not take insulation measures, and the *Kang* is used to heat merely, the temperature of bedroom can only reach 15 °C and the temperature of entrance hall can only reach 11 °C. It can not meet the requirement of human comfort.
- Because of good insulation properties of the envelope, the temperature of the rural house can reach 20 °C and the temperature of the entrance hall is also increased to 14 °C. In conclusion, improving the insulation structure of the envelope is an effective method to improve the indoor thermal environment.
- According to the previous simulation, setting the envelope insulation can be put forward as the recommendations of improving the comfort of indoor thermal environment.

The heat loss which is through the envelope, the cold air penetration and the cold air intrusion can be reduced effectively by setting the envelope insulation. At present, China is in the third stage of energy which is saving 65%, the heat transfer coefficient of the envelope can be designed in according to the *Design standard for energy efficiency of a building in severe cold and cold zones* (JGJ26-2010). Not only can setting the envelope insulation improve the indoor thermal environment without use other energy, but also it can be conducive to energy conservation. It meets the China’s development strategy.

Acknowledgment

This work was supported by the Fund Project Daqing City Science and Technology Project (Zd-2016-130).

Nomenclature

c_p – specific heat capacity, [Jkg^{-1}K^{-1}]
g – gravity acceleration in direction of z, [ms^{-2}]
h – convection heat transfer coefficient of the inner surface which is equivalented, [Wm^{-2}K^{-1}]
h_1 – convective heat transfer coefficient of exterior surface of the building envelope, [Wm^{-2}K^{-1}]
κ – thermal conductivity, [Wm^{-1}K^{-1}]
p – pressure, [Pa]
T_0 – temperature of the reference point, [K]
T_w – temperature of the wall, [K]
T_f – temperature of the air near the wall, [K]
t_f – temperature of the exterior fluid, [K]
u, v, w – the velocity component of the fluid in direction of x, y, and z, [ms^{-1}]

Greek symbols

β – thermal expansion coefficient, [lK^{-1}]
δ – thickness of building envelope, [mm]
λ – thermal conductivity, [Wm^{-1}K^{-1}]
μ – fluid dynamic viscosity, [Pa·s]
ρ – fluid density, [kgm^{-3}]

References

[1] Jin, H., *et al.*, Study on Indoor Thermal Comfort Environment of Rural Residential Buildings in Severe Cold Areas, Report No. 38, Harbin Institute of Technology, *12* (2006), pp. 2108-2111
[2] Zhen, M., *et al.*, Optimum Design of Rural Residential Thermal Environment in Northeast Cold Region, Harbin Institute of Technology, *10* (2016), pp. 183-188
[3] Chen, Z. H., Dynamic Simulation and Analysis of Residential Building Energy Consumption in Severe Cold Area, M. Sc. thesis, Xinjiang University, Xinjiang, China, 2007
[4] Xue, K., Study on Thermal Environment and Energy Saving Technology of Rural Residential Buildings in Daqing Area, M. Sc. thesis, Northeast Petroleum University, Daqing, China, 2011
[5] Ma, Y. L., Thermal Environment and Energy Saving Analysis of Rural Residential Buildings in Severe Cold Areas, M. Sc. thesis, Shenyang Jianzhu University, Shengyang, China, 2015
[6] Fu, C. J., Simulation Study on Thermal Performance and Indoor Thermal Environment of Light Roofing Building, M. Sc. thesis, Chongqing University, Chongqing, China, 2015
[7] Georges, L., *et al.*, Simplified Space-Heating Distribution Using Radiators in Super Insulated Apartment Buildings, *Energy Procedia*, *96* (2016), Sept., pp. 455-466
[8] Orosa, J. A., Oliveira, A. C., A Field Study on Building Inertia and its Effects on Indoor Thermal Environment, *Renewable Energy*, *37* (2012), 1, pp. 89-96
[9] Kim, J. G., *et al.*, Indoor Thermal Environment of Temporary Mobile Energy Shelter Houses (MeSHs) in South Korea, *Energies*, *8* (2015), 10, pp. 11139-11152
[10] Couret, D. G., *et al.*, Influence of Architectural Design on Indoor Environment in Apartment Buildings in Havana, *Renewable Energy*, *50* (2013), 3, pp. 800-811
[11] Amr, S. H. A., *et al.*, Integration of Evaporative Cooling Technique with Solar Chimney to Improve Indoor Thermal Environment in the New Assiut City, Egypt, *International Journal of Energy and Environmental Engineering*, *4* (2013), 1, pp. 1-15
[12] Taro, S., *et al.*, Control of Indoor Thermal Environment Based on Concept of Contribution Ratio of Indoor Climate, *Building Simulation*, *3* (2010), 4, pp. 263-278
[13] Yoshino, H., *et al.*, Indoor Thermal Environment of Urban Residential Buildings in China: Winter Investigation in Five Major Cities, *Energy and Buildings*, *36* (2004), 12, pp. 1227-1233
[14] Georges, L., Skreiberg, O., Simple Modelling Procedure for the Indoor Thermal Environment of Highly Insulated Buildings Heated by Wood Stoves, *Journal of Building Performance Simulation*, *9* (2016), 6, pp. 663-679
[15] Yang, S. W., *et al.*, An Experimental Study of the Indoor Thermal Environment of One-Person-Households under Various Conditions of Daily Life, *Korea Environmental Journal*, *23* (2016), 4, pp. 536-544
[16] Lu, L., *el al.*, Influence of Heating Method on Indoor Thermal Environment in Rural Residential Building, *Low Temperature Building Technology*, *11* (2011), pp. 91-93

Paper submitted: August 21, 2017
Paper revised: October 13, 2017
Paper accepted: October 15, 2017